Mobile Computing in Digital Ecosystems: Design Issues and Challenges

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Presentation **outline**

- **Problem** definition and **proposal** description
- Inside the **Digital Organism**
- The **Digital Ecosystem**
- Proposed approach: **desiderata** and **feasibility**
- Optimizing the Digital Organism
- Digital Organisms and the Digital Ecosystem
- **Seamless connectivity**
- Optimizing the Digital Ecosystem
- **Data dissemination** in the Digital Ecosystem: **gossip based**
- **Computation** and **storage** issues
- Conclusions and future work

Problem definition: *many devices*

Problem definition: *with different characteristics*

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CPU
battery
WLAN/Bluetooth
GPS
storage

Problem definition: *with different characteristics*

Problem definition: *with different characteristics*

CPU
battery
GSM/UMTS/...
WLAN
storage

Problem definition: *with different characteristics*

CPU
battery
storage
Bluetooth

Problem definition: a **D**igital **O**rganism (**DO**)

CPU
battery
GSM/UMTS/...
WLAN
storage

CPU
battery
GSM/UMTS/...
WLAN
Bluetooth
GPS
storage
sensors

CPU
battery
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Problem definition: a **D**igital **O**rganism (**DO**)

Problem definition: an **e**xtended **D**igital **O**rganism (**eDO**)

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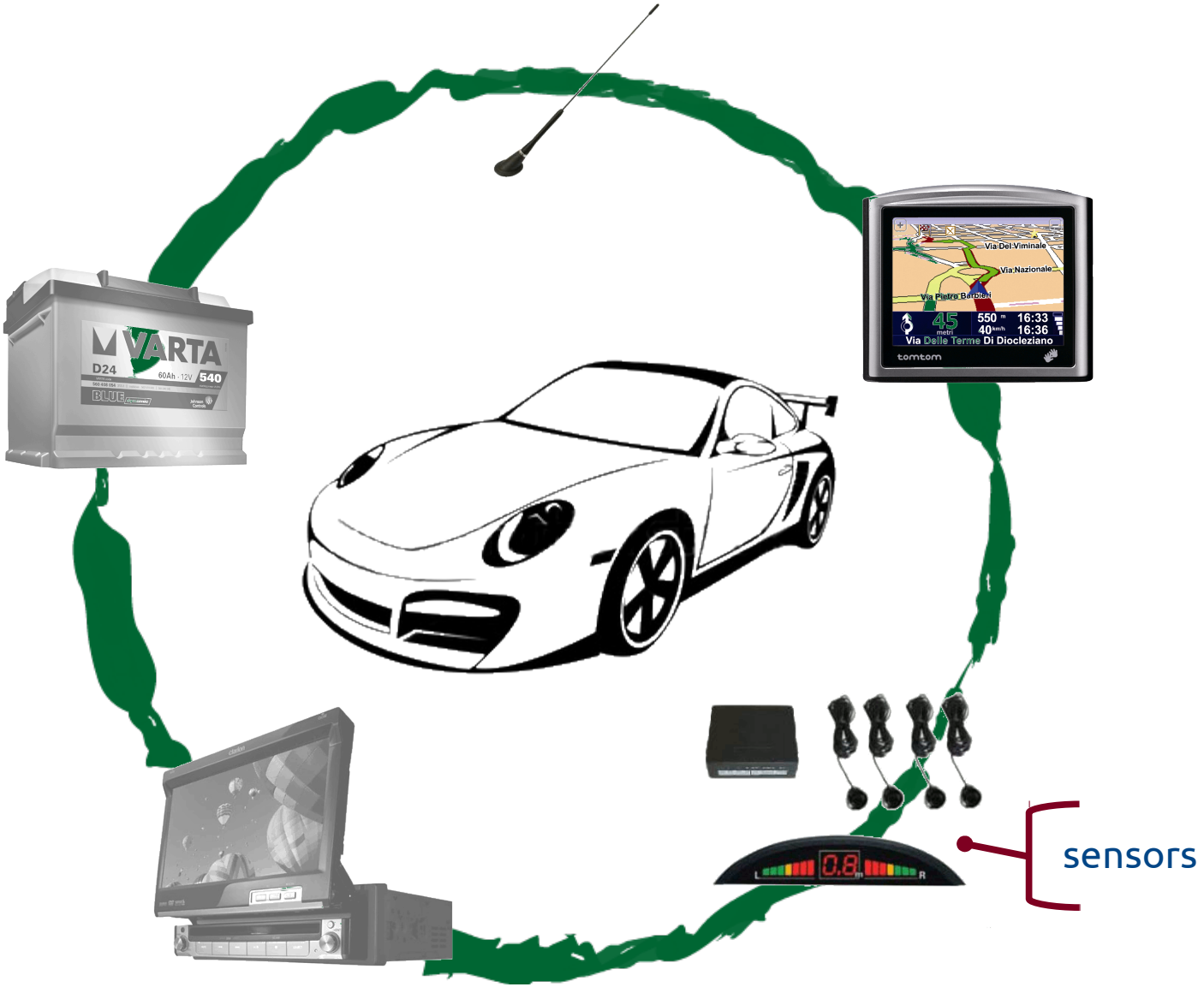
CPU
Bluetooth
GPS
maps

