

MACRO-ROUTING: a hierarchical routing protocol for MPLS using mobile agents

Sanda Dragos
Supervised by Dr. Martin Collier

Hierarchical ...
... protocols
MPLS
Mobile Agents
Macro-routing
Counting Waves
Mathematical model
Simulation results
Conclusions

Hierarchical routing protocols

Why do we need them?

- ▶ The Internet increases in size & in demands;
- ▶ The Internet Service Providers (ISP) deploy:

Traffic Engineering

Quality of Service routing

- ▶ scalability problems

- ▷ storage overhead
- ▷ computational overhead
- ▷ update overhead

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)



Page 2 of 18

[Go Back](#)

[Full Screen](#)

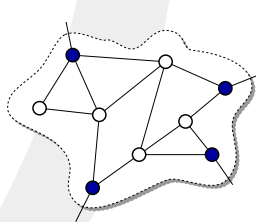
[Close](#)

[Quit](#)

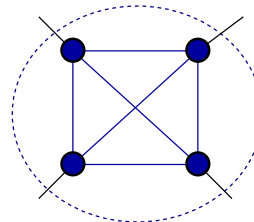
Hierarchical routing protocols

Topology aggregation

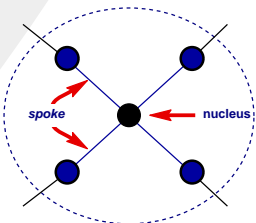
The network is divided into domains. Detailed routing information is delivered only inside each domain, and only aggregated routing information is transmitted across domain boundaries.



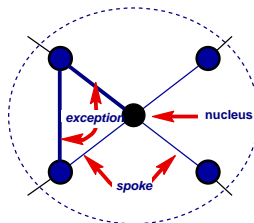
(a) Original topology



(b) Full-Mesh



(c) Symmetric Star



(d) Complex-Node

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)

◀ ▶

◀ ▶

Page 3 of 18

[Go Back](#)

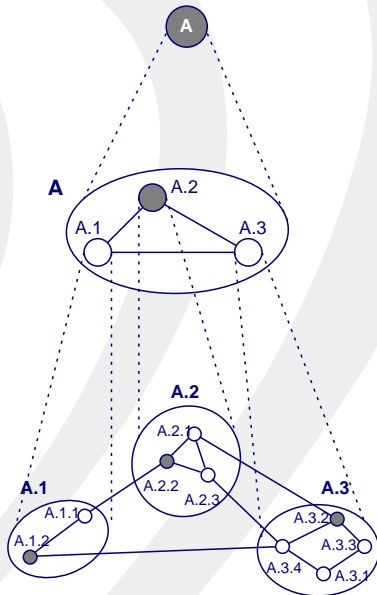
[Full Screen](#)

[Close](#)

[Quit](#)

Hierarchical routing protocols

Examples



- ▶ Open Shortest Path First (OSPF)
- ▶ Private Network-to-Network Interface (PNNI)
- ▶ Hierarchical Distributed Protocol (HDP)
- ▶ Viewserver Architecture

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)

◀◀ ▶▶

◀ ▶

Page 4 of 18

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

Multi-protocol Label Switching (MPLS)

Why?

- ▶ Quality of Service & Traffic Engineering
- ▶ *hierarchical forwarding*

Hierarchical ...

... protocols

MPLS

Mobile Agents

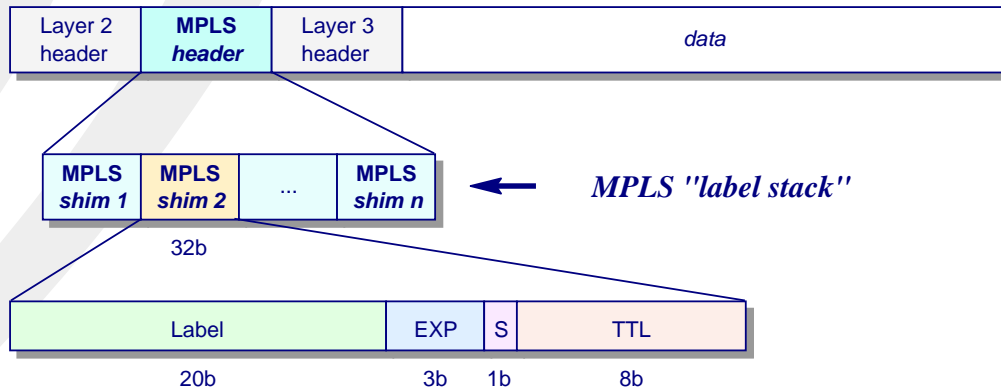
Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions



