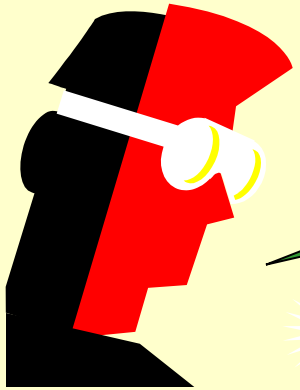
Exploiting the Mobile Agent Paradigm for Network Management and Routing

Armin R. Mikler

Agents……..??



Shaken but not stirred…..

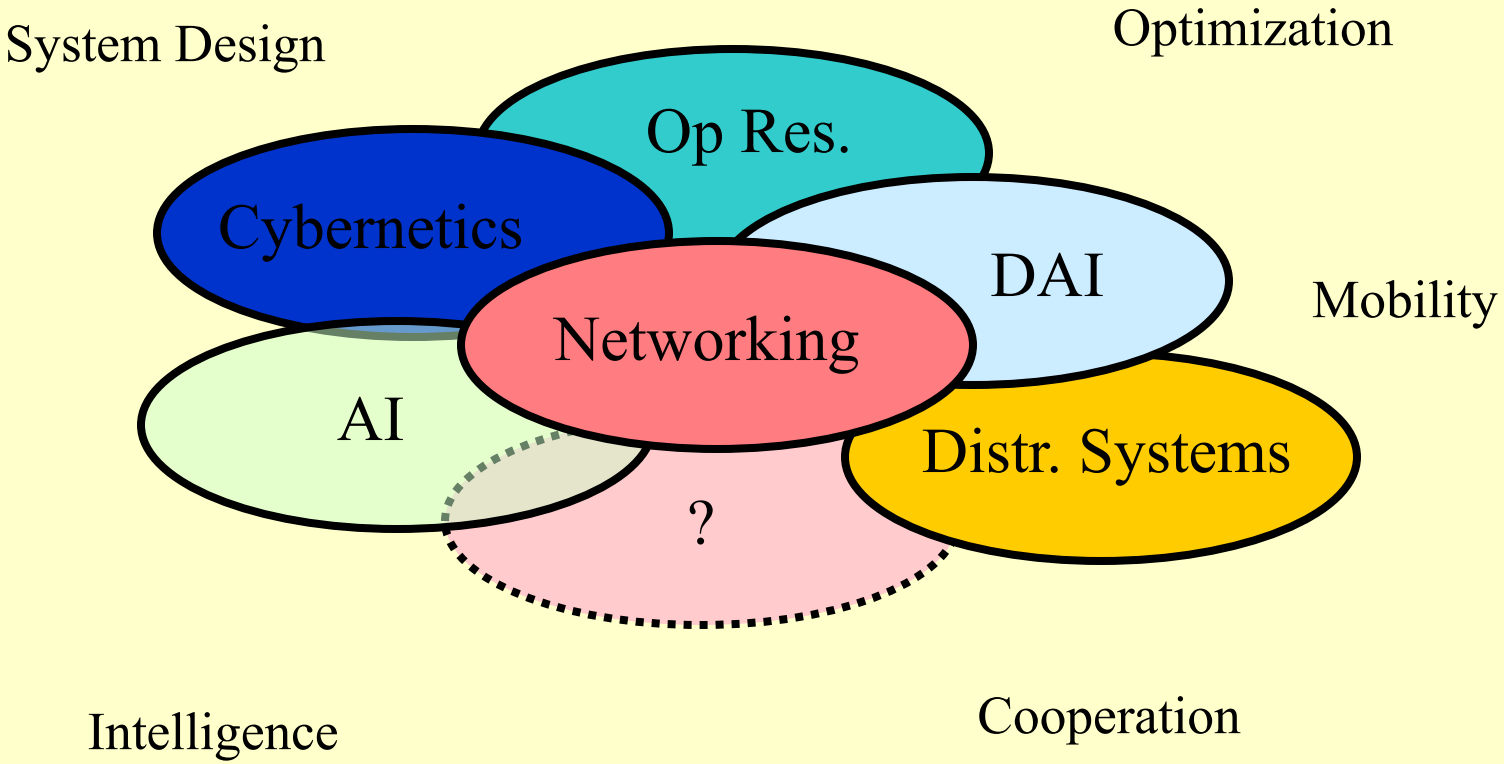
Martini?

The Mobile Agent Paradigm

An agent is viewed as an executable code fragment that has associated with it a knowledge base as well as a memory segment that describes its current state.

- Mobile Agent properties:
  - **Intelligence**: the ability to adapt to circumstances brought upon by the dynamics of the system (i.e., the federated cluster infrastructure).
  - **Cooperative Behavior**: the ability to share knowledge among agents and/or to negotiate a common strategy.
  - **Autonomy**: the ability to execute without intervention of users, i.e. independent decisions as perceived suitable.
  - **Mobility**: the ability to migrate between different hosts (or clusters)

Combining Know-How



Network Routing

Routing:

The process of discovering, selecting, and maintaining communication paths from one node in the network to another and using these paths to deliver data.

- Broadly classified:
  - Central vs. Distributed.
  - Static vs. Dynamic
  - Shortest-path vs. Heuristic

- Distributed Dynamic Shortest-Path Routing
  - Link-State

    (Dijkstra)

  - Distance-Vector ←

    (Bellman-Ford)

Distance Vector Routing

Based on a distributed version of the Bellman-Ford Equation:

$$D_i^{h+1} = \min(d_{ij} + D_j^h)$$

with: $D_1^h = 0$, $D_i^0 = \text{inf}$

➔Single Destination

Used in the Routing Information Protocol (RIP)

- Nodes know the distance to their neighbors.
- Neighbors inform neighbors of routes they know.
- Convergence after several update cycles
- Topological changes can force message activity to escalate!

Mobile Agents in Routing

- Biologically inspired:
  - Foraging activities of Ant colonies
  - Principles of Stigmergy

- Different approaches:
  - Schoonderwoerd et al.
    - Agent-based routing in symmetric circuit switched networks.
    - Agents traverse to a destination and update routing tables at the destination (Forward Agents).

  - AntNet
    - Agent-based routing in asymmetric packet switched network.
    - Hence, the concept of forward agents and backward agents.
    - Intrinsically slow due to two types of agents.

