# Opportunistic Communication for eNetworks Cyberengineering

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***Abstract*—Within the broader context of the Adaptive Risk Management (ARM) Platform described in [27], the aim of this work is to show practically a proof of concept for a network architecture based on mobile code for Weiser's vision of ubiquitous computing [26] and opportunistic computing [22]. The proposed paradigm which animates the Opportunistic Communication Module (OCM) of the ARM Platform enhances both mobile and wireless sensor networks by leveraging on each other and will serve as a foundation for future investigation of interdependencies among heterogeneous large scale networks [7] while supporting our efforts to engineer eNetworked industrial ecosystems.**

***Keywords***. Opportunistic / Mesh Communication, eNetworks, Cyber-Physical Ecosystems, Sensor Networks Integration, Next generation Internet.

## I. INTRODUCTION

According to [7], the main recommendations for the approach to the Future Internet (Fig. 1) are to recognize the role of wireless technology as the main driving force and to increase research focus on flexible platforms for central network architectures related to future mobile, wireless and sensor scenarios. Network architecture is a subtle concept which cannot be satisfactorily understood and proven to work even through rigorous analysis and simulation.

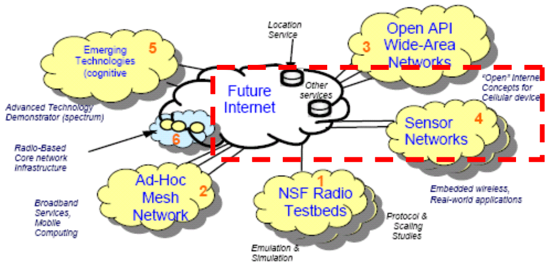


Fig. 1: The Future Internet [6]

Only through extensive live experimentation, usually done through large scale testbeds, is possible to achieve a complete understanding [15]. Most of the existing wireless testbeds do not have the real-world evaluation characteristics and do not provide end-to-end experimentation facility through a Wide Area Network with programmable protocols [8]. The ARM platform, Fig. 2, described in detail in [27] offers such an experimentation facility to prove the versatility of various networking paradigms which can then be incrementally extended to real-world scenarios.

Future Internet is envisioned to leap towards a radical transformation from how we know it today (a mere communication highway) into a vast *hybrid network* (eNetwork) seamlessly integrating physical (mobile or static) systems to power, control or operate virtually any device, appliance or system/infrastructure. The Adaptive Risk Management platform (ARM) [27] is concerned with the development of universal models for integrating industrial systems/infrastructures (and the environments to which they are applied) with an overlay control network, i.e. the e-Network. The shaded area of Fig. 2 shows the ARM test bed of which *the Opportunistic Communications Module* (marked C in Fig. 2) deals with the integration of pervasive networks.

Our focus in this paper is on the physical topology (lower part of Fig. 3) of a network as support for the implementation of various paradigms required by eNetworks implementation as superstructure for the Future Internet.

Researchers have been constantly working for the next big technology development that would take us into the next phase of ubiquitous computing. In our opinion the current stage consists of having unlimited number of sensors integrated into our environment and, hence, providing reality to the vision of "invisible computing…in fabric of life" that Weiser stated almost 15 years ago. In the current era of computing we see many devices associated to one person as compared to the previous computing eras [2]. A lot of work done in the advancement of ubiquitous computing was reported, e.g. with fovus on fabricating smaller devices and creating a smaller software footprint so that multi-year battery life can be achieved[9],[10],[11] or on better protocols for these sensors [12],[13],[14].

