WAC05

Service Evolution in a Nomadic Wireless Environment

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The Vision

FUTURE PERVASIVE ENVIRONMENTS

- Technological trend toward the inclusion of embedded devices with computing/communication capabilities in all(?) surrounding objects
- Possibility of envisioning and introducing novel services, able to provide a radical shift in people/technology interactions
- In order to exploit the possibilities of such ICT-immersive environments, novel computing & communication paradigms are needed

The Vision (contd.)

Issues and Challenges

- Two main issues arise when dealing with such novel systems: *scalability and complexity*
- Scalability: the resulting network should be able to scale well up to billions of nodes & the E2E communication paradigm of the Internet does not (recall Gupta and Kumar's lesson). Direction to go: give up the connectivity constraint & support disconnected operations
- Complexity: need to perform network management functions over a large-scale disconnected system. Direction to go: put the user at the center of the network operations and build autonomic services to control the system
- **But**: nature has been confronted with and successfully resolved such issues long time ago . . .

The Framework

TARGETING AUTONOMIC SERVICES AND NETWORKS

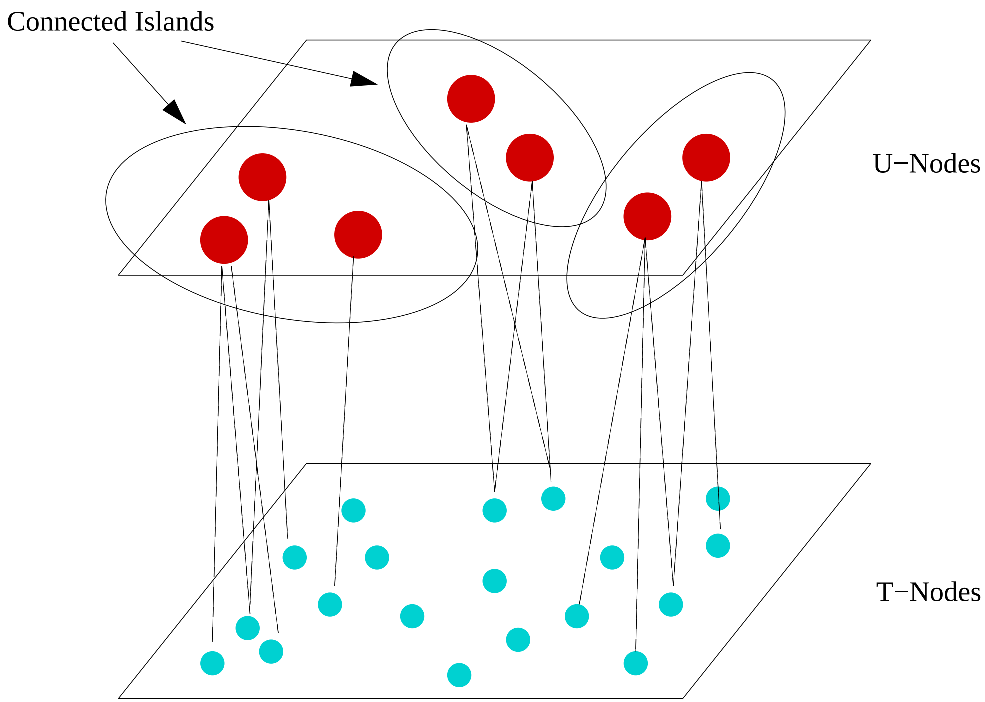
- Long-term goal (I): build a fully distributed network architecture able to support innovative services while scaling up to billions of nodes
- Long-term goal (II): provide a support for a dynamic eco-system, in which autonomic services evolve to adapt to the local environment and user's needs
- Common flavour: look for bio-inspired solutions
- Paper's goal: investigate the service evolution process in a nomadic wireless networks, targeting the design of *service mating policies*, understanding their limiting properties (stability, optimality) and studying the impact of some parameters on the convergence speed

Network Architecture

NOMADIC WIRELESS NETWORS

- ▷ Exploit heterogeneity by splitting network nodes in two categories
- ▷ U-Nodes are complex devices that run *situated* services (e.g., smartphones)
- ▷ T-Nodes are simple, cheap, low-power devices with sensing capabilities (e.g., RFIDs)
- ▷ T-Nodes devices are passive and can be read by U-Nodes in proximity (no communication stack required, no store-and-forward operations)
- ▷ U-Nodes exchange information (data, codes etc.) on the fly when getting within mutual communication range
- ▷ No need for addressing: all communications are based on single-hop broadcast
- ▷ Moving from E2E to localized peer-to-peer interactions

Network Architecture (contd.)



