

BIONETS: THE CONVERGENCE OF GENETICS, EVOLUTION AND ENGINEERING

*Beyond the
Internet and
Towards
Autonomic
Networks*



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Outline

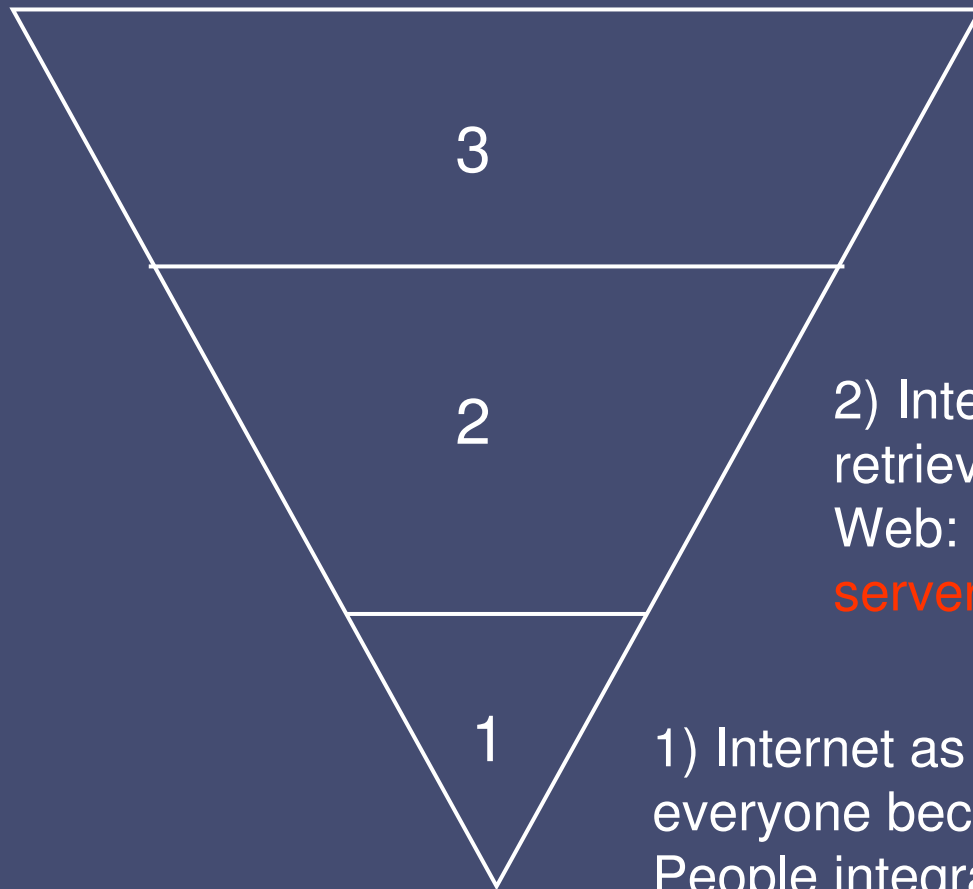
- Part A – The Vision
- Part B – the BIONETS Project
- Part C – On the way to BIONETS: Preliminary Results
- Clustering with other IPs?

Part A The Vision

... the next ICT revolution?

try to learn from history...