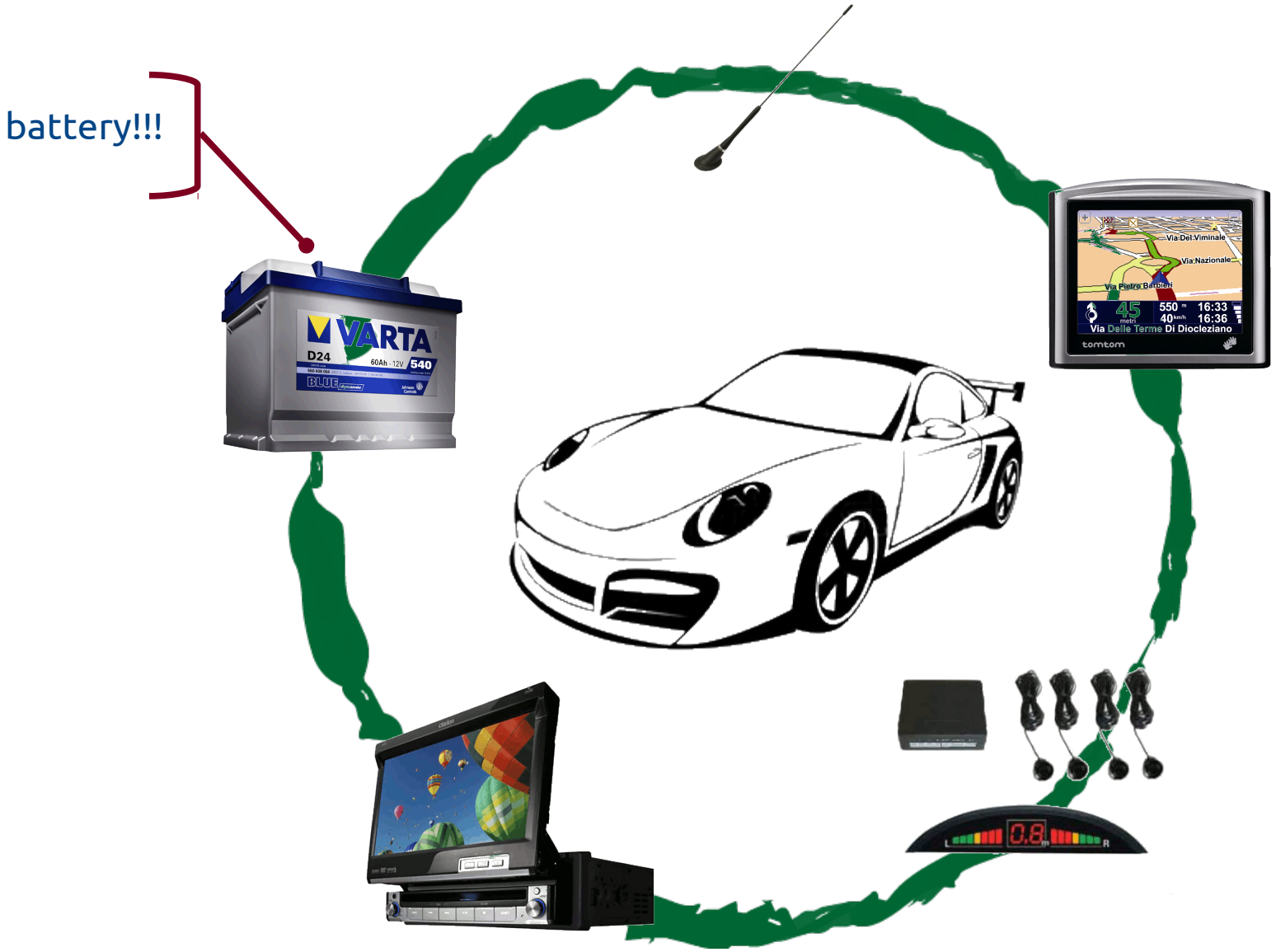
Problem definition: an **e**xtended **D**igital **O**rganism (**eDO**)



Problem definition: an **e**xtended **D**igital **O**rganism (**eDO**)

CPU
Bluetooth
storage

Problem definition: an **e**xtended **D**igital **O**rganism (**eDO**)



Problem definition: an **e**xtended **D**igital **O**rganism (**eDO**)