[Home Page](#)

[Title Page](#)

[◀](#) [▶](#)

[◀](#) [▶](#)

Page 5 of 18

[Go Back](#)

[Full Screen](#)

[Close](#)

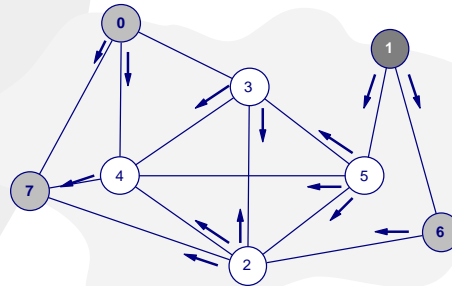
[Quit](#)

Mobile Agents

A *mobile (software) agent* is: a computational entity

- which acts on behalf of others,
- is *autonomous, proactive, and reactive*,
- exhibits capabilities to *learn, cooperate, and move*.

...for routing



advantages

- ↗ flexibility
- ↗ modularity
- ↗ scalability
- ↗ adaptability
- ↗ robustness

disadvantages

- ↘ efficiency
- ↘ security
- ↘ provability

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Home Page

Title Page

◀◀ ▶▶

◀ ▶

Page 6 of 18

Go Back

Full Screen

Close

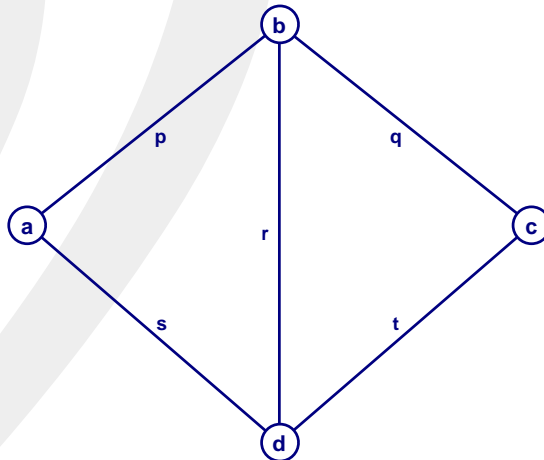
Quit

Mobile Agents



The WAVE technology

... is based on spatial matching of recursively defined strings in the navigational WAVE language with the network topology.



Computer Network

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)



Page 7 of 18

[Go Back](#)

[Full Screen](#)

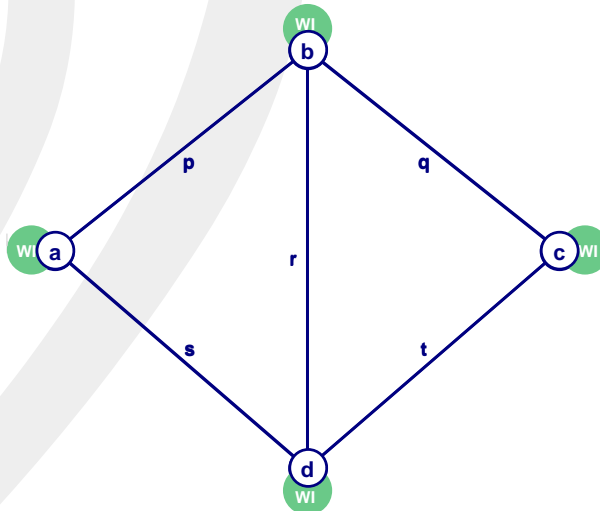
[Close](#)

[Quit](#)

Mobile Agents

The WAVE technology

... is based on spatial matching of recursively defined strings in the navigational WAVE language with the network topology.