The Three Revolutions

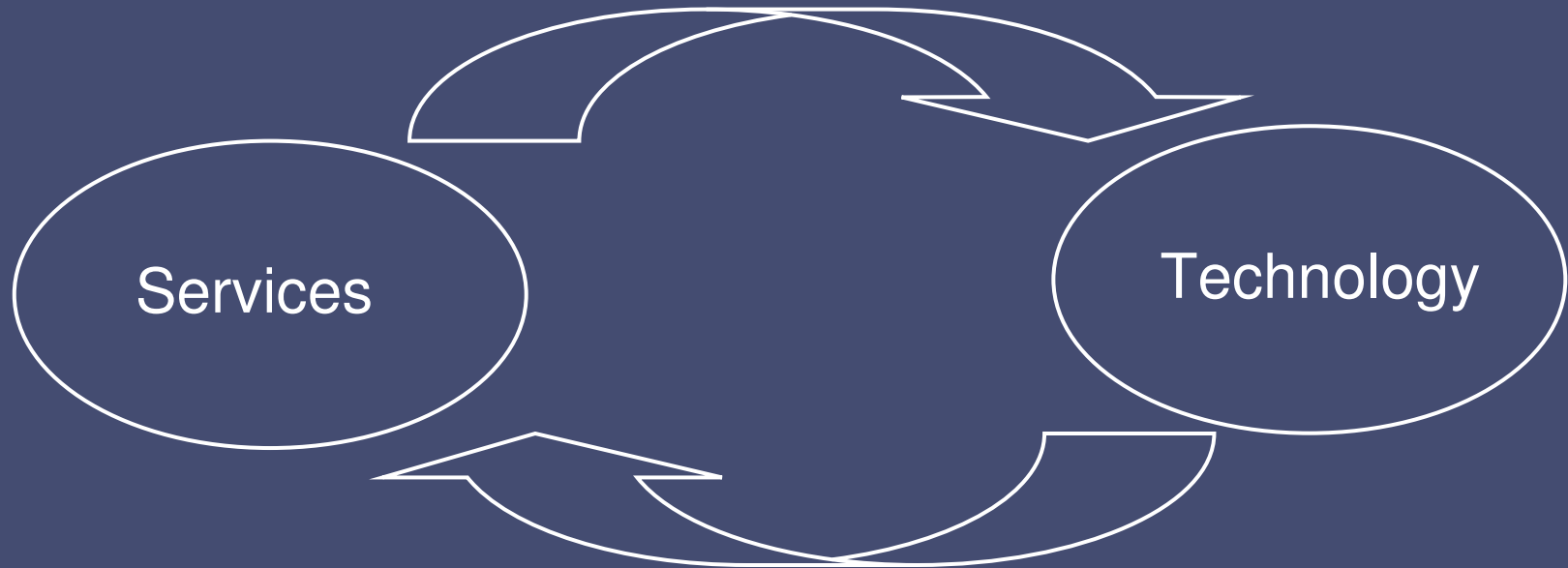


3) Beyond Internet: everyone becomes its own **service provider**. People/information/environment integration.

2) Internet as an information retrieval/content provisioning system. Web: everyone becomes its own **server**. People/information integration.

1) Internet as a data transport engine. E-mail: everyone becomes its own **post office**. People integration.

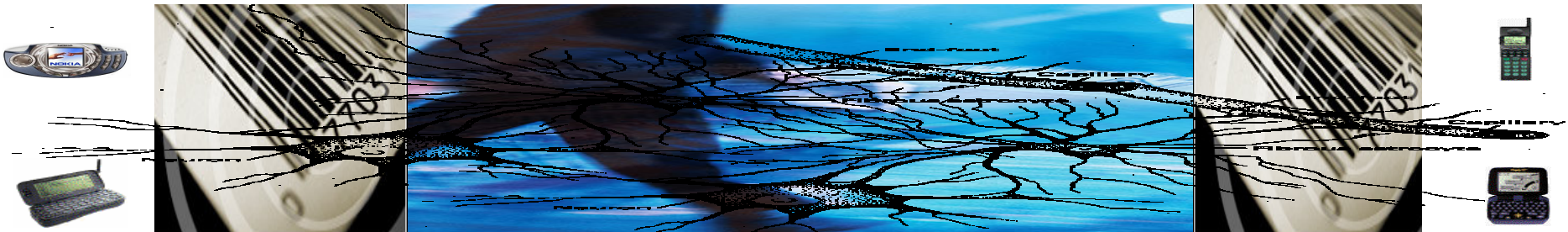
The Driving Factor?



- Most of the times, it is the technology which starts the process (e.g., Internet) but there is a constant **interaction** between the two

A Look at Technology

- The emerging XXI century scenario:
 - large number of user devices with growing computing / communications capabilities
 - billions of simple sensing/identifying devices enabling interaction with the environment
- And emerging disconnected worlds of conventional networks co-existing with **pervasive computing environments**



The “Difficulties” of Pervasive Environments

From the perspective of today’s conventional networking theorist

- Tremendous amount of data flows in the network leads to **network explosion**
- Network-wide **management** on this scale impossible
- Network **heterogeneity and size** (nodes ranging from sensors, RFIDs to laptops and servers) make use of adapted **standard protocol stacks impossible**

And the Opportunities ?

- The pervasive computing environment offers opportunities to exploit:
 - Comprehensive and real time information about the environment (sensing/identifying)
 - Multi-level interacting with local environment
 - Availability of huge unused computing power / storage capabilities in mobile user devices
 - Opportunity to extend localization of information & communications to service localization
- How can the user benefit from these opportunities?
Revolutionary services concepts built on top of revolutionary communication tenets

Where Conventional Approaches Fail

- **At the network level**, the network explodes due to the scalability problems of traditional communication approaches – better ad hoc networks just won't do...
- **At the management level**, the radically distributed nature and size of the local Webs does not lend itself to conventional (centralized) management approaches
- **At the service level**, the situated autonomous nature of ad hoc local services cannot be mapped to traditional centralized server approaches

Looking for...