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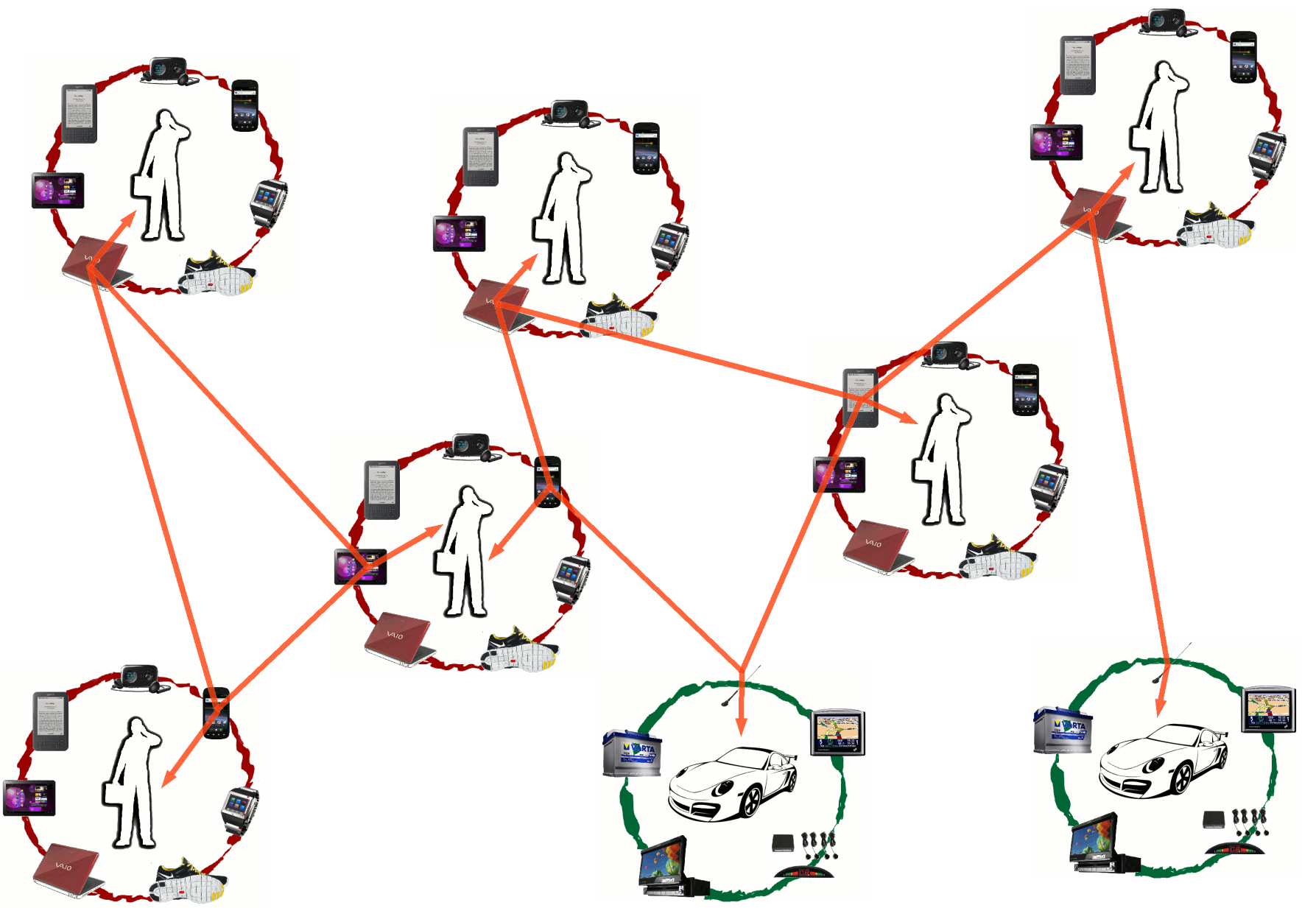
Problem definition: *a Digital Ecosystem (DE)*



Inside the **Digital Organism**

- A **D**igital **O**rganism (**DO**) is composed of many different devices, each with a **specific technical profile**
- Some characteristics are **static**:
  - **hardware**
  - **communication** and **computation** capabilities
- Others are **dynamic**: for example, the **battery level**
- There are many **technological limitations** to overcome, each device is seen as **separate tool**
- The human user often has to do **complex configurations** on each device and take decisions on many low-level details

Inside the **Digital Organism**: a few examples

- Short **range wireless technologies** (e.g. Bluetooth, ZigBee) can be used for the **intra-DO communications** (often more efficient than WLAN or UMTS)
- The **DO** should be an **integrated community of devices**
- One (or more) devices have to be used as "gateways" for **inter-DO communications** (e.g. to reach Internet)
- **How is the gateway device chosen?** The "**best available network**" should be used
- **What is "best"?** Is it the one with the **lowest latency**? **Higher bandwidth**? **Cheapest**? More **energy efficient**?
- Many factors... such as the **battery level** of each device, the **telco rates** and **policies**

The **Digital Ecosystem**

- The **D**igital **E**cosystem (**DE**) is **populated** by **DO**s
- **DO**s can enter and exit the **DE**: **very dynamic behavior**
- Each **DO** is a **computation** and **communication resource**
- It can **forward messages** (e.g. multi-hop network) but this is **not its main role**
- **Smart P2P schemes** must be used among **DO**s to **share data** and **resources** (e.g. peripherals)
- How is the **DE organized**? What is its **topology**? How resources can be **accessed** by other **DO**s? What **access control schemes** have to be used?