WAVE Interpreter

- interpret the navigational WAVE language
- capable of *arbitrary* data processing in nodes
- asynchronous communication with other nodes
- system calls

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)

◀◀ ▶▶

◀ ▶

Page 7 of 18

[Go Back](#)

[Full Screen](#)

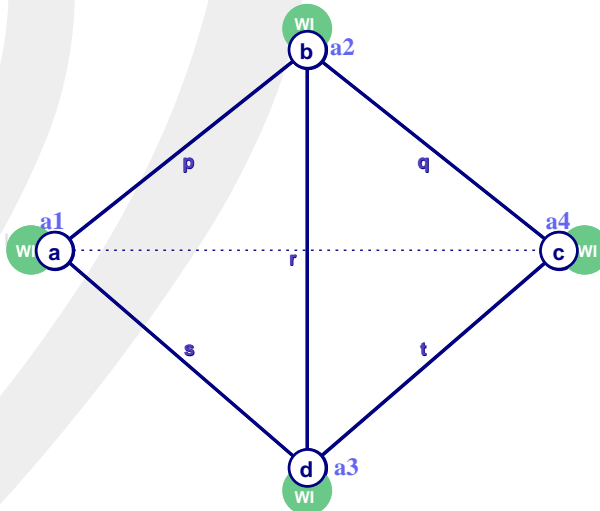
[Close](#)

[Quit](#)

Mobile Agents

The WAVE technology

... is based on spatial matching of recursively defined strings in the navigational WAVE language with the network topology.



Knowledge Network

- distributed *arbitrarily* in a data network
- can persist and reflect any declarative or procedural information
- each KN node has a unique address using which it can be directly accessed from any other node

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Home Page

Title Page

◀◀ ▶▶

◀ ▶

Page 7 of 18

Go Back

Full Screen

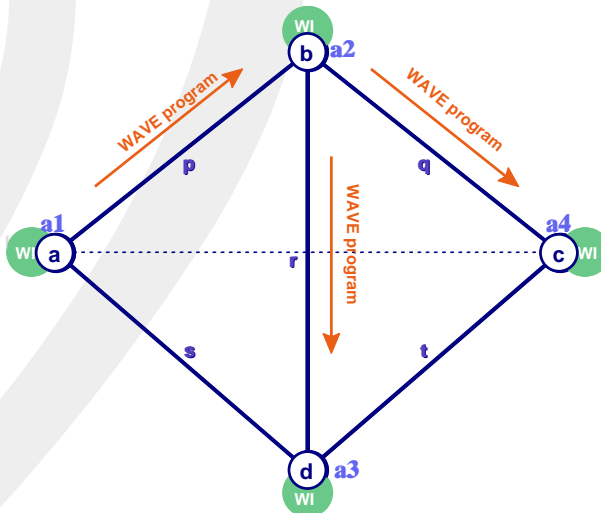
Close

Quit

Mobile Agents

The WAVE technology

... is based on spatial matching of recursively defined strings in the navigational WAVE language with the network topology.



WAVE programs

- recursive code
- dynamically self-spreading
- may be injected from any agent
- propagates together with intermediate data

- *very compact*: (Ex: finding the shortest path three in a link-weighted network:)

@#a.F=0.RP(N~,F<N.N=F.N1=P.\$,F+L)

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Home Page

Title Page

◀ ▶

◀ ▶

Page 7 of 18

Go Back

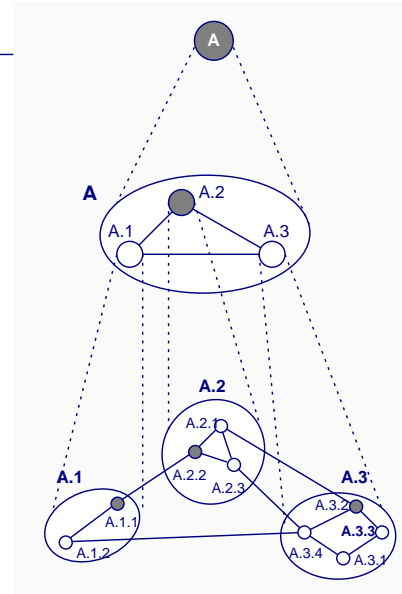
Full Screen

Close

Quit

Macro-routing

hierarchical routing protocol designed for *MPLS* networks that uses for the routing process mobile agents called *waves*