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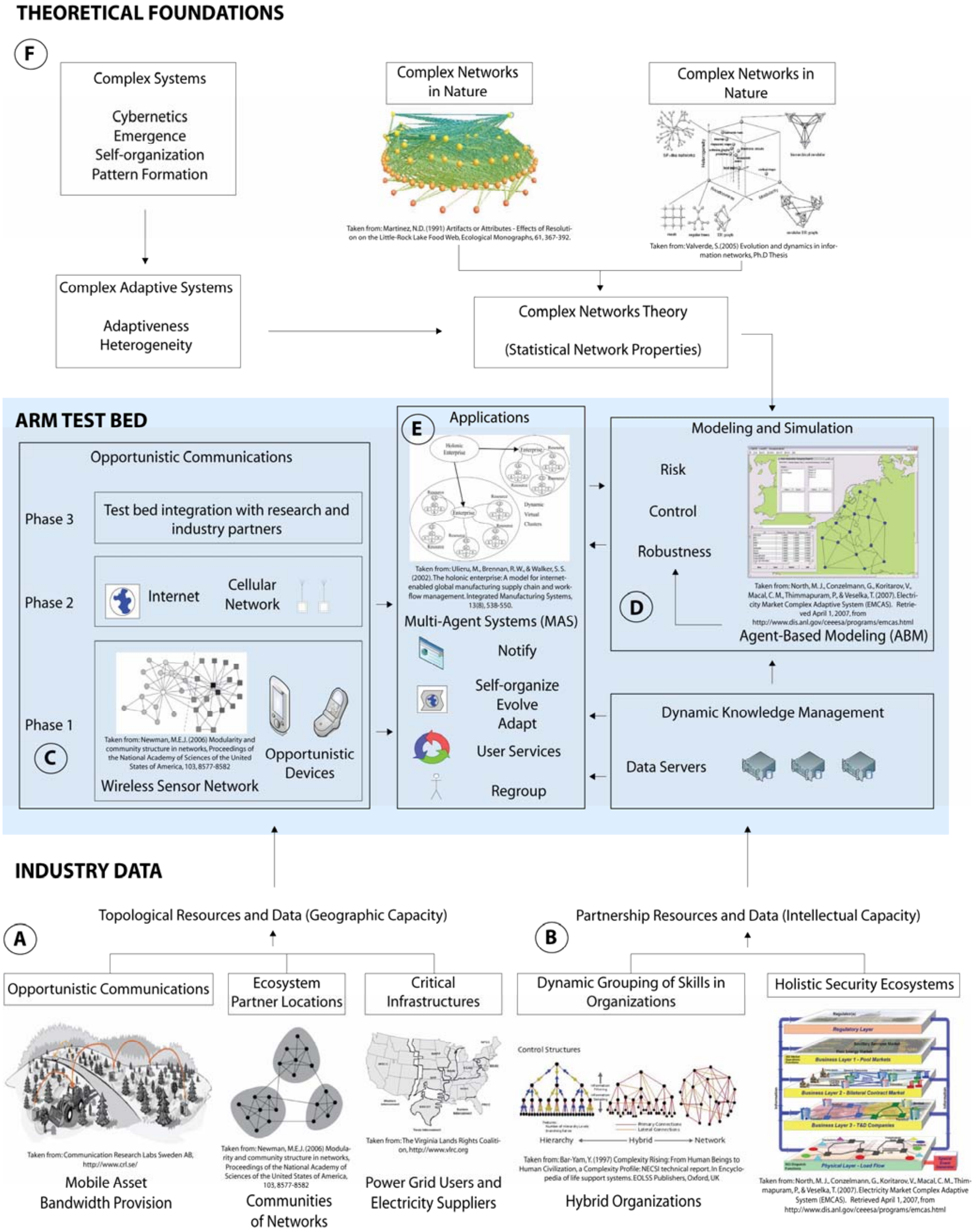


Fig. 2. A platform for design and evaluation of eNetworked Ecosystems.

Without undermining the significant breakthroughs in these respective fields, ***what is needed is a deployable paradigm for integration between the existing Information and Communication Technologies (ICT) and the next generation of sensor infrastructures.*** Such an integrated environment is also termed as a Cyber-Physical Ecosystem [27] and should not only be flexible but should also be resilient against man made attacks or natural disasters.