A communication system supporting millions of localized services in an environment consisting of billions of heterogeneous nodes, intermittently connected and extremely low-cost

Why “Old and New” Internets Won’t Do the Job ...the *cost* problem

- Internet = “all nodes are equal!”
 - Same protocol stack for routing and transport
 - “one size fits all”
- Billions of communication enhanced objects transporting data
 - Increase power consumption, weight and size of each device
 - Need redundant devices for connectivity
 - Energy consumption grows exponentially with the number of nodes
- Can never have all this embedded for 1 cent!
 - Mass production does not solve the energy problems
 - A realistic inclusion of the environment is not possible



...the *scalability* problem

- Mobile Ad-Hoc Networks (MANETs) are the existing candidates for the new environment
- MANETs scale poorly - given n nodes, according to [GuptaKumar00], the throughput of each connection scales as $\Theta\left(\sqrt{\frac{1}{n \log(n)}}\right)$ refined by [FranceschettiDousseTseThiran05] $\Theta\left(\sqrt{\frac{1}{n}}\right)$
- In case of sensors data collection, scalability is even worse [MarcoDuarte-MeloLiuNeuhoff03] $O(1/n)$
- In all the cases, **scalability tends to zero**, i.e., the network does not scale

...the *management* problem

The End to End (E2E) Internet principle imposed on MANET leads to:

- Intractable management in a billion nodes network
- Need for constant adaptation in highly dynamic situations
- Packet-forwarding concept which requires cooperation without providing real motivation for it

Why sacrifice your resources, privacy and integrity to relay data packets of far and unknown nodes?

Exploit Heterogeneity and Mobility

- Given:
- **Unutilized** millions of *nomadic* User nodes (U-nodes)
 - Sophisticated mobile devices
(e.g. laptops, PDAs, mobile/smart phones, wearable computers)
 - Rich in resources in terms of
 - available energy
 - processing power
 - communication capabilities (i.e., full protocol stack)
- **Overutilized** billions of Tiny nodes (T-nodes)
 - Provide information about
 - an object (RFIDs)
 - the environment (sensors)
 - Extremely low-cost, consequently poor in resources

For a P2P Communication Architecture

- T-nodes:
 - only read by U-nodes in proximity
 - removing cost/complexity: routing, forwarding, protocol stack
- U-nodes
 - communicate with T-nodes to collect/exchange data
 - communicate with U-nodes
 - **exchanging information in a peer-to-peer fashion with other U-nodes on the move running the same service**
 - exploiting the mobility of U-nodes for connectivity
 - connection throughput scale as [TseGrossglauser01] $\Theta(1)$
 - act as a gateway to the backbone having the resources

Towards a New Communication Paradigm

Where *service* drives the P2P information exchange
replacing the E2E network protocol stack and
providing the needed incentive for autonomous users to
cooperate

Network in the conventional sense disappears

Resulting in ...

- The *cost* problem solved: T-node cost reduced to minimum
- The *scalability* problem solved: network *scales* without limitation
- The *network management*: now P2P, localized and under the responsibility of the service

BUT - how to define/run/manage localized services, allow them autonomously adapt to the constantly changing environment, and make the P2P communication support these services?

The BIONETS Paradigm

- Build the solution on the best example around!
 - *Adaptation by evolution* is the way organisms evolved in nature
- Make the *service the organism's epicenter*, and apply the rules of genetics and let the process of evolution/adaptation do its job

BIO-inspired NExt generaTion networkS

Mapping Concepts from Biology

- Each instance of a service corresponds to a *service chromosome*
- U-nodes are the *organisms* carrying chromosomes
- As in nature
 - Organisms live in and interact with the environment
 - *Learn* about it by:
 - reading T-nodes (data)
 - exchanging information with other U-nodes
 - Population adapts to its environment by *evolution*
 - Organisms mate with attractive organisms defined by fitness
 - Successful organisms populate (*fitness to mate* defined as the ability of the service to work well in the environment)

The Service Chromosome

- A chromosome is a program, describing the related *service behavior* in terms of **rules of**
 - data collection from (environment) T-nodes
 - data exchange with other (attractive) U-nodes
 - the decision making (natural selection) process
- A chromosome consists of *genes*, each describing one aspect of its behavior
 - a gene corresponds to a parameter/routine in the service program
 - *alleles* are different forms of the same gene
 - Different values of (former) MIB variables
 - each organism has its own version of a chromosome which can differ in its alleles (genetic diversity)

The Organism Evolution

Organisms evolve by *mating* (as in nature)

- Mating takes place when two organisms (U-Nodes) meet and exchange (genetic) information about the services they are running
- Users with a high level of fitness will be judged more attractive
- New chromosomes inherit genetic features from both parents
- *Offsprings* are generated, replacing service versions and introducing a new generation
- Offsprings will be different from parents
- Genetic diversity increases adaptive behavior
 - Different genetic information yields organisms with different behaviours

The Service Evolution

- Only attractive organisms mate
 - Attractiveness is determined by fitness (to environmental conditions)
 - Mating is selective
 - Attractive organisms mate, unattractive organisms - organisms not carrying attractive services, will not survive!
- *Fitness* depends on genetic information carried and environment
- Therefore environment determines natural selection through P2P data and service exchange leading to continuous adaptation
- The service evolution process is transparent to the user

*Each service adapts and evolves
through survival of the fittest*

BIONETS in the Pervasive Environment?