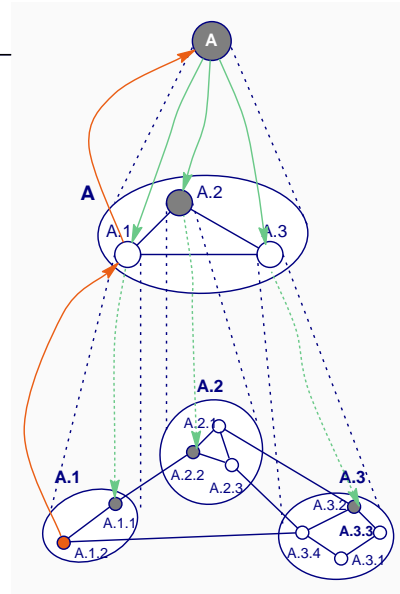
Hierarchical ...
... protocols
MPLS
Mobile Agents
Macro-routing
Counting Waves
Mathematical model
Simulation results
Conclusions

Macro-routing

hierarchical routing protocol designed for *MPLS* networks that uses for the routing process mobile agents called *waves*

1. Determination of participant domains

- *upwards search* for the root
- *downwards search* for the **participant domains**



Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Home Page

Title Page

◀ ▶

◀ ▶

Page 8 of 18

Go Back

Full Screen

Close

Quit

Macro-routing

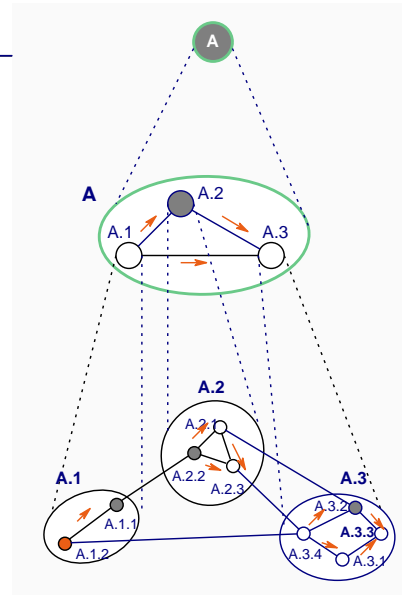
hierarchical routing protocol designed for *MPLS* networks that uses for the routing process mobile agents called *waves*

1. Determination of participant domains

- *upwards search* for the **root**
- *downwards search* for the **participant domains**

2. Path computation

- create the **aggregate representation** for every domain
- **build** the next hierarchical level
- repeat the process until having one domain



Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Home Page

Title Page

◀ ▶

◀ ▶

Page 8 of 18

Go Back

Full Screen

Close

Quit

Macro-routing

hierarchical routing protocol designed for *MPLS* networks that uses for the routing process mobile agents called *waves*

1. Determination of participant domains

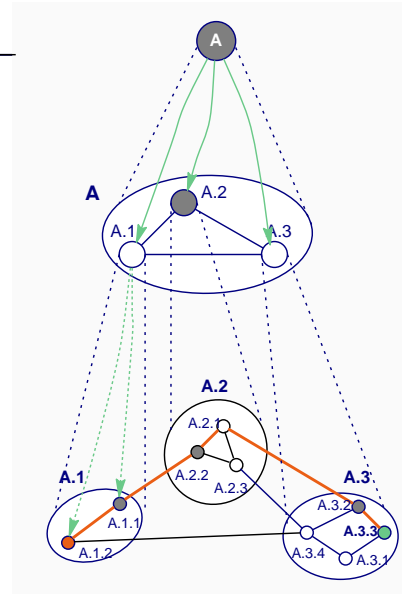
- *upwards search* for the **root**
- *downwards search* for the **participant domains**