Proposed approach: 4 main points

- All the devices within a **DO** must be integrated using **auto-configuration strategies**
- Each **DO** is equipped with a software module capable of **multi-criteria adaptive decision schemes**
- **Smart P2P schemes** to share data/resources among **DO**s:
  - **social aspects** (e.g. friends, colleagues, family)
  - **trust**, **security** and **privacy**
  - **smart discovery** of resources
  - **strategies** for resources access (e.g. tit-for-tat schemes)
- Creation of a global overlay network with some **desired topology**, to guarantee an **effective data dissemination**

Desiderata and **feasibility**

- **Novel interaction algorithms**: "optimal" organization of resources both at global and local level
- **Goal**: building an ubiquitous architecture in which the devices are configured **transparently**, **dynamically** and **adaptively** depending on:
  - the characteristics of the device
  - the environment in which it is deployed
  - the other users, their devices and the interactions
- Most of the **technologies** for these target paradigms are **already available**
- What is missing is their **integration**!

Optimizing the **digital organism**

- **Full interaction** among all computing resources is needed
- It requires to **optimize the use of networks** that are available to the user's devices
- **Decisional procedures** based on **several criteria**
- The goal is to model each **DO** as a **computational environment** and to find the **best configuration** for it
- All nodes must **broadcast** (to the whole **DO**) their **technical details** (and working state) to enable a **proper configuration** of other devices in the **DO**s
- A **coordination-based approach** is quite promising: distributed algorithm for its election have to be implemented

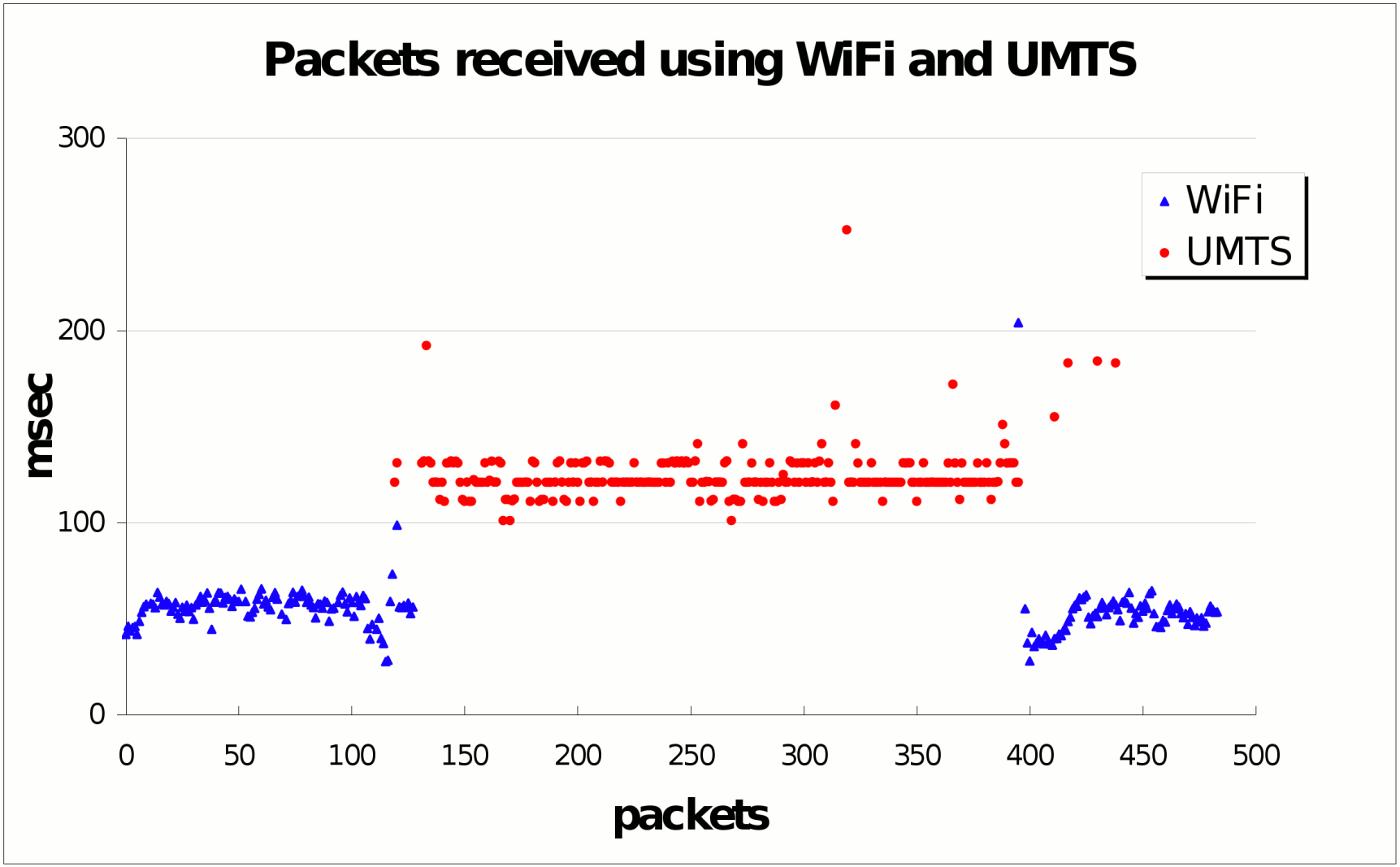
Digital organism and **digital ecosystem**