- Based on genetic rules that are inherently local (context-awareness)
- Evolve in order to better fit the requirements of each user (self-optimization)
- Are robust as they keep genetic diversity (self-healing)
- Are user-centric (distributed)
- Are based on localized information (scalability)

Summing it up...

- Explosive growth of the pervasive information environment
- Different approaches towards technology and services needed
- Architecture, strictly localized matching information, and exploit node heterogeneity and mobility
- Local ad hoc services revolution that builds on autonomic of pervasive environments
- With other revolutions affecting science, engineering, economics, business, law, social sphere, ...on the way

Part B

The BIONETS Project

The Consortium

- CREATE-NET (in cooperation with Univ. Trento and CNR Pisa) (IT)
- Universität Basel (CH)
- Technische Universität Berlin (DE)
- Hamburger Informatik Technologie-Center e.V. (DE)
- RWTH Aachen University (DE)
- Imperial College London (UK)
- Budapest University of Technology and Economics (HU)
- Valtion Teknillinen Tutkimuskeskus - VTT (FI)
- Institut National de Recherche en Informatique et Automatique - INRIA (FR)
- National and Kapodistrian University of Athens (GR)
- London School of Economics and Political Science (UK)
- Nokia Corporation (FI)
- Telecom Italia Learning Services SpA (IT)
- Sun Microsystems Iberica SA (SP)



The Objectives

- Definition of a bio-inspired network architectures
- Design and analysis of innovative algorithms for information diffusion
- Study of novel cooperative algorithms based on social network models
- Services and protocols evolution based on genetic algorithms, genetic programming and metabolic models (gene expression)
- Bio-inspired models for automatic code generation
- Autonomic control algorithms based on social network models
- Bio-concepts to a large-scale multimedia P2P application

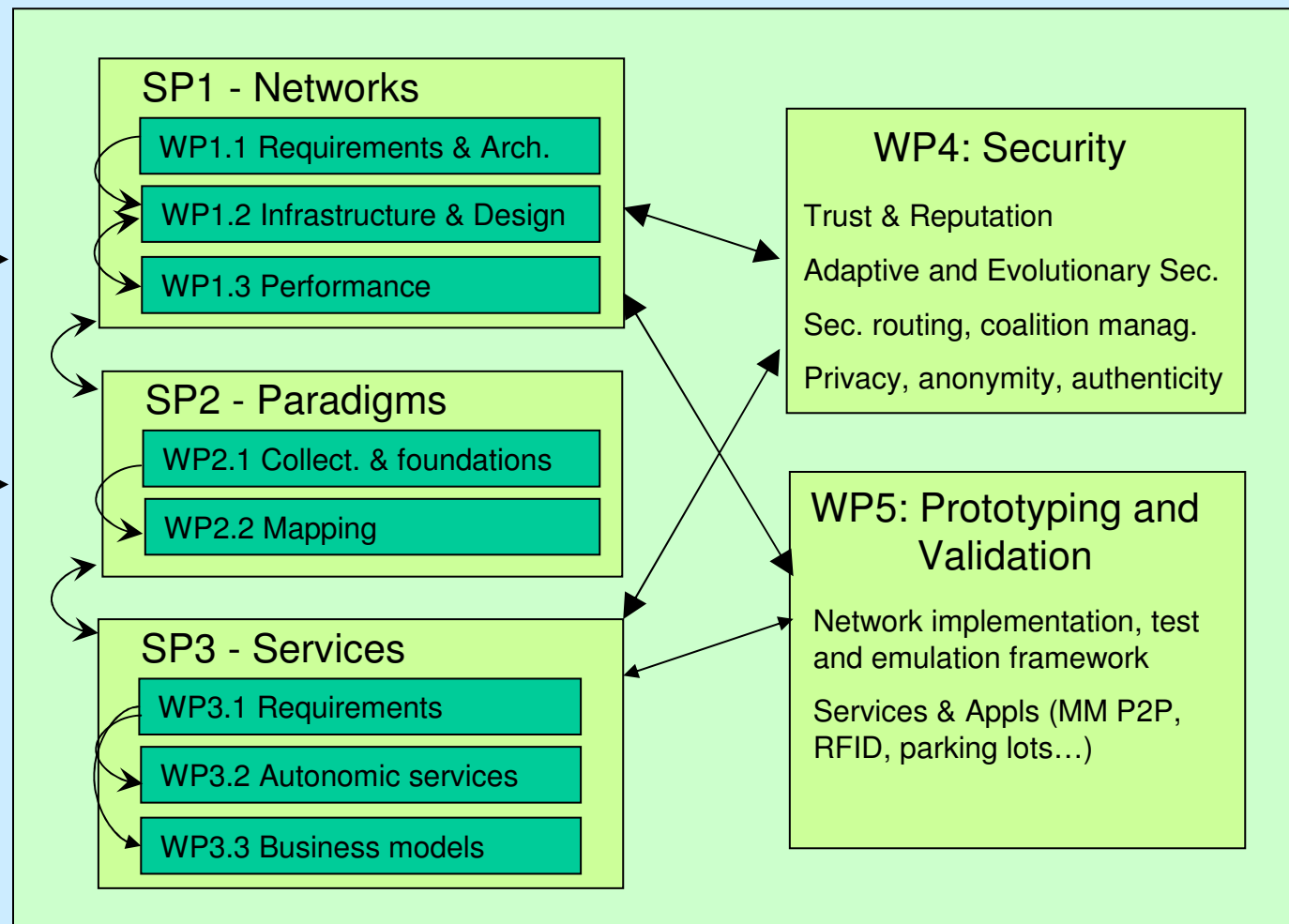
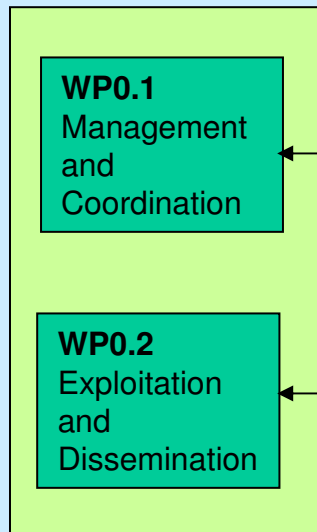
The Objectives (contd.)