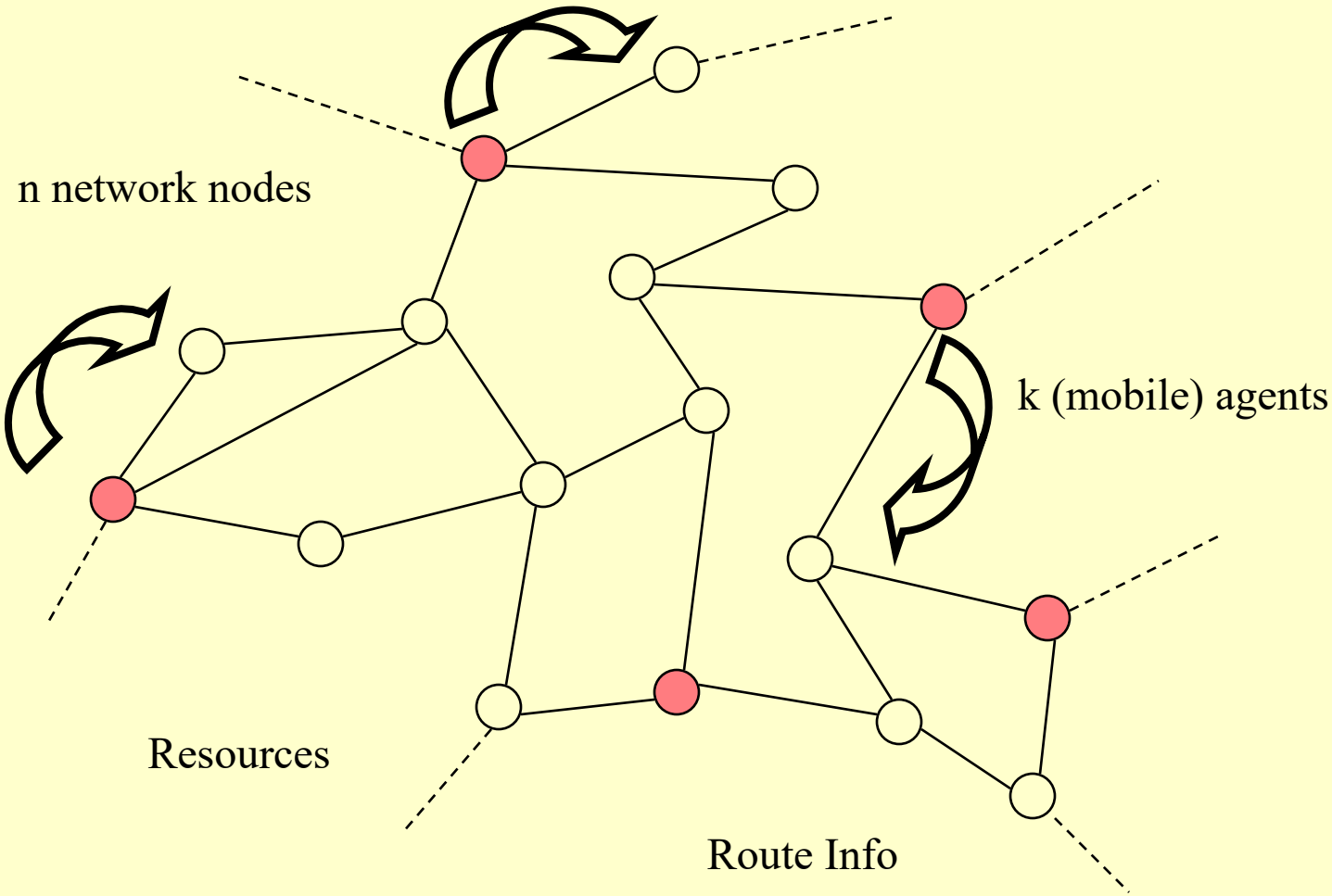
Mobile Agents in Routing …

- Different approaches …
  - Co-operative Asymmetric Forward Routing (CAF)
    - Agent-based routing in asymmetric packet switched network.
    - Uses statistical traffic information at individual nodes to eliminate the need for backward agents.
  - MIT Media Labs
    - Agents use Swarm Intelligence.
    - Population of agents continuously traversing the network maintaining an itinerary of its journey.
    - Exchange itinerary information among themselves.
    - Due to a similar itinerary, agents form clusters in certain regions of the network.
- Agents offer an elegant, flexible, and adaptive solution to the routing problem.

ADVR: Agent-Based Distance Vector Routing

- A population of Mobile Agents continuously traverses the network
- Agents carry routing table entries of previously visited nodes
- Routing table entry are integrated into the routing table of the *next node* as per the *Distributed Bellman-Ford* equation.
- Agents coordinate their actions through **stigmergetic means** i.e., they manipulate/modify the environment.

- The Goals:
  - To eliminate the Broadcast Storm Problem
  - To reduce the resource overhead (instantaneous messages activity) due to routing updates
  - To reduce the total bandwidth consumption for routing.
  - Algorithm *must scale* for different low resource networks, e.g. Wireless and Ad-Hoc networks


n network nodes
k (mobile) agents
Resources
Route Info

ADVR …

Distributed Coordination of Agents' to achieve:

- Effective traversal of the network.
- Minimization of Data Overhead.
- Sufficient Agent Activity.
- Flexibility
- Robustness/Fault Tolerance

- How do agents coordinate movement in the network?
- What routing table selection algorithm must the agent use?
- What agent population must be deployed in the network?

Agent Migration Strategy

- It is important that agents co-ordinate their movement so that they do not form clusters in some part of the network while neglecting others.

- Several migration strategies available in literature:
  - Random Walk
  - Depth-First Search
  - Principles of Stigmergy

- ADVR combines the exploratory feature of depth-first search with the biological principles of stigmergy.