- Each **DO** needs a **set of protocols** to interact with peer **DO**s in the same **home ecosystem**
- What is the **best available network**? **Multi-criteria** choice:
  - **bandwidth**
  - connection **cost**
  - **battery** state and consumption
  - probability to maintaining the connection active while moving (to minimize **hand-offs**)
- And furthermore... enable the **simultaneous** and **opportunistic** use of **all the available networks**

Digital organism and **digital ecosystem**

- Following a bottom-up approach, we have started investigating in deep some specific aspects
- **Goal**: allow the use of multiple network interfaces **transparent at the application level**
- **Proposed implementation**: **cross-layer architecture** that uses a proxy-based system to offer **continuity in the communication** of a given mobile node with a remote proxy
- **Testbed**: a mobile node was equipped with two network interfaces (Wi-Fi and UMTS)
  - the **coverage** of both technologies depends on the **node position**
  - is it possible to have a **seamless switch** without interrupting the end-to-end communications?

Seamless connectivity: a testbed



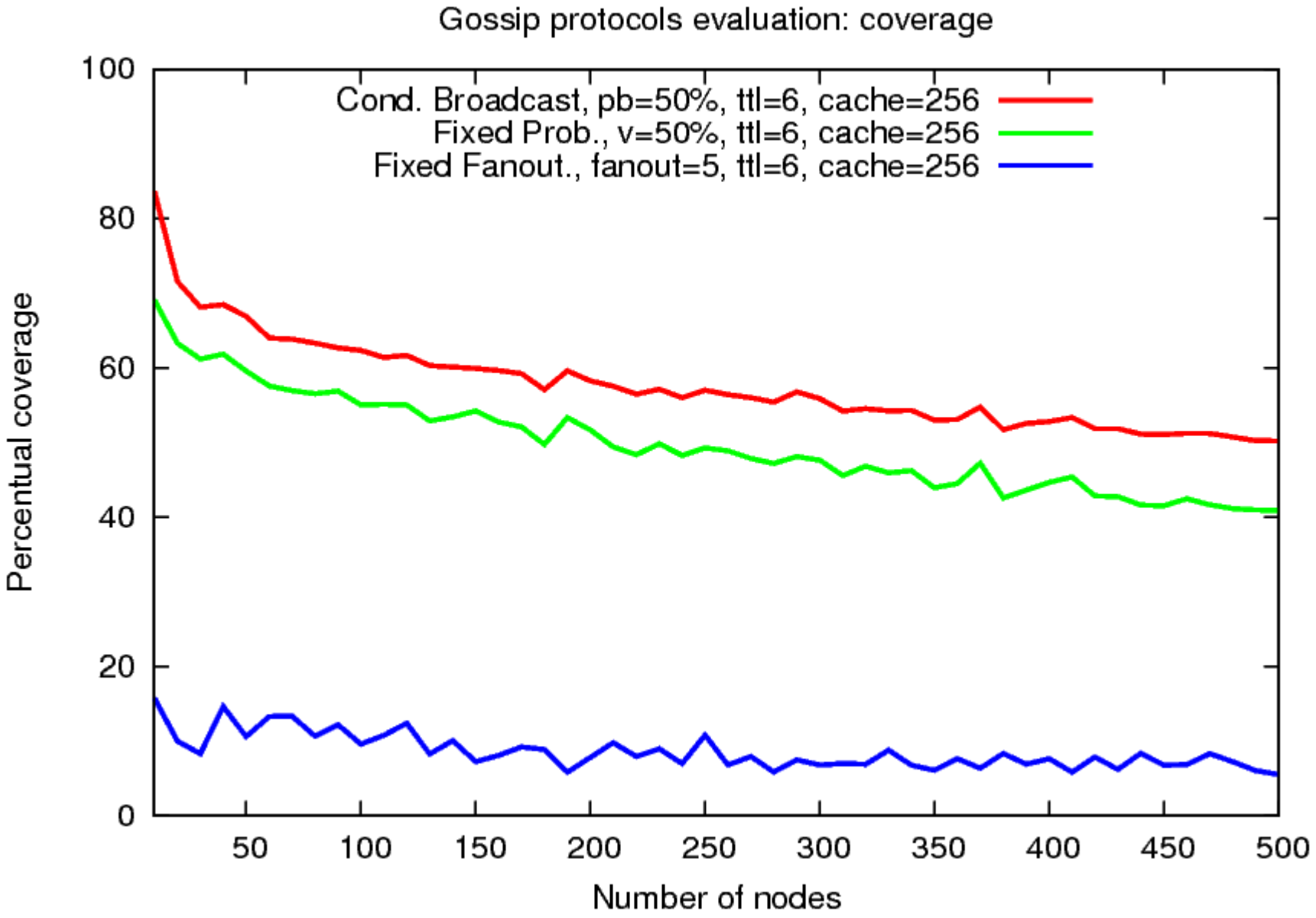
Optimizing the **digital ecosystem**

- The **DO**s have to be organized as a set of interacting nodes
- Many approaches are possible (e.g. overlay or mesh networks)