- Enablers for autonomic services life-cycle: service creation/description/discovery/management/deprecation
- New related business models: definition of actors, analysis of value proposition, economics for pervasive environments
- Innovative trust/reputation mechanisms
- Adaptive & evolutionary security
- Privacy, anonymity & authenticity
- Emulation of BIONETS in GRIDs
- Implementation and testing of bio-inspired autonomic services

The Work Breakdown Structure

Scientific and Technological Work

SP0: Management and Dissemination



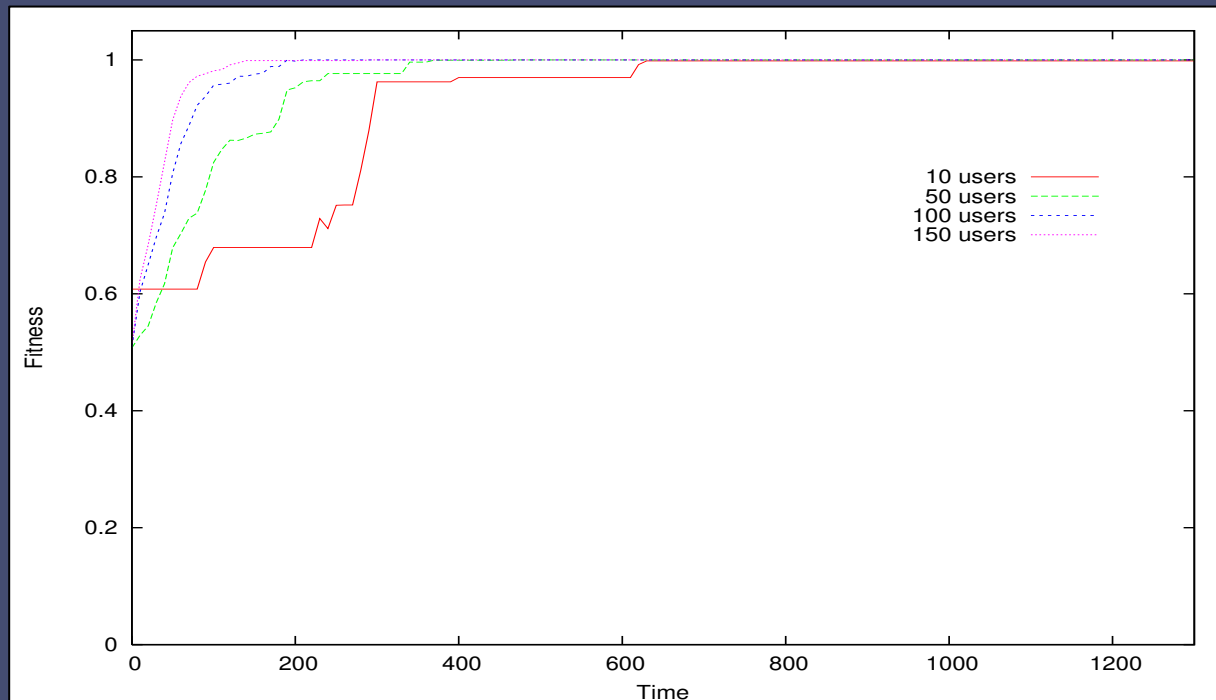
Expected Outcome

- Provide significant contributions to the establishment of theoretical foundations for bio-inspired networking and service provisioning
- Implement a GRID-based emulation environment for large-scale complex networks
- Use city-wide CREATE-NET testbed to implement self-adapting services, exploiting a large user base of university students

Part C

On the way to BIONETS: Preliminary Results