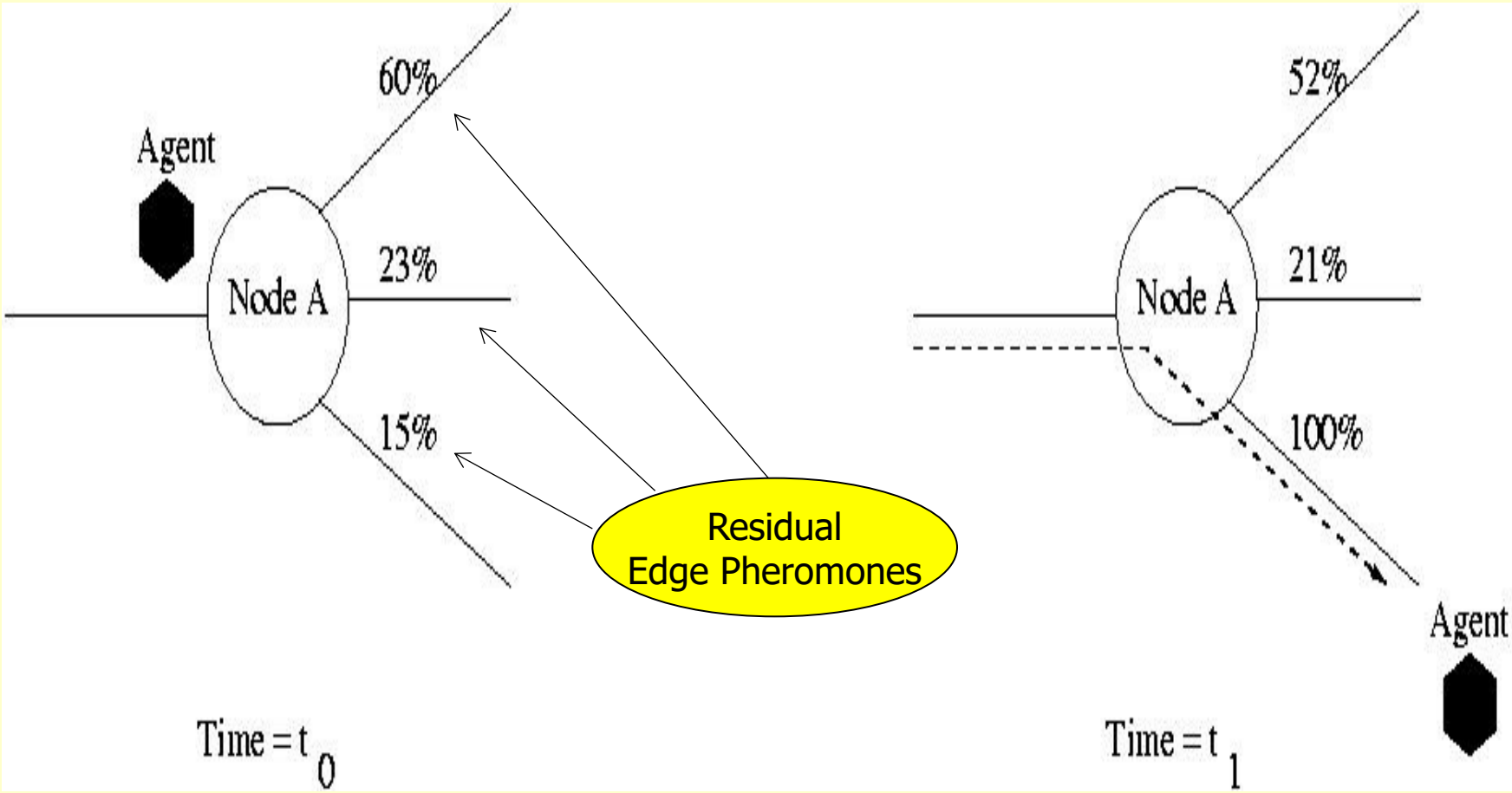
Agent Coordination and Control

- Efficiency Route Discovery is characterized by way agents migrate through the network
- ADVR uses a stigmergetic approach to collectively perform a *depth-first search* of the network
- *Pheromones (EDGE)* are used to guide agents in the selection of the *next node*
- Pheromones may be deposited to indicate the order of visitation or to mark the Δt between visitations.
- Simulated Pheromones:

$$rp = e^{-\lambda \Delta t}$$

Here, *rp* is the *residual pheromone.*

Agent Migration – Neighbor Selection

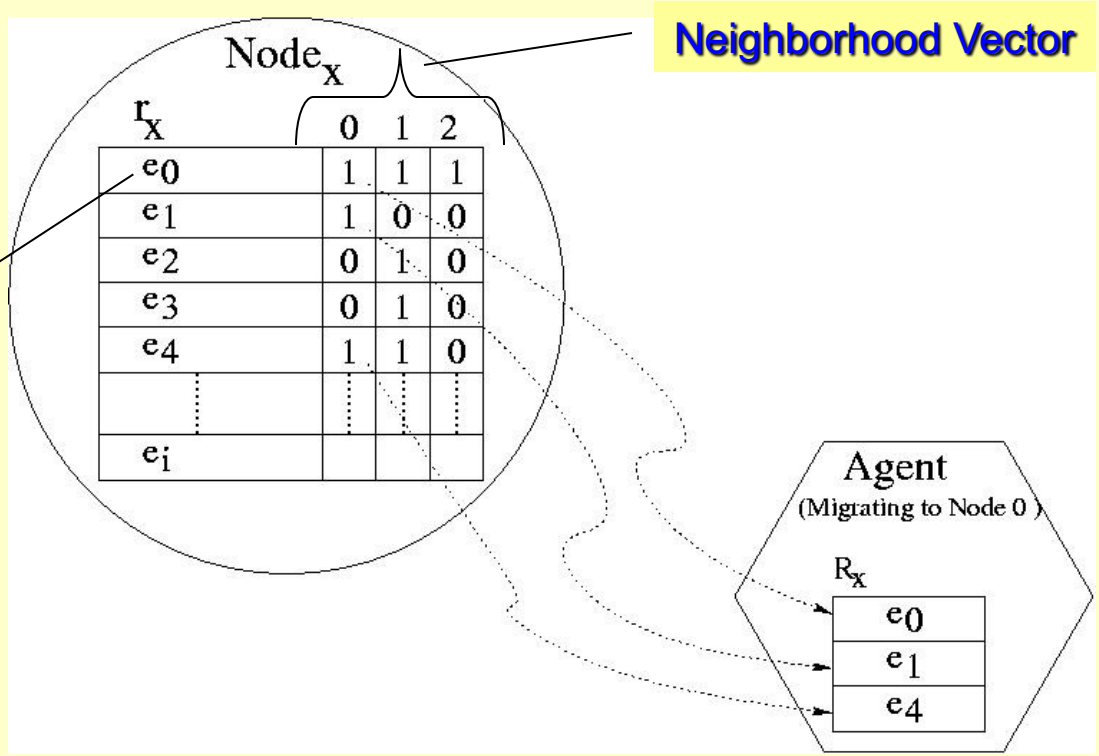


Routing Table Selection Algorithm

- At every node the agent makes a decision regarding the routing data it carries to the next node.

- Agents identify the routing table entries that have been modified, yet have not been transferred to a particular neighbor.