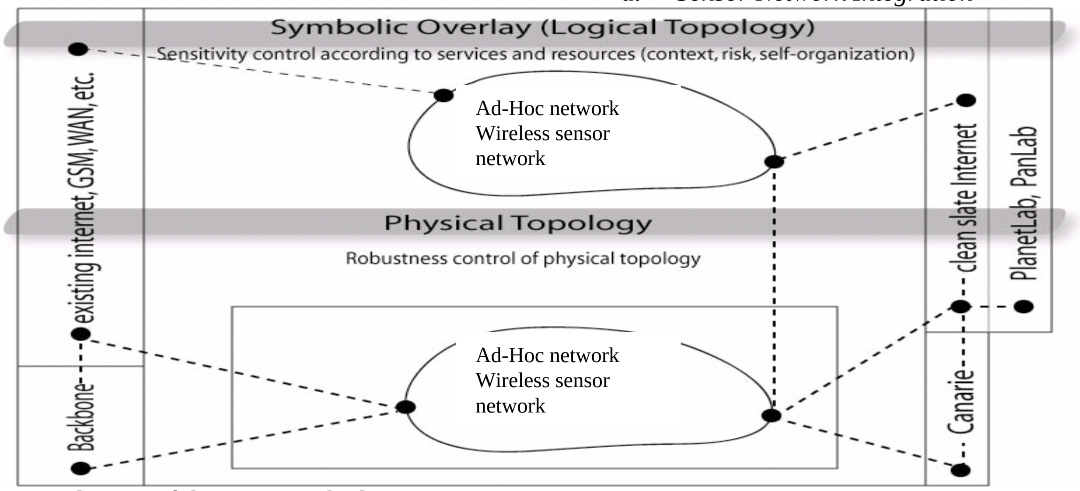


Fig. 3: A Layered View of the ARM testbed

## II. Opportunistic Communications Module (OCM)

### A. OCM Research Focus

In a broad sense, the OCM (marked with C. in Fig. 2) provides a platform for the design and testing of eNetworks as foundation for the Future Internet. Whereas the current Internet provides a means of communication, the Future Internet provides both a means of communication and an interface for seamless connection to our physical environments. Wireless technology is identified in [1] as a main driving force for realizing the Future Internet. In order to achieve these objectives, module C comprises three development phases (Fig. 2 and 4):

*Phase 1* horizontally integrates a Wireless Sensor Network with opportunistic communication devices, e.g. smart phones and PDA's.

*Phase 2* vertically integrates the architectures of *phase 1* with the existing Internet and cellular networks.

*Phase 3* integrates the combined architectures of *phases 1* and *2* with external industrial and academic research platforms of a Future Internet.

In a narrower sense, the Wireless Sensor Network component of *Phase 1* emulates the gathering of location-based device data as described in [27]. The Wireless Sensor Network component of our test bed represents a subset of Wireless Mesh Networks [28]. It adds to a regular mesh network the ability to sense specific location-based data from a large number of sensor nodes.

The research focus in the OCM component undertakes challenges in two main areas:

#### *a. Sensor Network Integration*

Wireless Sensors Networks are an integral part of Cyber-Physical Systems; however their integration in the internet faces numerous challenges [30]. The OCM research focuses on a paradigm for seamless connectivity between a sensor network and multiple other networks with different characteristics (for e.g. WiFi and Cellular). The paradigm will achieve this in two ways:

- The individual network's capabilities will be enhanced by creating a flexible integration based on a combination of over the air programmed base stations and opportunistic communication.
- The architecture of the individual networks will not change, hence, allowing them to retain their uniqueness.

The OCM testbed component we propose will be capable of broadening the approach of inferring context from digital items (everyday objects with sensors) that are not in the immediate environment (within range of 20-30m).

Additionally, the wireless devices (Crossbow Motes4) being used in the testbed are targeted for large scale networks and data collection; hence the emphasis is on communication, networking and data propagation. This positions us to answer the challenges associated with Robust Gateway Architectures and real world networking issues [30]. Additionally, the sensor network integration characteristic of the testbed component, perfectly aligns it

[3] The challenges are highlighted in Section 2
[4] www.xbow.com

with the prototype vision of many state-of-the-art networking testbeds ( for e.g. ANA[21] ) and test-bed federating initiatives (for e.g. GENI[24] ). This will enable the ARM testbed to become a part of several international federating platforms and by this opens an immense amount of opportunities for the ARM Laboratory research group to contribute to shape the Future Internet through experimentation [27].

*b. Opportunistic\Mesh Communication*

Almost all of the state-of-the-art projects\research [30] deal with some kind of opportunistic networking paradigm. Opportunistic and mesh networking are considered to be the main evolutions of multi-hop adhoc networks [22]. They also give us the chance of tackling the challenges associated with Gateway architectures [2] and resource constrained communication paradigms that the current ICT and sensor networks infrastructure pose [30]. We aim to create a mix of both these networking worlds by taking the best of them both. Such a mix is necessary for scenarios that require the flexibility of opportunistic networking but lesser delay which is a characteristic of mesh networks.