- General model for stability/convergence of a distributed evolution process: draws results from the theory of stochastic processes to define conditions for service mating policies, under which convergence of the evolving services can be ensured



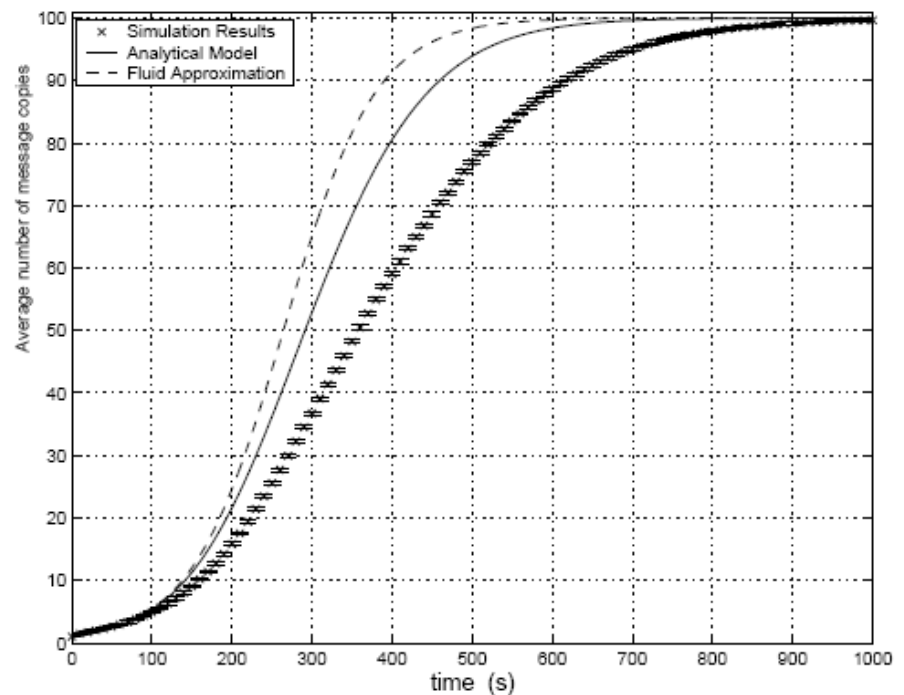
Simulation outcomes: average fitness value vs time for various population sizes (clone & mutate mating policy)

On the way to BIONETS: Preliminary Results (contd.)

- Application of evolutionary game theory in the communication fields (focus on ESS - Evolutionary Stable Strategy – to achieve stability)
- Genetic programming: crossover by homologous recombination (exchange of compatible modules only) helps producing non disruptive programs

On the way to BIONETS: Preliminary Results (contd.)

- Information filtering: development of an information-theoretical framework for limiting the diffusion of sensor-generated data by exploiting space/time correlation
- Stochastic models for the diffusion of messages through U-Nodes in BIONETS



Clustering with other IPs?