2. Path computation

- create the **aggregate representation** for every domain
- *build* the next hierarchical level
- repeat the process until having one domain

3. Path reservation and set-up

- reserve the resources
- set the Label Switched Paths (LSPs)



Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Home Page

Title Page

◀ ▶

◀ ▶

Page 8 of 18

Go Back

Full Screen

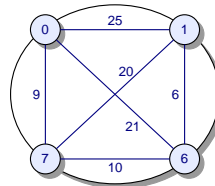
Close

Quit

Macro-routing

- ▶ no routing information dissemination
- ▶ overcomes inaccurate aggregation by using the *full-mesh* aggregation
- ▶ parallel processing
- ▶ distributed processing with multiple simple tasks
- ▶ finds the best path
- ▶ finds multiple paths

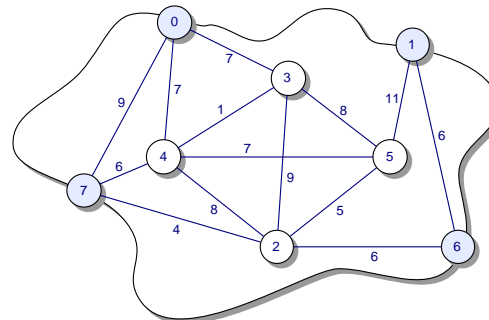
...advantages



(b) the aggregated node

ingress node	egress node	list of traversing nodes	path cost
0	1	4, 5	25
0	6	4, 2	21
0	7	-	9
1	6	-	6
1	7	2, 5	20
6	7	2	10

(c) the information content for the aggregated node



(a) the physical domain

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

Macro-routing

...issue

Macro-routing might generate too much traffic !

How much traffic?

- mobile agent size
- number of mobile agents

How to limit the traffic?

- *waves* are very small ($< 1K$)
- introduce a TTL-type limit: *lifespan*

Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)



Page 10 of 18

[Go Back](#)

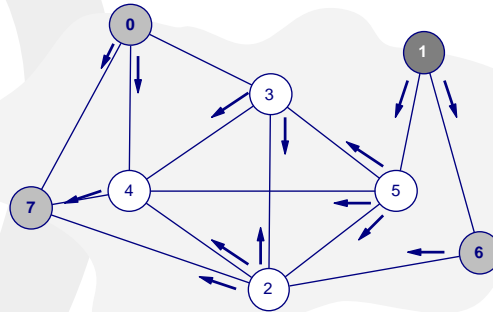
[Full Screen](#)

[Close](#)

[Quit](#)

Counting Waves

...count waves by simulations



Hierarchical ...

... protocols

MPLS

Mobile Agents

Macro-routing

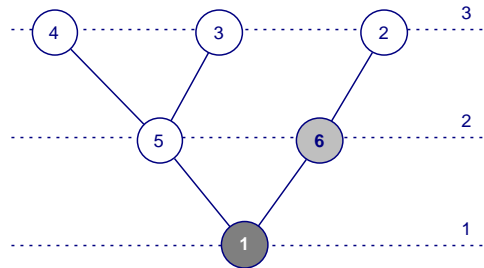
Counting Waves

Mathematical model

Simulation results

Conclusions

Mathematical model



X_k - number of waves which traversed k nodes

$$X_{k+1} = f(X_k)$$

Home Page	
Title Page	
◀◀	▶▶
◀	▶
Page 11 of 18	
Go Back	
Full Screen	
Close	
Quit	

The mathematical model

...by using *Markov Chains*

Branching Process (aka. Galton-Watson process)

$$X_{n+1} = \sum_{k=1}^{X_n} Z_n^{(k)}, \quad (1)$$

where $Z_n^{(k)}$ is the number of descendants from k

Assumptions

$Z_n = 0$, if cycle
 0 , if border node
 α - average node outdegree

$$\Rightarrow X_{n+1} = (X_n - C_n - B_n) \cdot \alpha$$

$$C_n = X_n \cdot p_{cn}$$

$$B_n = X_n \cdot p_{bn}$$

$$\Rightarrow X_{n+1} = X_n \cdot (1 - p_{cn} - p_{bn}) \cdot \alpha$$

Hierarchical ...