(Destination, Cost, Next Hop)

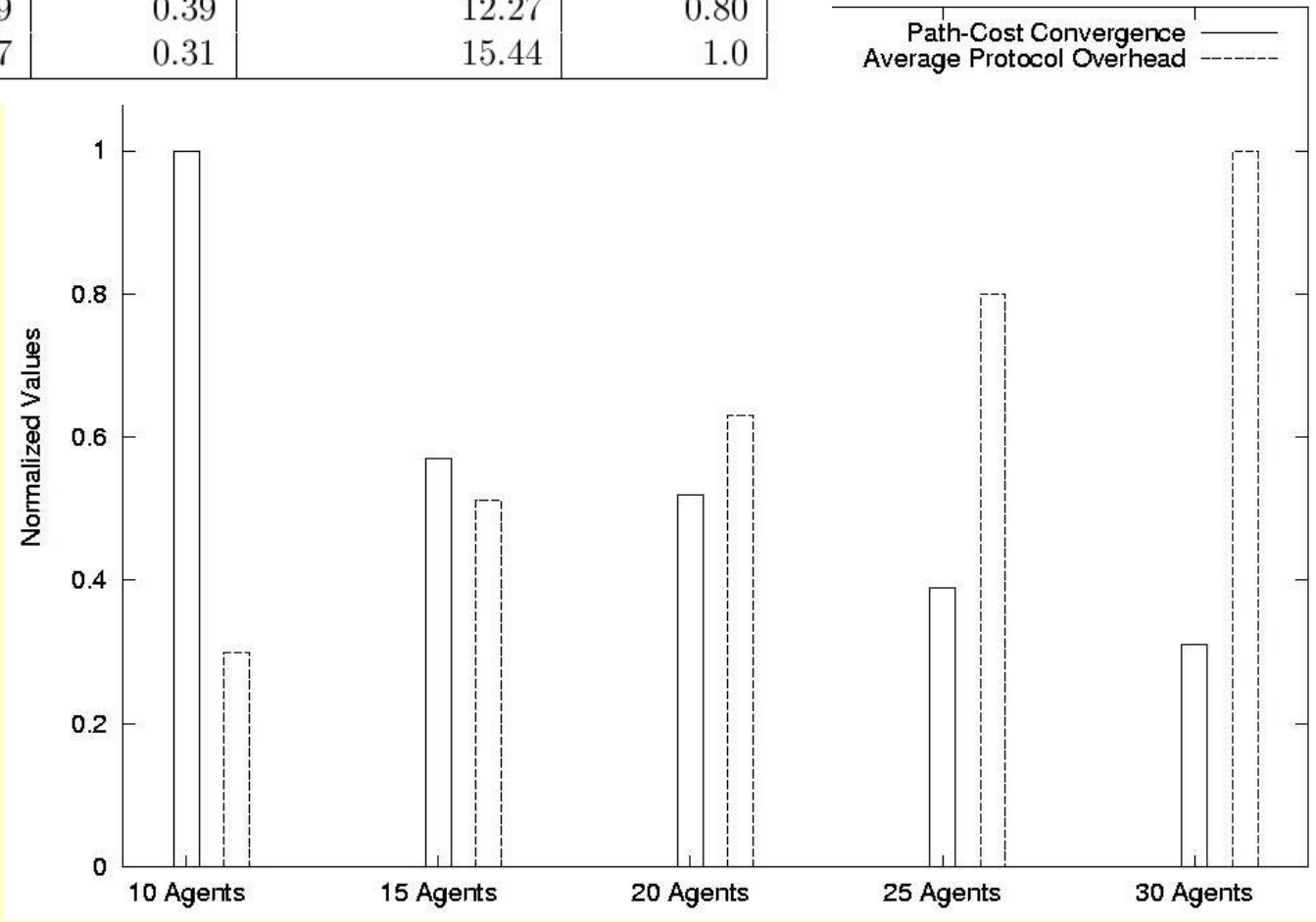


Agent Population

- In ADVR, the size of the agent population manifests the routing overhead in the network.
- A static agent population represents the upper bound on the routing overhead and the degree of concurrency.
- A large agent population would increase the concurrency (performance) as well as the routing overhead.

Agent Population …

# *Agents*	*Convergence Time*		*Average Routing Overhead*	
	Measured (ms)	Normalized	Measured (KB/ms)	Normalized
10	150	1.0	4.73	0.30
15	85	0.57	7.91	0.51
20	78	0.52	9.70	0.63
25	59	0.39	12.27	0.80
30	47	0.31	15.44	1.0