- Joint dissemination strategies for maximizing impact and raise awareness of EU researchers in SAC
- Minimization of risks associated to each individual IP, by exchanging information and lessons learned in other projects
- Promotion of a 360 degrees approach to SAC challenges, exploiting the complementary nature of the research approaches pursued by the 4 IPs to shape SAC research in FP7



Support Slides

Background Knowledge

- Already existing close relationships with researchers in bioscience and applied-biology to bring the necessary knowledge to the project.
 - Corrado Priami (Microsoft Research - University of Trento Centre for Computational and Systems Biology)
 - Pierre Bernhard (Université de Nice Sophia Antipolis - Ecole Supérieure en Sciences Informatiques)
 - Mustafa Djamgoz (Imperial College, Department of Biology)
 - Eric Wajnberg (Institut National de la Recherche Agronomique)
 - Jean-Luc Gouze (Institut National de Recherche en Informatique et Automatique)
 - Claudio Varotto (Istituto Agrario di San Michele all'Adige - Biodiversity Group)
 - E. van Nimwegen (University of Basel - Natural Science Faculty - Bioncenter)
 - Elias Manolakos (National and Kapodistrian University of Athens)
- Building the BIONETICS Interest Group to foster inter-disciplinary cross-fertilization of ideas that can lead to new bio-inspired algorithms and protocols to be applied to BIONETS autonomic networks and services
- Organizing the BIONETICS conference: The first international conference on the application of approaches inspired by the living world to ICT

ICT Today

- The emerging world is pervasive and strives to integrate people, environment and knowledge
- The supporting communication systems, including IP networks, are technology oriented rather than service oriented
- Social networks and information networks are divided and dissonant
- Emerging systems will have to be autonomic, scalable and adaptive, to respond to the social communication needs

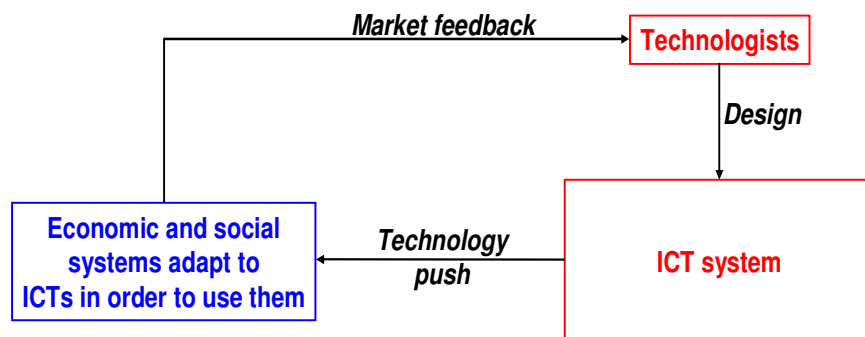
ICT Tomorrow: BIONETS

- **Autonomic communication** mechanisms bringing together the **socio-economic** world of people and the **technological** world of ICT
- How: **Biologically-inspired** approach coupling genetic and social evolutions
 - Evolution by “natural selection” (survival of the fittest) driven by service needs
 - Security driven by social networks and trust: evolutionary, adaptive security
 - Scalability to billions of heterogeneous pervasive devices through disconnected autonomic operation
- Consequence: change the way people communicate

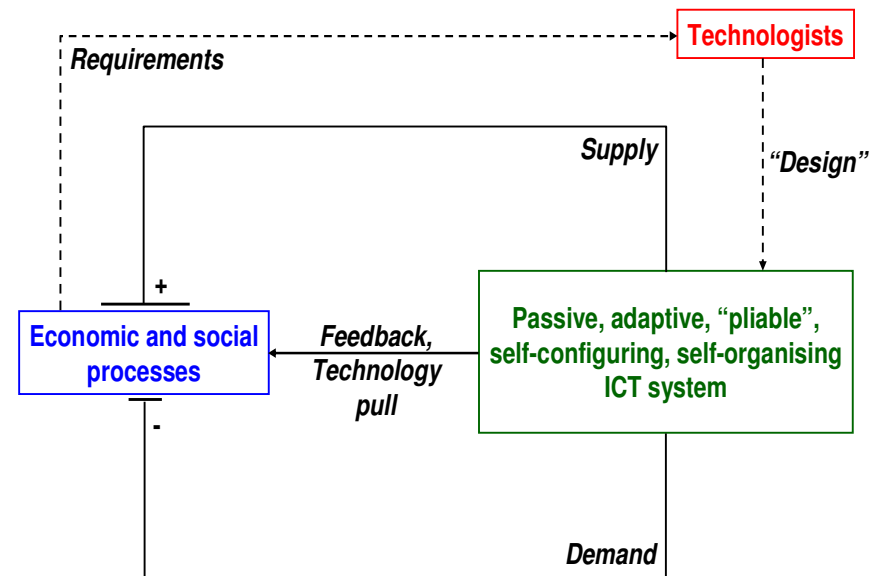
Construction of order and the « breath of life »

- Self-organizing and evolutionary systems amaze us with their ability to construct order against the odds, i.e. to defeat entropy.
- Social and economic processes create a “potential” that can be harnessed to drive the self-organization processes of information and communication systems.
- The potential difference between supply and demand “pushes” the information through the system.
- A distributed, dynamic, and intelligent architecture of a system allows it to learn from the flow of information it mediates, adapting over time to the needs of its users, and achieving self-organization whilst remaining essentially a passive system with memory.