...protocols

MPLS

Mobile Agents

Macro-routing

Counting Waves

Mathematical model

Simulation results

Conclusions

[Home Page](#)

[Title Page](#)

◀◀ ▶▶

◀ ▶

Page 12 of 18

[Go Back](#)

[Full Screen](#)

[Close](#)

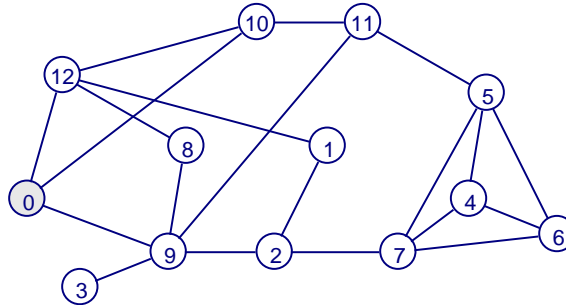
[Quit](#)

Simulation results

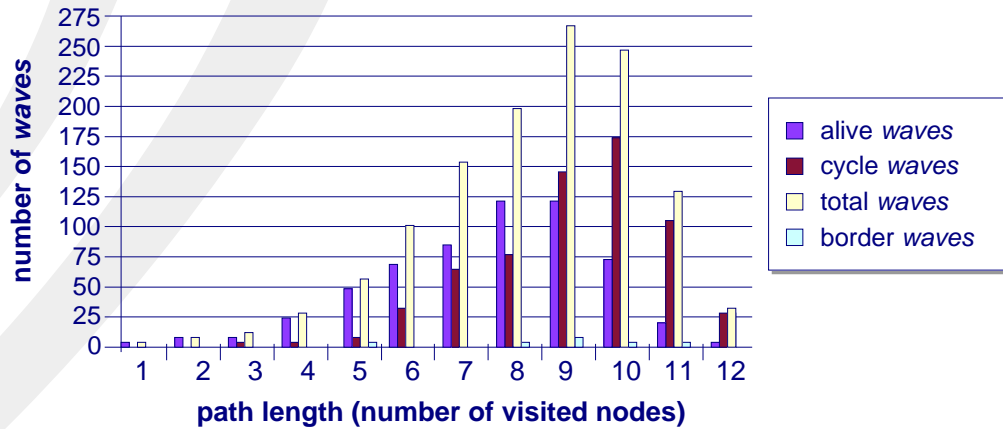
...number of waves propagating from a border node

13 nodes
20 links

diam: 4
average degree:3

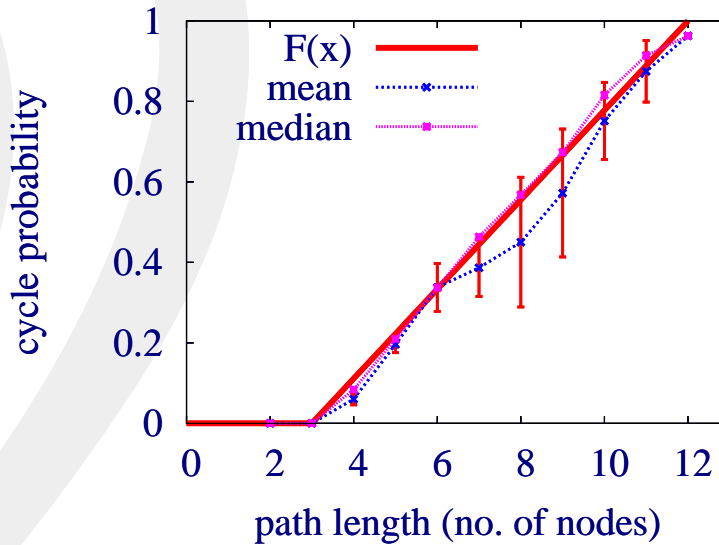


Hierarchical ...
...protocols
MPLS
Mobile Agents
Macro-routing
Counting Waves
Mathematical model
Simulation results
Conclusions