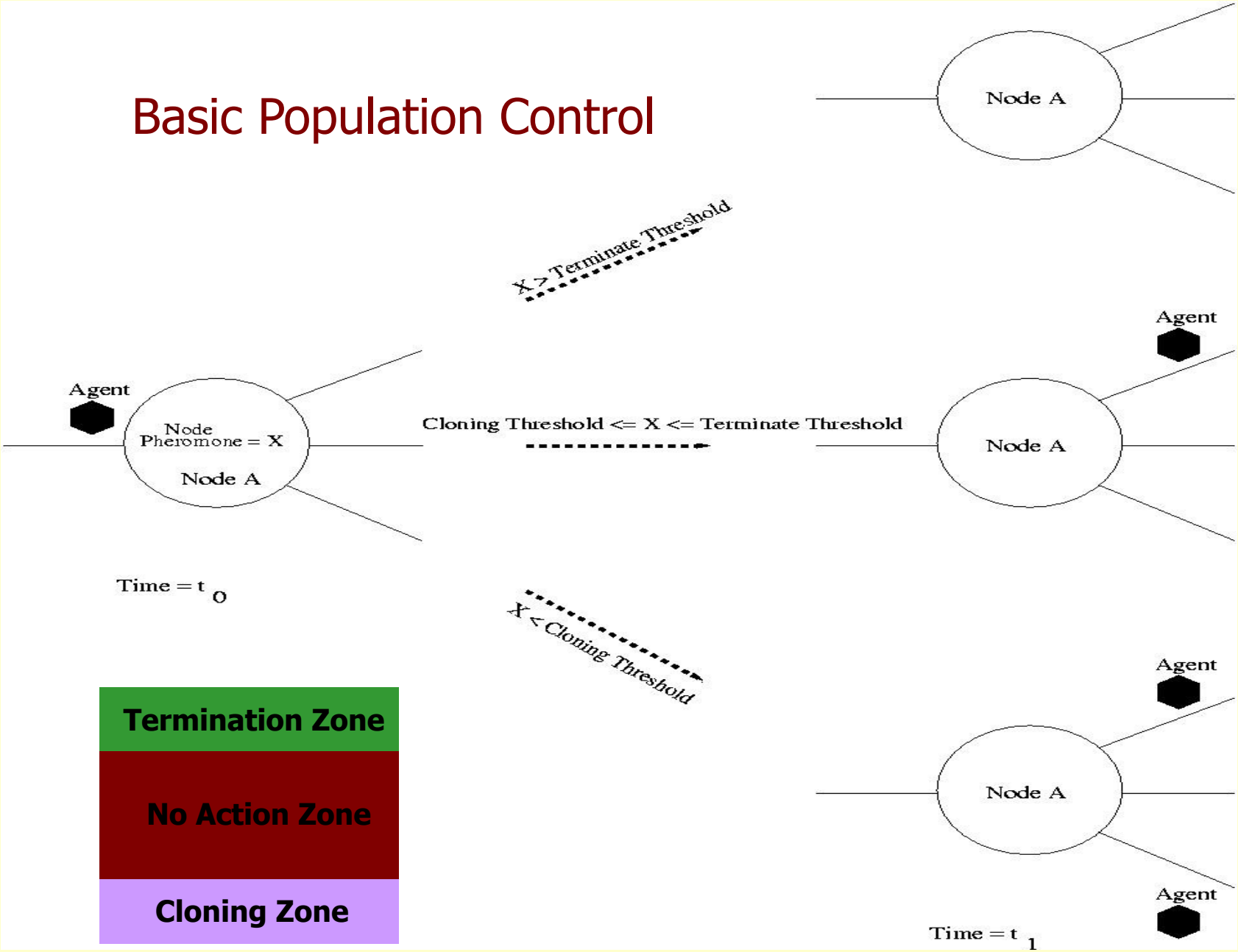
Agent Population …

- There is a need for a dynamic control mechanism that adjusts the agent population.
- Once again agents exploit the principles of stigmergy by using pheromones (Node Pheromones).

Control Mechanism:

- Node pheromones are expressed as $rp = e^{-\lambda(\Delta t)}$ where $\Delta t = t_2 - t_1 \, (t_1 < t_2)$
- An agent visiting a node at t_2 extracts the value of rp left by another agent at t_1 .
- If the rp is greater than the Termination Threshold (Ψ), the agent kills itself.
- If the rp is less than the Cloning Threshold (Ω), the agent clones itself.
- Otherwise the agent, neither clones nor kills itself.

Basic Population Control



Auxiliary Agents

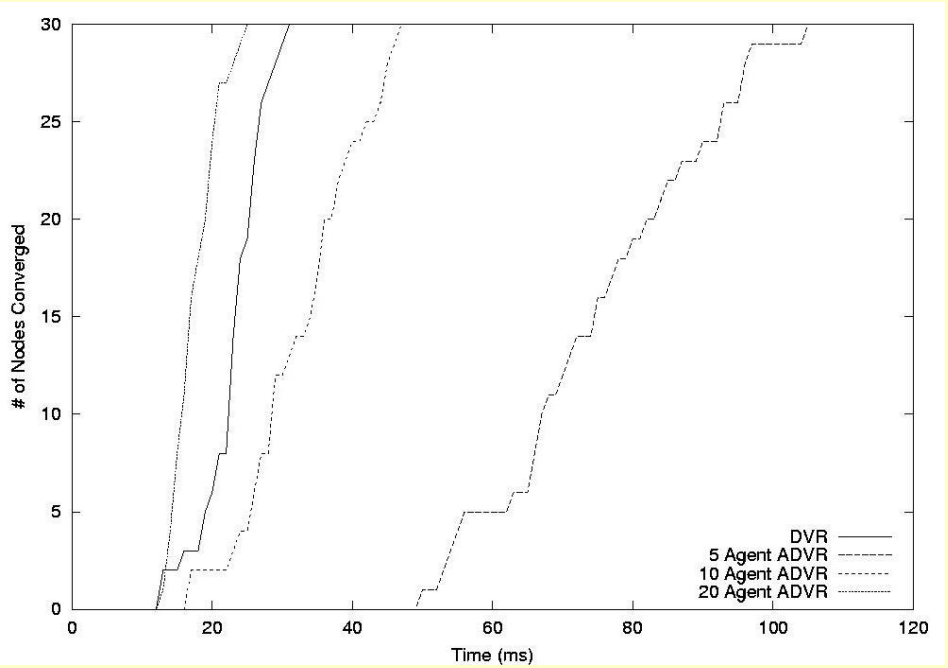
- It is important that agents respond quickly to changes in network topology.
- Any new routing information must be quickly propagated to individual nodes to avoid routing loops.

- Nodes that detect a network failure generate special type of agents.

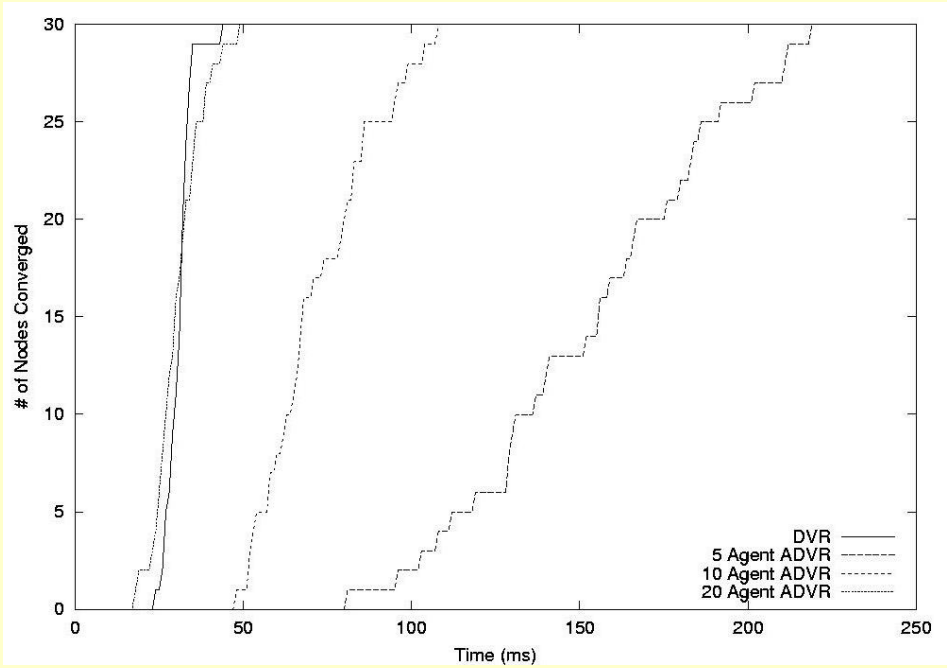
- Properties:
  - Propagate negative information.
  - Not governed by rules of dynamic agent population control.
  - Lifespan controlled by a hop count

Analysis of Path-Cost Convergence

- Path-Cost Convergence: **Process where every node in the network is obtaining the shortest-path route to every other node in the network**.