Top-Down Vs. Bottom-Up Views of ICT Adoption



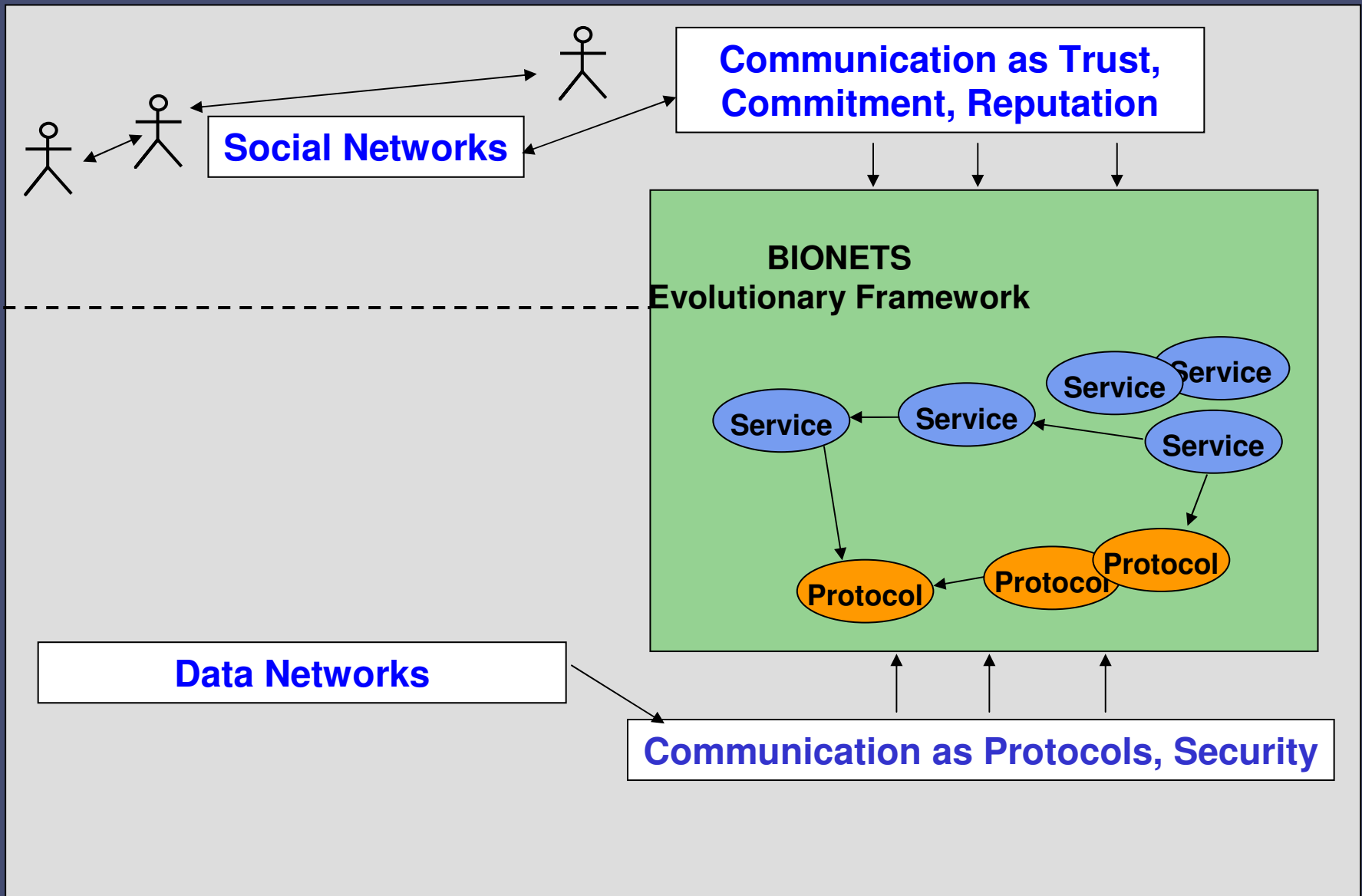
Top-Down, technocentric view



Objective : To match the impedance between blue and green boxes

Bottom-Up, biology-inspired view

Bridging the Two Views



BIONETS Fact Sheet

- **BIOlogically-inspired autonomic NETworks and Services**
- Proposal Number: 027748
- Program: FP6
- Call: FP6-2004-IST-4
- Activity:
 - IST-2004-2.3.4 – FET Proactive Initiatives
 - **Situated and Autonomic Communications (SAC): Targeting autonomic services for pervasive communication and computing environments**
- Instrument: IP
- Duration: 48 months