- The theory of **complex network** can help identify the more adequate **topology** (e.g. random, scale-free, small-word)
- Other factors have to be considered, such as **local strategies** based on **nodes targets**, **resources**, **services** and the **human identities behind the DO**s (**privacy concerns**)
- (**Semi**)**automatic configuration mechanisms** based on:
  - nodes **topology** in the environment
  - **type of network** to be created
  - **type of services**
  - node characteristics in terms of **computation** / **communication**
  - **clustering** / **proximity** (also in terms of **social features**)

Data dissemination in the digital ecosystem

- Dissemination strategies must be adopted to **broadcast messages** (e.g. for the discovery of **DO**s, resources, paths for messages)
- The network is **highly dynamic**: static and centralized approaches are **not feasible**
- **Unstructured P2P** solutions are much more promising: for example **gossip dissemination** strategies
- Many **advantages**: fully decentralized, based on local information, very robust and simple
- **Drawbacks**: high overhead (in some conditions)
- Using simulation, we have investigated the most common gossip protocols (**conditional broadcast**, **fixed probability**, **fixed fanout**) and proposed a new generation of **adaptive protocols**

Evaluation: gossip protocols



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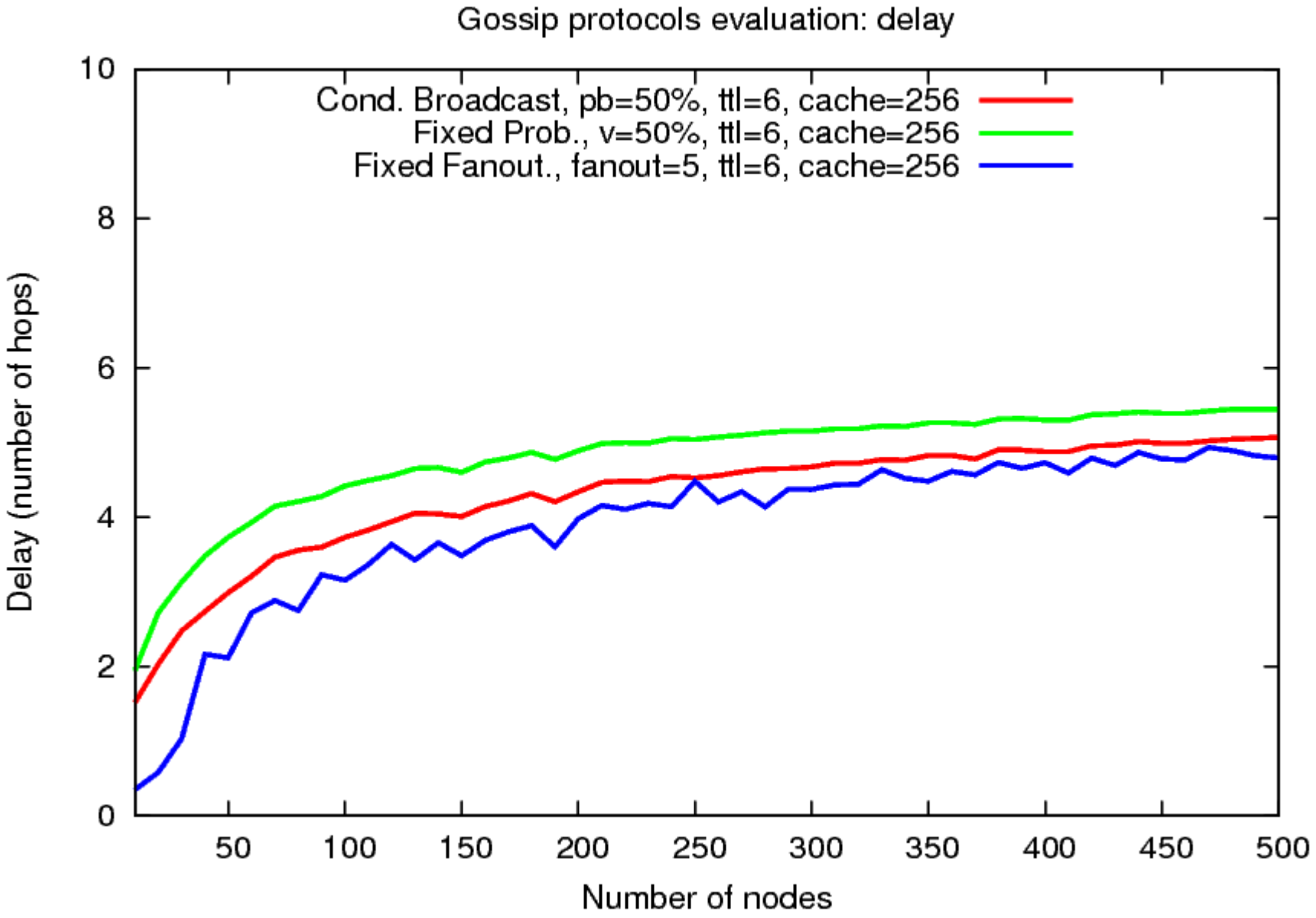