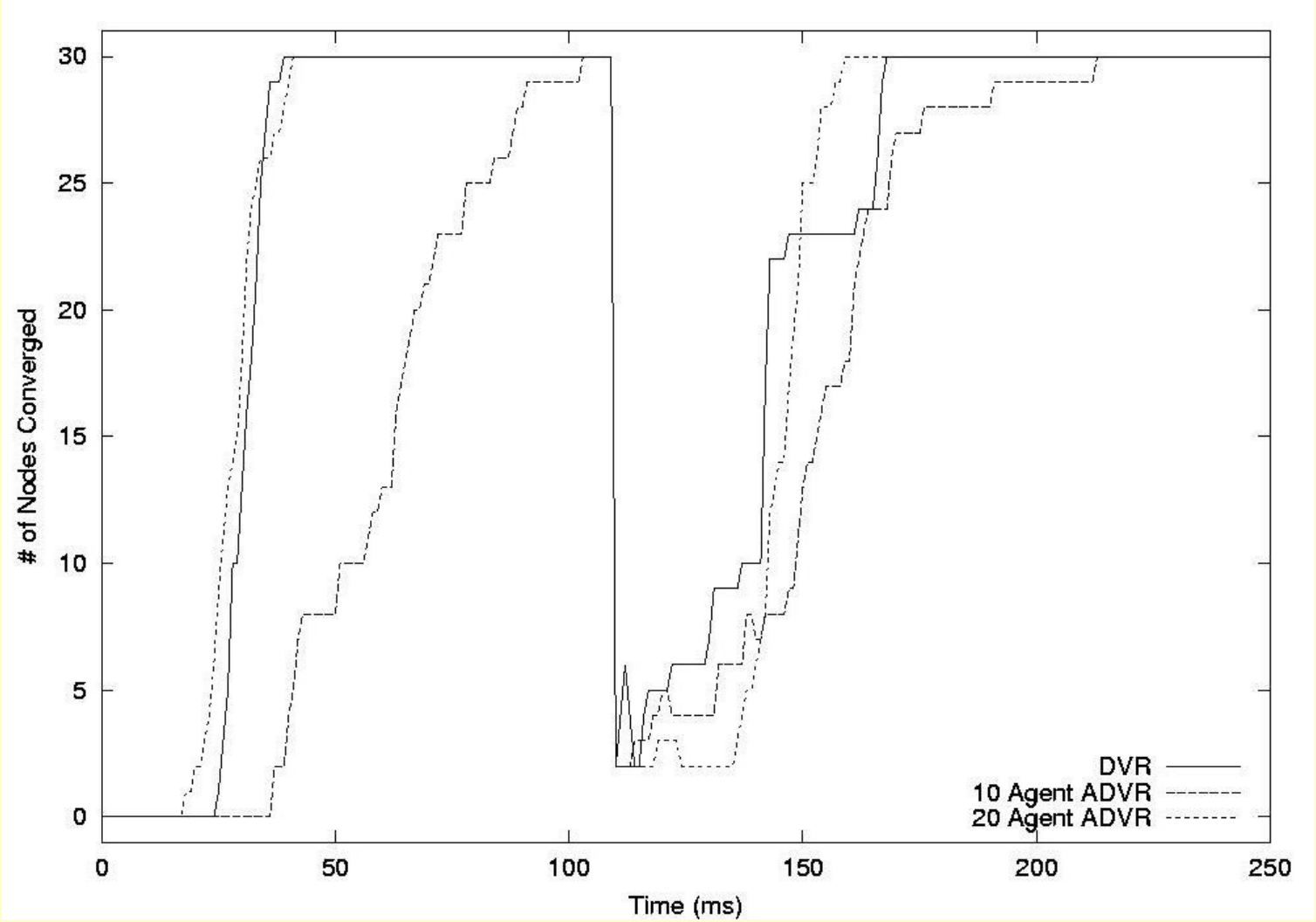


Network::(30,3)



Network::(30,6)