- ▷ An *archipelago*-like topology: the network breaks in connected islands
- ▷ U-Nodes' mobility is exploited to convey information among different islands
- ▷ No routing protocol is needed

Self-Evolving Services

THE PICTURE

- The "old" question: where to place *intelligence*?
- A radically distributed user-centric approach: services are in charge of controlling (in a cooperative way) the network. Since services are user-situated, the user becomes the *king*
- Need for self-organizing, self-optimizing, self-healing & self-protecting (in a single word: *autonomic*) services
- Apply a bio-inspired paradigm for the deployment of such services

A Bio-Inspired Approach

TOWARD A DYNAMIC DIGITAL ECO-SYSTEM

- Services are user-situated and present a modular structure; each module is called *gene*
- Each service is characterize by a *fitness* level, assumed to be in the range $[0, 1]$
- The fitness level depends on a variety of factors, including user's satisfaction, trust level etc.
- When users meet, their services can decide to *mate*, depending upon the respective fitness levels
- Mating rules are common to all nodes and compose a *service mating policy*

A Bio-Inspired Approach (contd.)

SYSTEM MODEL

- Each instance of the service is composed of the set of its genes, represented as a binary vector $\underline{v}_i = [v_i(1), \ldots, v_i(T)]$
- The fitness level associated with such vector is assumed to be:

$$I_i = \frac{\sum_{k=1}^{T} v_i(k)}{T}$$

- The parameters we consider are the average and minimum fitness level of the network at time t:

$$X(t) = \frac{1}{N} \sum_{i=1}^{N} I_i(t) \qquad Y(t) = \min_{i=1,\ldots,N} I_i(t)$$

- We consider the evolution of such processes embedding at the meeting instants

Optimality & Stability Criteria

- **Definition 1** *A service mating policy is called stable if it leads to convergence of $X(t)$ [$Y(t)$] with unitary probability.*
- **Definition 2** *A service mating policy is called optimal if it leads to convergence of $X(t)$ [$Y(t)$] to* 1 *with unitary probability.*
- The optimality condition is, in general, not sufficient for a mating policy to be efficient. Indeed, *efficiency* concerns the dynamics of the process $X(t)$, i.e., its ability to converge fast to the optimal operating point

3 Service Mating Policies

- ▷ **Definition 3 (Clonation mating policy)** *Let us assume* $l_1 > l_2$ *(if* $l_1 = l_2$ *no mating takes place). Then user* 2 *downloads (clones) user* 1*'s service. User* 1 *keeps its service unchanged.*
- ▷ **Definition 4 (Clone-and-mutate mating policy)** *Let us assume* $l_1 \geq l_2$ *(if* $l_1 = l_2 = 1$ *no mating takes place). Then user* 2 *downloads user* 1*'s service. Mutation is then performed on the new vector* $\underline{v}_2$*, by changing each digit independently with a given probability p (called the mutation probability). If* $l_1 > l_2$*, user* 1 *keeps its service unchanged.*
- ▷ **Definition 5 (Combine-and-mutate mating policy)** *Let us assume* $l_1 \geq l_2$ *(if* $l_1 = l_2 = 1$ *no mating takes place). User* 2 *downloads user* 1*'s service. A number* $k \in \mathcal{U}\{1, \ldots, T\}$ *is generated. A new vector* $\underline{v'}_2 = [v_1(1), \ldots, v_1(k), v_2(k+1), \ldots, v_2(T)]$ *is formed. Mutation is performed on this vector. If* $l_1 > l_2$*, user* 1 *keeps its service unchanged.*