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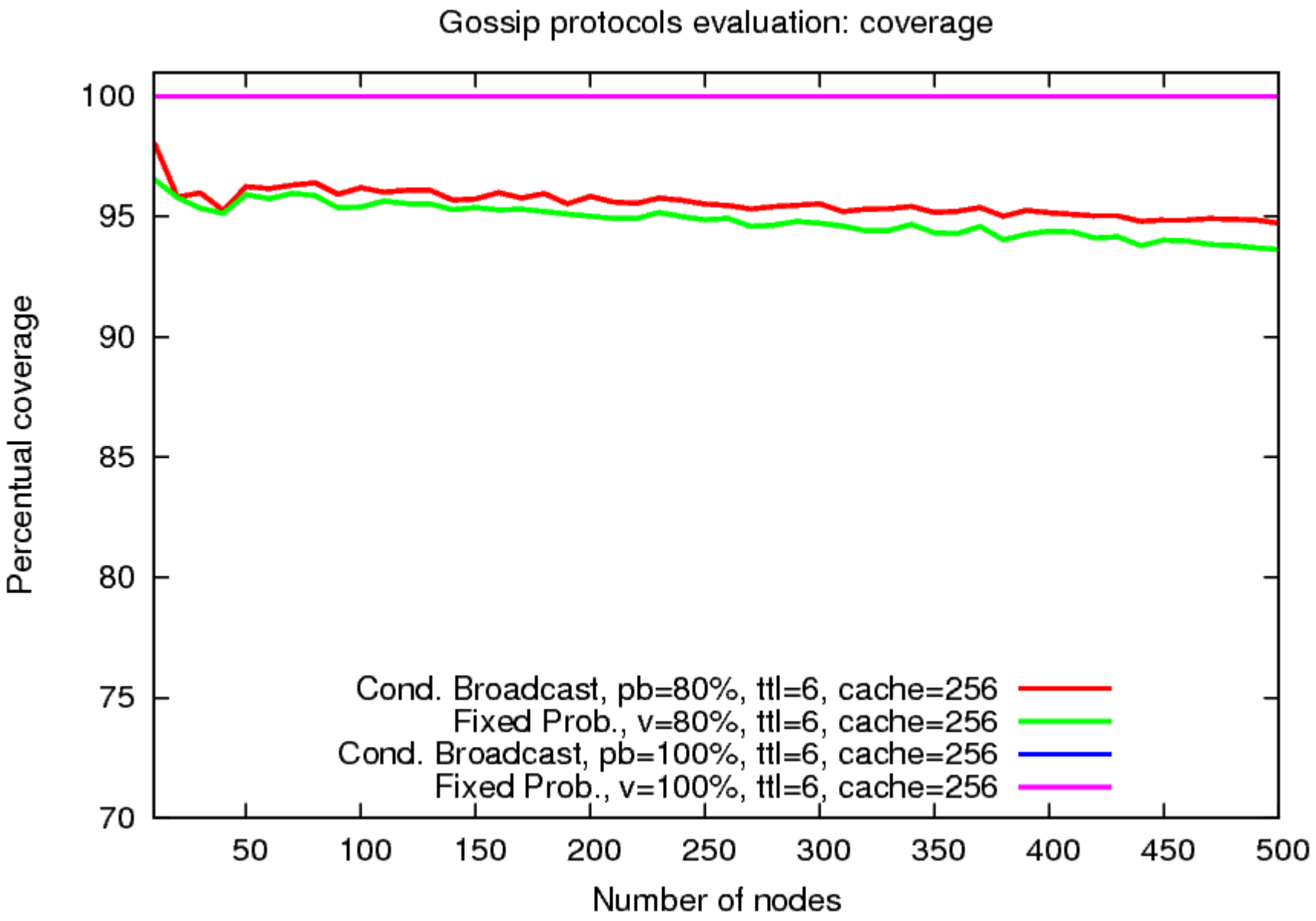