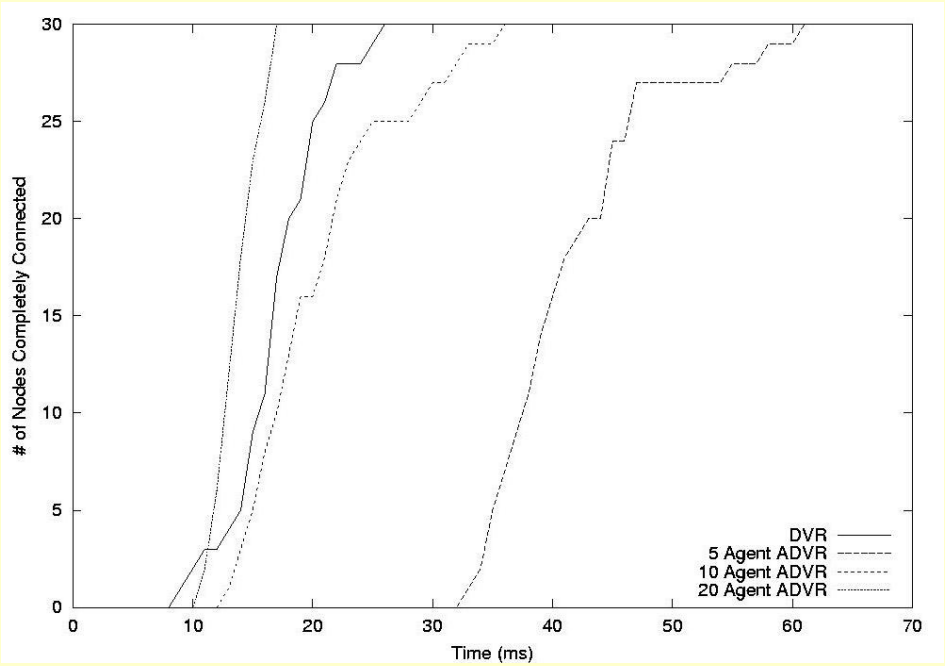
Analysis of Path-Cost Convergence …



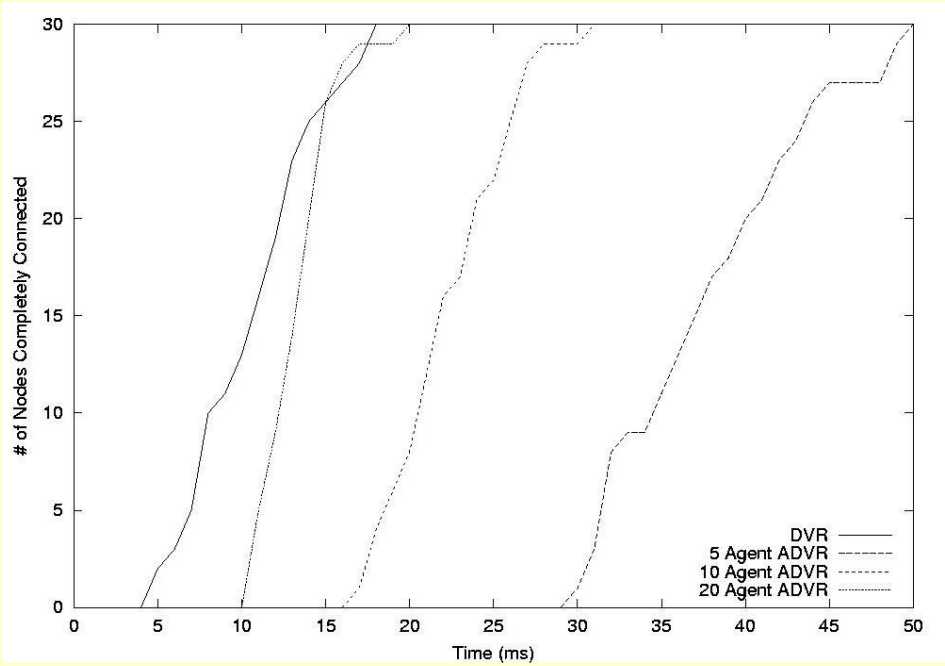
Network::(30,6)

Analysis of Route Discovery

- Route Discovery: **Process where every node in the network obtains a route to every other node in the network**.



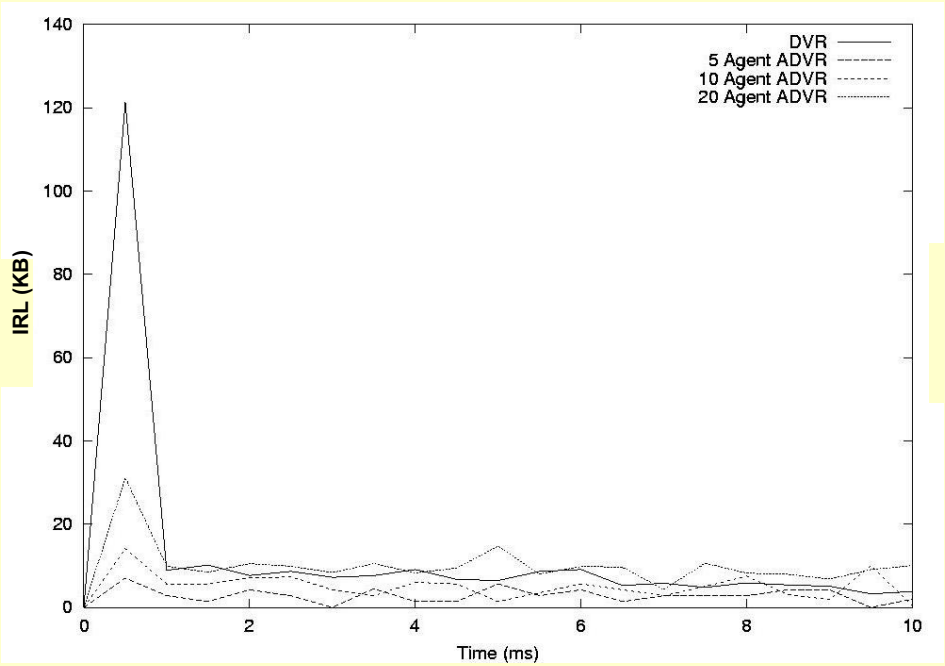
Network::(30,3)



Network::(30,6)

Analysis of Routing Overhead

- Instantaneous Routing Load (IRL): **The routing load concurrently traversing the network at that instant**.



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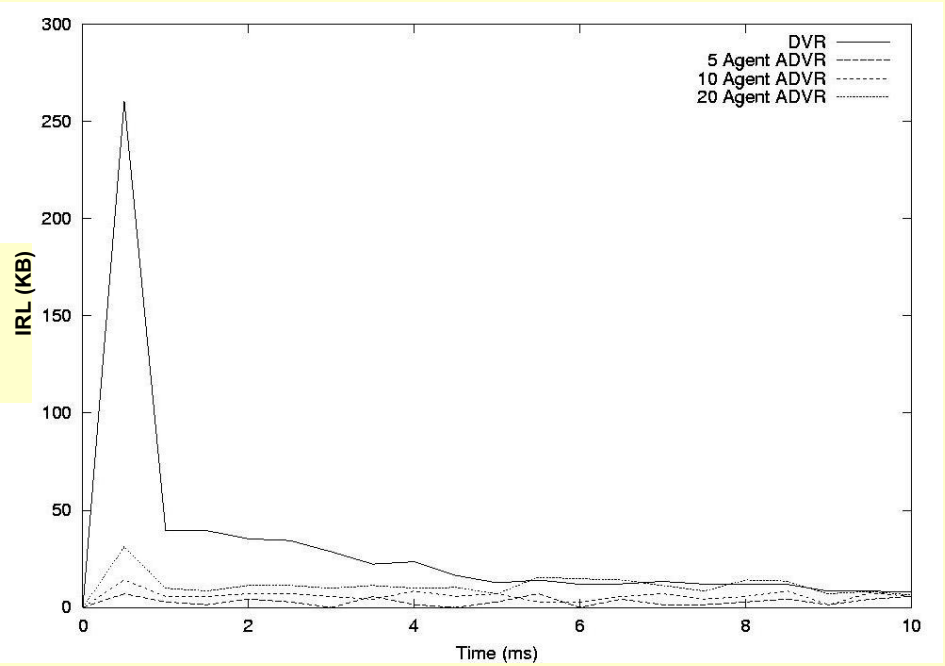
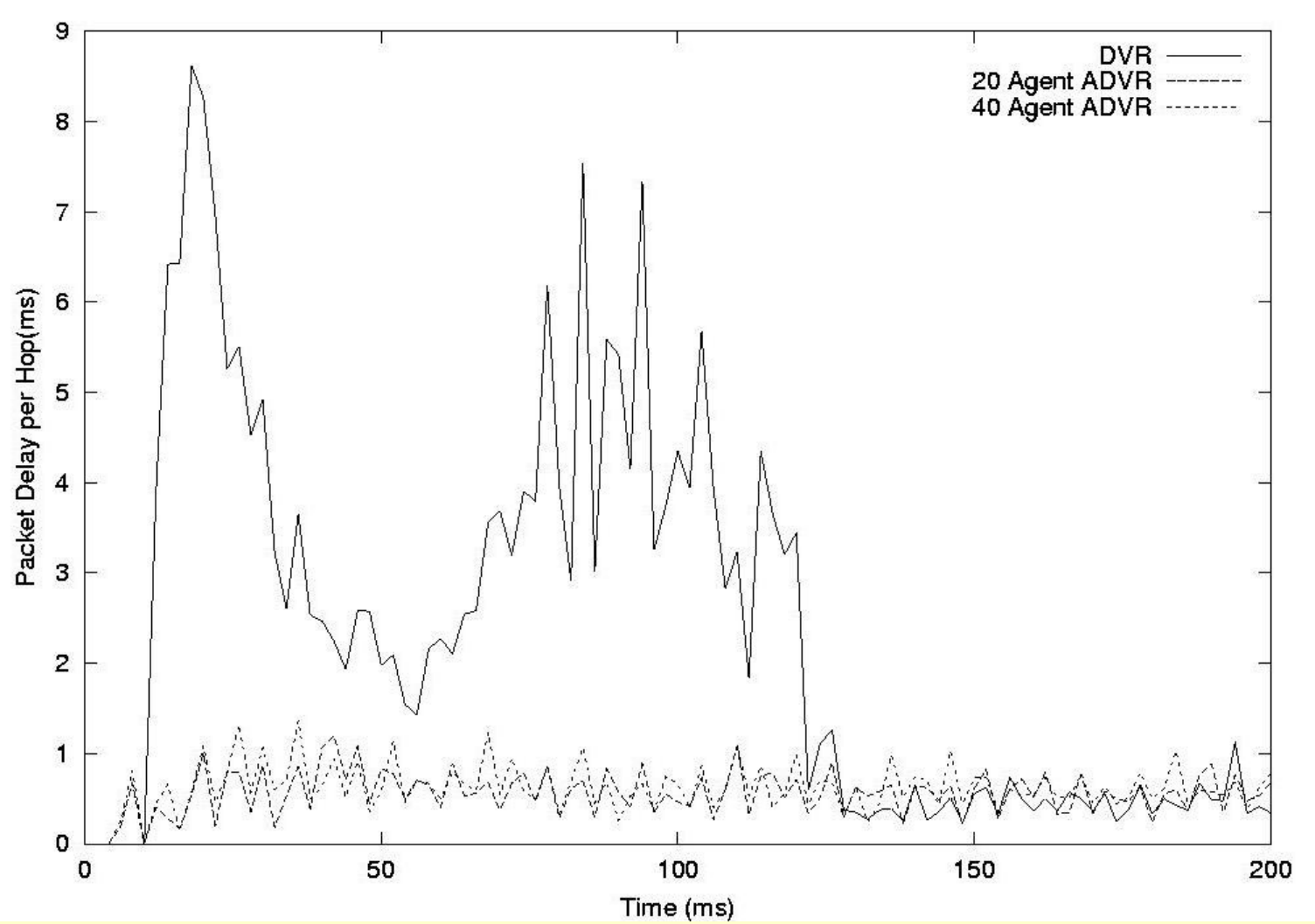