Simulation results

...cycle probability



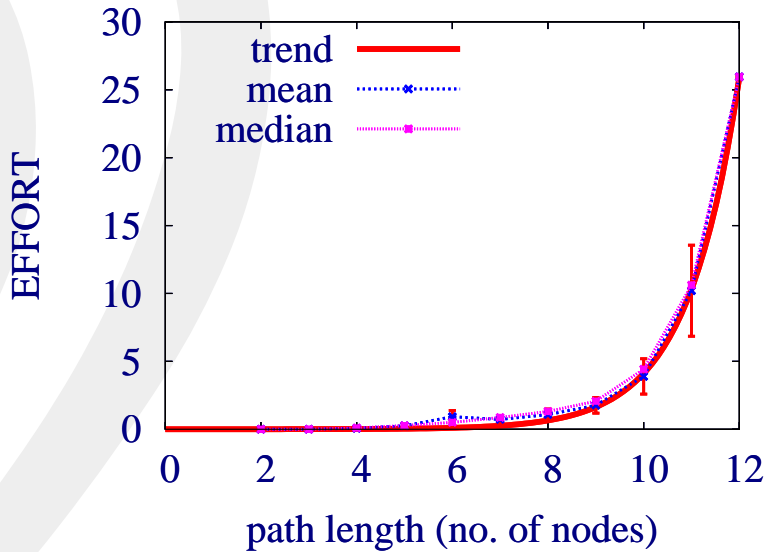
$$F(x) = \begin{cases} 0 & \text{if } x < 3 \\ \frac{x-3}{N-2} & \text{if } x \geq 3 \end{cases}, \text{ where } N = 12 \text{ is the number of nodes} \quad (2)$$

- Hierarchical ...*
- ... protocols*
- MPLS**
- Mobile Agents*
- Macro-routing*
- Counting Waves*
- Mathematical model*
- Simulation results**
- Conclusions*

Simulation results



...effort for obtaining long paths



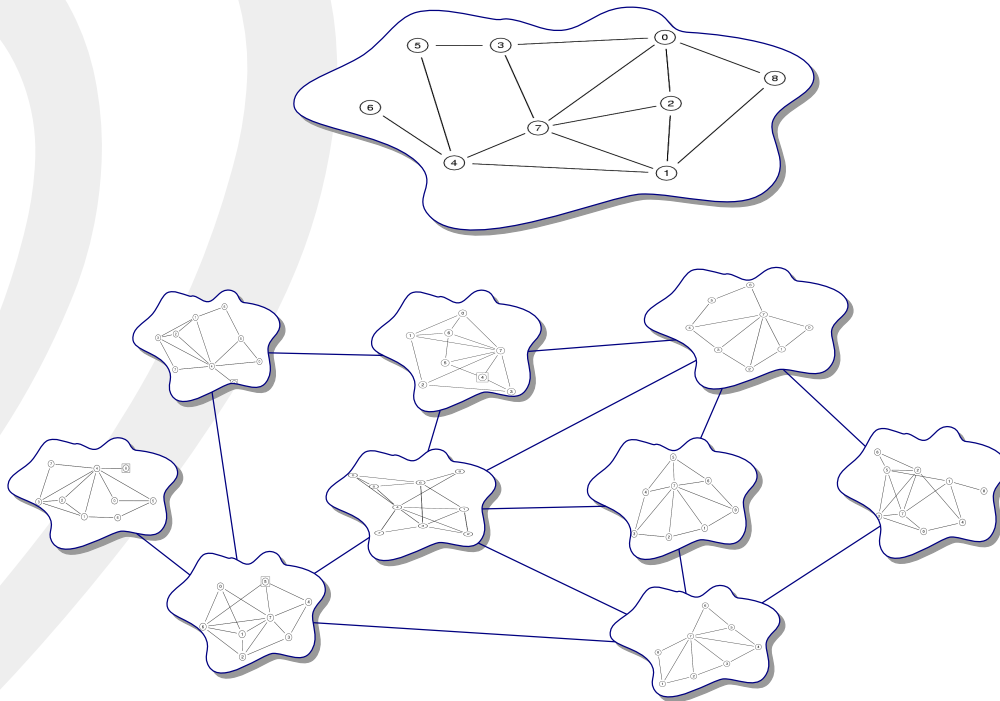
$$F(x) = \frac{\text{the number of "cycle waves"}}{\text{the number of "border waves"}} \quad (3)$$