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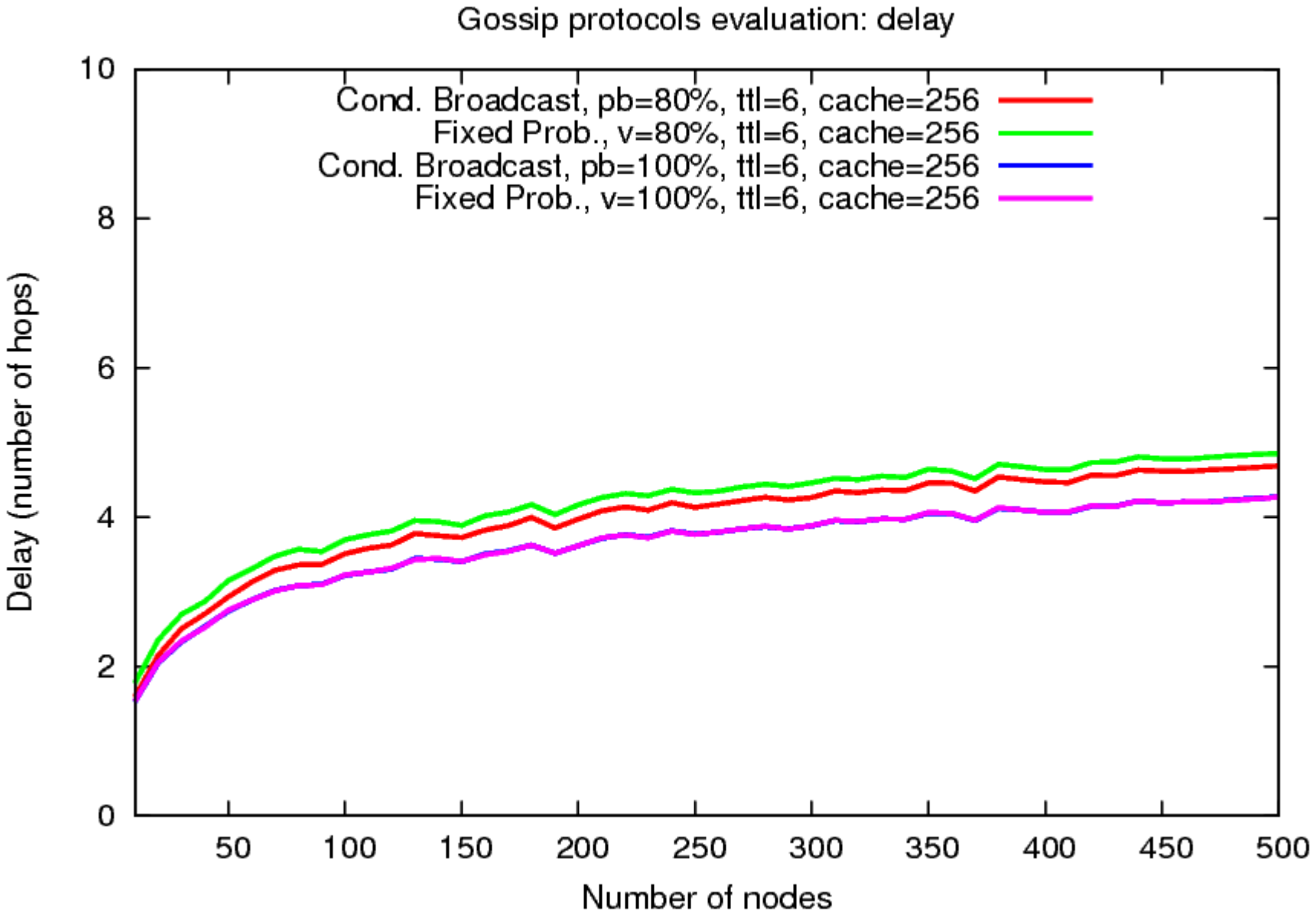

Computation and **storage** issues

- Computation demanding queries can be **handled in an adaptive manner**: a **cloud based system over mobile ad-hoc technologies**
- The computations can be performed on **unknown hosts**, **trusted servers** or **hosts in the same user domain**
- The best allocation strategy has to be found, but properties as **privacy**, **accountability** and **non reputability** must be guaranteed
- Something similar also for **remote storage**: the best storage for some data is outside the local **DO**, somewhere in the **DE** or even on Internet

Conclusions and future work

- We have discussed a methodology to **optimize interactions** of mobile users
- Each user is seen as a **D**igital **O**rganism (**DO**) that lives in dynamic and heterogeneous ecosystem, called **D**igital **E**nvironment (**DE**)
- The idea is to optimize the use and interaction of devices inside each **DO** and the interactions between **DO**s in the **DE**
- The technologies needed to build such a system are **mostly already available**, what is missing is their **integration**
- Following a bottom-up approach we have **investigated some basic aspects** such as **seamless connectivity** and **gossip dissemination schemes**
- The next step is the detailed design and implementation of the rest of the system

Further information

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A **draft version** of this paper is freely available at the following link:

- http://arxiv.org/pdf/1105.2458v1

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