Limiting Properties

- The following results can be drawn on the 3 mating policies, exploiting a classical result in stochastic processes (i.e., the submartingale convergence theorem)
- **Proposition 1** *The clonation/clone-and-mutate/combine-and-mutate mating policies are stable.*
- **Proposition 2** *The clonation mating policy is not optimal.*
- **Proposition 3** *The clone-and-mutate mating policy is optimal.*
- **Proposition 4** *The combine-and-mutate mating policy is optimal.*

Understanding the Dynamics of the Fitness Evolution Process

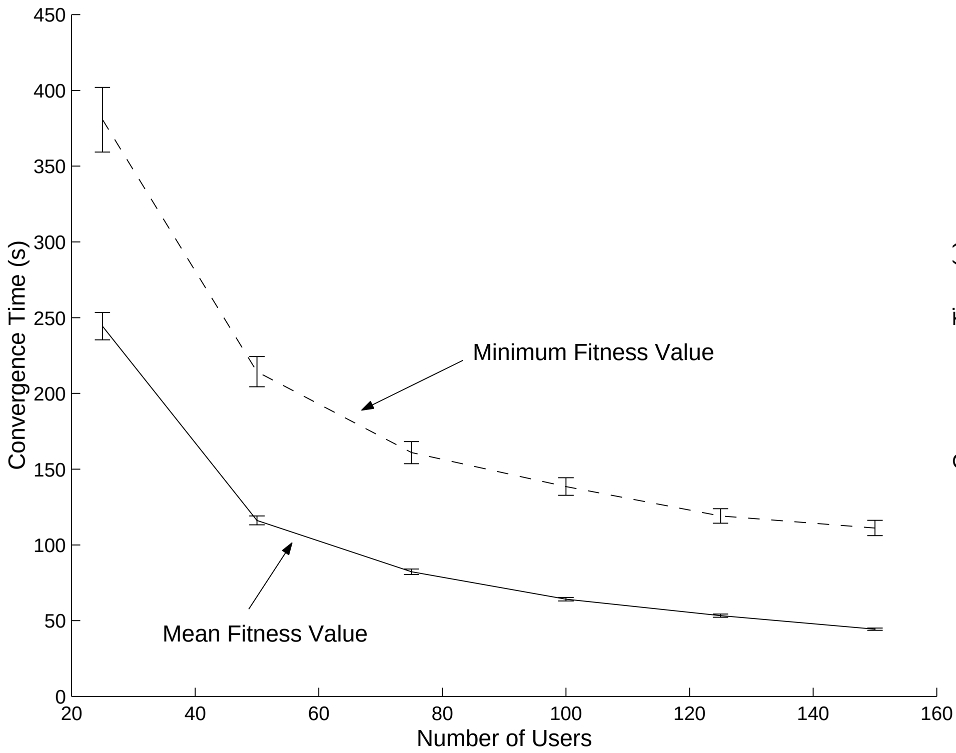
CONSIDERATIONS

- ▷ The limiting property does not tell us much about the actual performance of the mating policies
- ▷ We resort to numerical simulations (Omnet++) to study the impact on the convergence time of (i) the number of nodes (ii) the nodes speed (iii) the mobility model