The OCM also aims to test the techniques of opportunistic communication by introducing the concept of a “mobile code” (real time programming over the air) on base stations in WSNs. From a biological perspective our contribution will enable the ARM testbed to become an evolving network due to its mobile code characteristic, however, what makes it distinct from other radically biologically inspired networks (for e.g. BIONETS[23]) is that the resource constrained nodes (sensors) are able to communicate amongst themselves and also with higher level devices ( cell-phones, PDAs etc). The OCM offers a preliminary architecture towards the evolution of biologically inspired communication networks and the results gathered from it can make us better understand the feasibility of networks based on biological principles.

## III. Opportunistic Communication Framework

A.. OCM Set-Up Within the ARM testbed

The three layers of the OCM are further expanded in Fig. 4. To keep the networks implementation simple and avoid troubleshooting complications, each layer will be implemented in a separate phase. The higher layers will be dependant on the functionality of the lower layers. The rest of this section will give a brief outline of the layers.

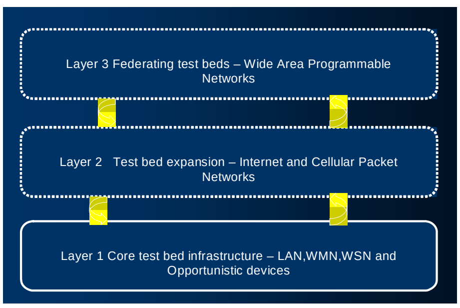


Fig. 4. Layered architecture of the Opportunistic Paradigm

*i. Core Testbed Infrastructure*

This layer is composed of the Core infrastructure of the paradigm. It includes a Local Area Network of various desktops and laptops, Wireless Mesh Network based on Avaya-AP7 Routers, Wireless Sensor Networks from Crossbow and a few mobile devices with opportunistic communication capabilities. This layer is not dependant on any other communication infrastructure and hence, is self-dependant. The main reason for the independence of this layer is that it provides us with the flexibility and isolation of testing various fault-tolerant and risk adaptation algorithms without endangering any other infrastructure. Additionally, it gives us the chance of learning about the eccentricities of inter-dependencies on a toy-model with out the risk involved in large-scale real-world networks.

*ii. Testbed Expansion*

Layer 2 expands the network functionally and geographically by providing well defined interfaces to Wide Area Networks (WANs). This layer is composed of two WANs which are connected to Layer 1 and can be disconnected at any time without affecting the self-sufficiency of the Core. The first WAN chosen is the University of New Brunswick’s Communication\networking infrastructure(intranet) through which the Core Test bed can connect to the internet. The second WAN is the packet network of the cellular companies that are available in the city of Fredericton. This WAN is composed of interfaces to a CDMA\1xEV-DO(TELUS) and GPRS(Rogers) network.

*iii. Federating Testbeds*

This layer will connect the test bed globally with state-of the art network research facilities for e.g. PlabetLab (https://www.planet-lab.org/), PANLAB (http://www.panlab.net/) and GENI(http://www.geni.net/). The aim of this layer is to join the federation of international testbeds and make a contribution to the infrastructure of the Future Internet.

B. Opportunistic Paradigm Overview

The paradigm that we aim to develop and show as a proof of concept is illustrated in Fig. 5. The aim is to achieve seamless connectivity with a resource constrained infrastructure through opportunistic communication principles, according to which the client connects with the target infrastructure through the most efficient available opportunity.