- Hierarchical ...
- ... protocols
- MPLS
- Mobile Agents
- Macro-routing
- Counting Waves
- Mathematical model
- Simulation results**
- Conclusions

Home Page	
Title Page	
◀◀	▶▶
◀	▶
Page 15 of 18	
Go Back	
Full Screen	
Close	
Quit	

Simulation results

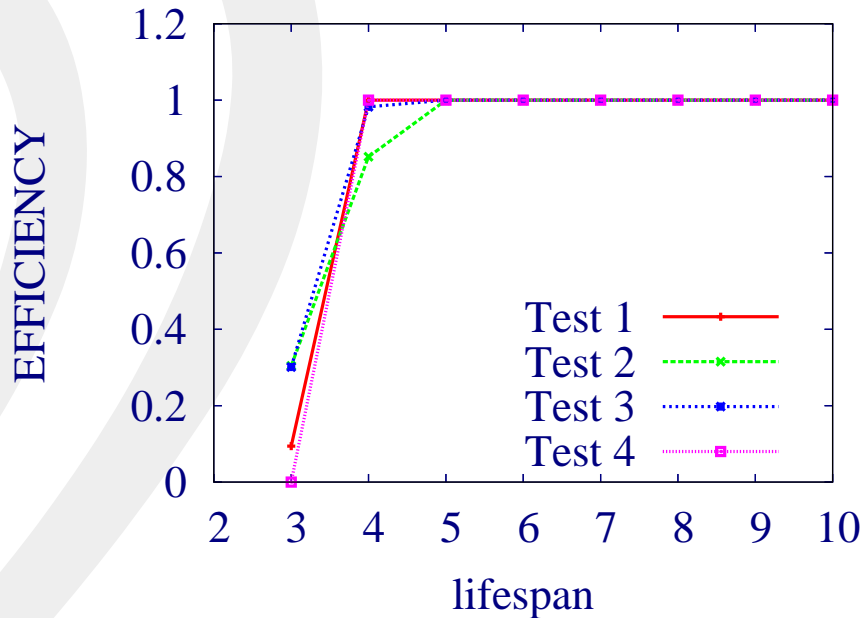
... test bed



- Hierarchical ...*
- ... protocols*
- MPLS**
- Mobile Agents**
- Macro-routing**
- Counting Waves**
- Mathematical model**
- Simulation results**
- Conclusions**

Simulation results

... Macro-routing efficiency when using the *lifespan*



$$F(x) = \frac{\text{the optimal performance}}{\text{Macro-routing's performance}} \quad (4)$$

- Hierarchical ...
- ... protocols
- MPLS
- Mobile Agents
- Macro-routing
- Counting Waves
- Mathematical model
- Simulation results**
- Conclusions

Conclusions and Future work

- ▶ *Macro-routing* - a new approach for hierarchical routing
- ▶ no information dissemination as the routing information is consulted *in situ*
- ▶ no imprecision introduced by topological state aggregation
- ▶ the mobile agents used in the routing process may generate too much traffic
- ▶ reduce the routing traffic by limiting the waves *lifespan*
- ▶ extending *Macro-routing* to multi-constraint hierarchical routing

Hierarchical ...
... protocols
MPLS
Mobile Agents
Macro-routing
Counting Waves
Mathematical model
Simulation results

Conclusions

Home Page

Title Page



Page 18 of 18

Go Back

Full Screen

Close

Quit