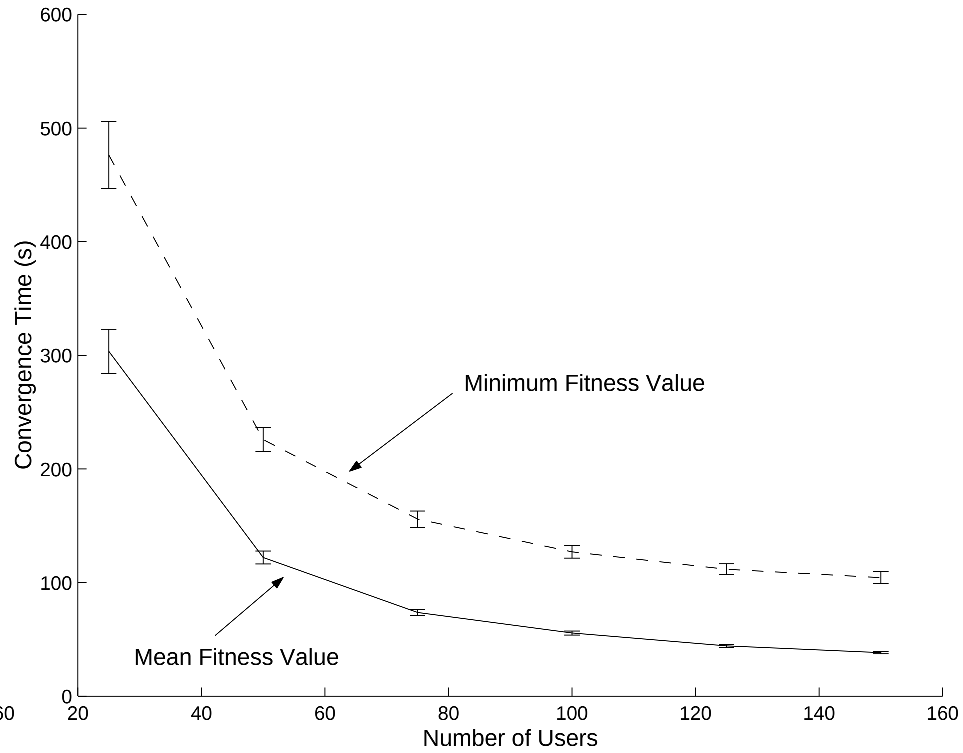
SIMULATION SETTING

- ▷ Square area of $2000 \times 2000\ m^2$; nodes equipped with an IEEE802.11b-compliant PHY and MAC
- ▷ Mutation probability $p = 0.1$, number of genes $T = 100$
- ▷ Mobility models: Random Waypoint Mobility (RWM) and Brownian Motion (BM)
- ▷ Parameters: time taken by $X(t)$ and $Y(t)$ to exceed the 0.95 threshold
- ▷ Results: 95% confidence interval over 50 simulations