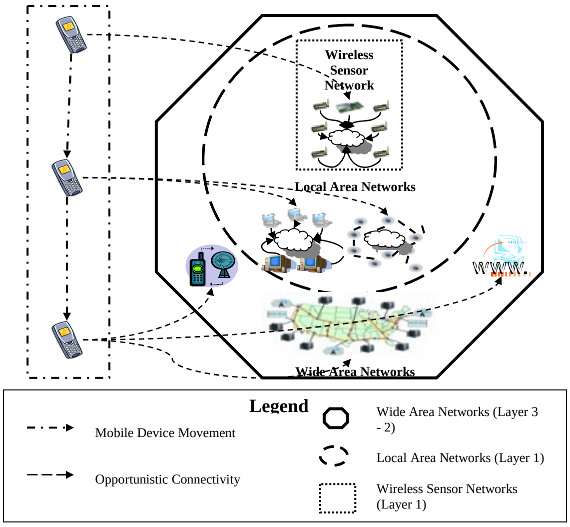


Fig. 5: Opportunistic Communication Framework

The client is the opportunistic device (shown as a mobile device on the left of Fig. 5) and this is where the intelligence resides for opportunistically choosing the most efficient route through the appropriate layer. The resource constrained infrastructure is the Wireless Sensor Network, shown as the innermost component of the framework in Fig. 5. This component is the target for the opportunistic device and serves as the source for data. As the mobile device moves to different environments it will have different type of opportunities to connect with other layers (Fig. 4), such as the Local Area Networks - layer 2 and Wide Area Networks – layer 3 ( shown as the outer components of the framework in Fig. 5). On the basis of various parameters such as distance from the WSN, amount of processing required, power constraints and congestion the opportunistic device will choose other networks to establish a connection with the target infrastructure (shown as dashed arrows from mobile device to other networks )

## IV. Paradigm Realization

The core of the proposed paradigm which is illustrated in Fig. 6, incorporates the following four components:

- Wired Local Area Network,
- Wireless Mesh Network,
- Wireless Sensor Network and
- Opportunistic devices

*Wired Local Area Network*

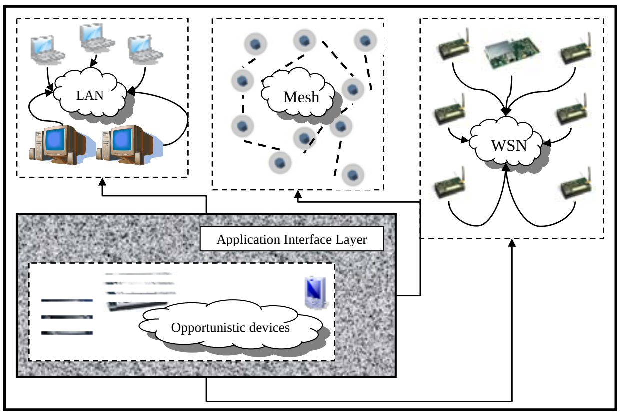


Fig. 6. Layer 1 detailed sketch of the Opportunistic Paradigm

This component consists of 10 desktop and 6 laptop computers. All of these devices are connected through an Ethernet switch and form an internal LAN in the ARM lab. These devices are used mostly for simulating various algorithms or emulating protocols.

*Wireless Mesh Network*

The Wireless mesh network will be based on 802.11 technology and aims to be composed of Avaya-AP7 switches that have mesh forming capabilities. The network components in this network will provide the flexibility of state-of –the-art switching devices and will put to test the opportunities created by embedded WiFi. This mesh network gives us the opportunity of studying various characteristics of 802.11 meshes such as robustness to attacks, failures and throughput analysis in various environments with varying level of interference. Such a study is becoming necessary because of the proliferation of end-user Wi-Fi devices which is driving the demand for always-on mobile connectivity and in turn is making a global pervasive wireless infrastructure imminent [29].

*Wireless Sensor Network*

To enable the ARM testbed to tackle the numerous challenges that deal with Cyber-Physical Environments [27], the WSN component is integral to the core of the test bed. This component serves many purposes, ranging from raw context extraction from the environment to resource constrained protocol experiments; however there are two main characteristics that we focus on. Firstly, we will be developing a sensor network gateway architecture that is robust based on mobile code and secondly, we will design an opportunistic paradigm of sensor network integration with other networks and test it with opportunistic devices. The aim will enable an opportunistic device to access the data from the sensor network from anywhere and hence, achieve seamless connectivity.

*Opportunistic Devices*

This component includes various prototypes which consist of Mobile devices (Cell phones, Smart Phones, PDAs etc.) that can communicate with the Wireless Sensor Network opportunistically. These prototypes will be capable of connecting to the sensor network through various interfaces depending upon the environment they are in. This opportunistic capability is not only due to special devices which have multiple physical communication interfaces but also due to an intelligent application interface layer which in fact performs the decision making of how to connect to the resource constrained sensor network. The performance of these prototypes will be the main focus of this component.

## V. Conclusions

Various components of the paradigm's core are in the process of being established at the Adaptive Risk Management(ARM) Lab at University of New Brunswick and will be used for the research in engineering of industrial ecosystems [27] and resilient critical infrastructures [3].

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