Performance Results



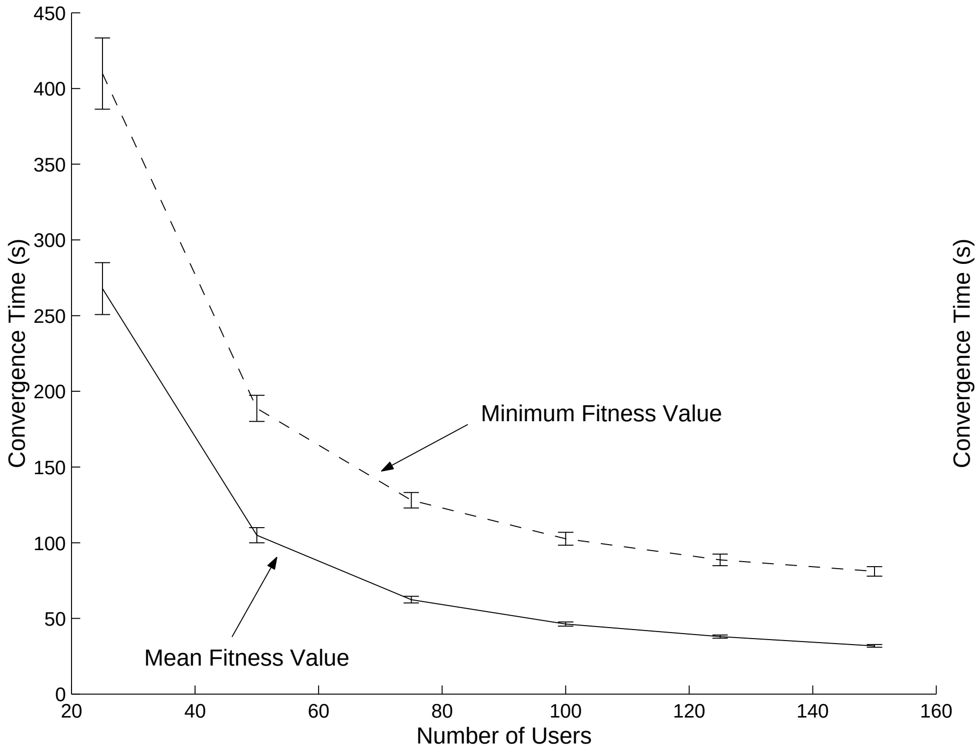
Clone & Mutate, v = 10 m/s, RWM



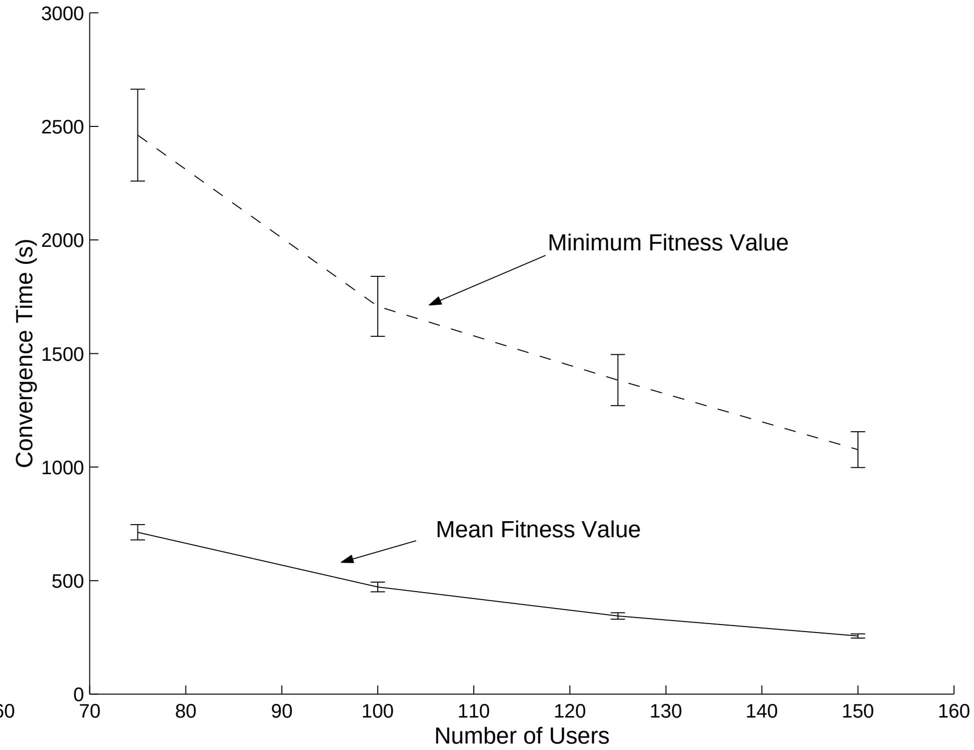
Combine & Mutate, v = 10 m/s, RWM

- ▷ Clone&Mutate performs usually better than Combine&Mutate, but the latter performs well in very dense highly mobile scenarios
- ▷ General consideration: the convergence process speeds up with both population size and nodes speed

Performance Results (contd.)



Combine & Mutate, v = 15 m/s, RWM



Combine & Mutate, v = 15 m/s, BM

- ▷ BM has convergence times that are one order of magnitude higher than RWM
- ▷ Cannot be explained by the different distributions of inter-meeting times
- ▷ A detailed trace analysis shows that in BM few nodes tend to remain isolated for a long time, thus leading to poor performance

Conclusions

Open Issues

- How can we realistically define the fitness? How to account for user's satisfaction?
- How to ensure the coexistence in the same ecosystem by different services?
- What about cooperation enforcement & trust mechanisms?

Directions for Future Research

- Model the dynamics of service evolution process
- Understand the impact of more realistic mobility models (i.e., with inter-meeting times following Zipf's law)
- Draw from results in GAs to design more performant combine & mutate policies