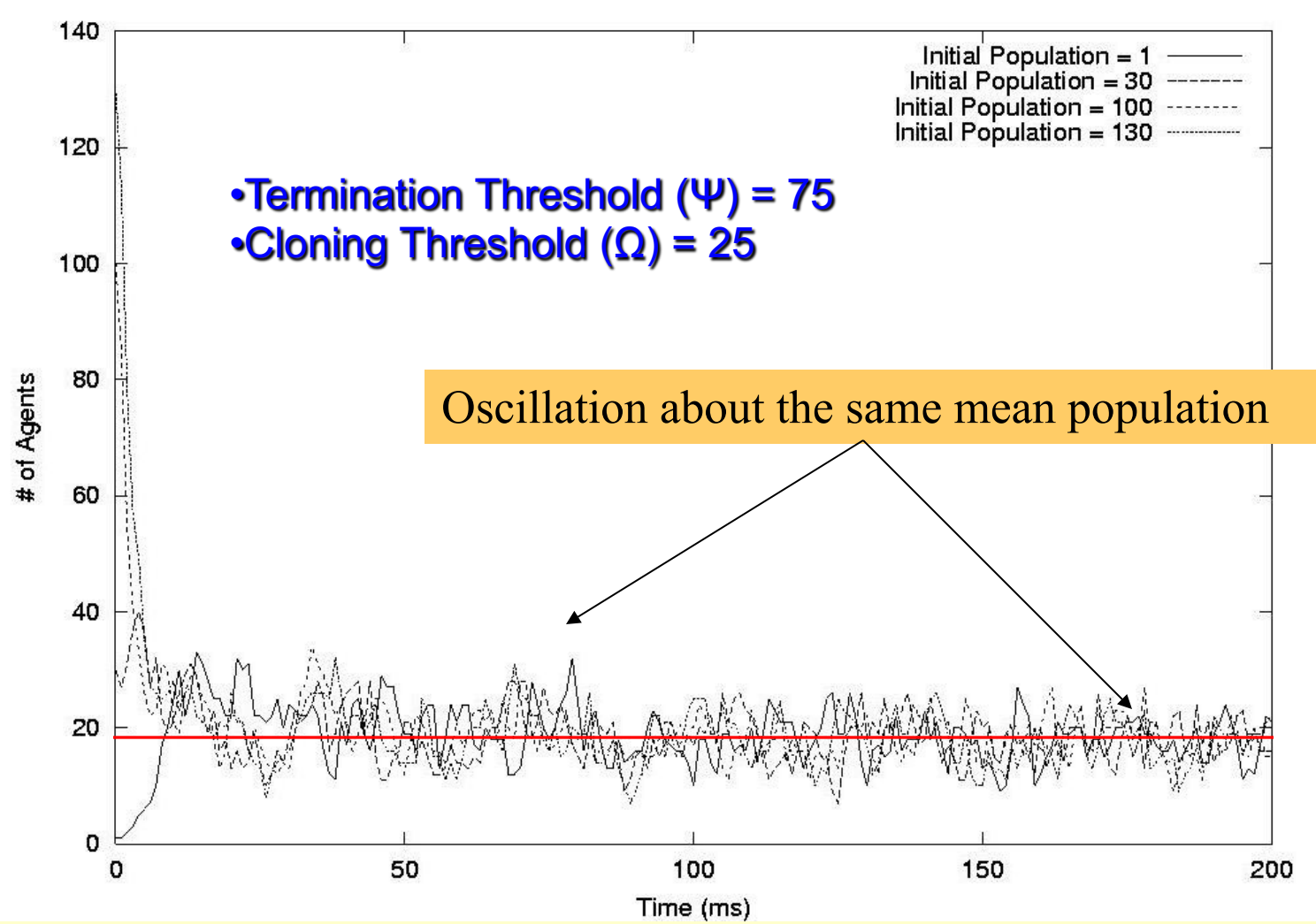
Network::(30,6)

Analysis of Routing Overhead …



Network::(30,3)

Aggressive Population Control



Towards Dynamic Control

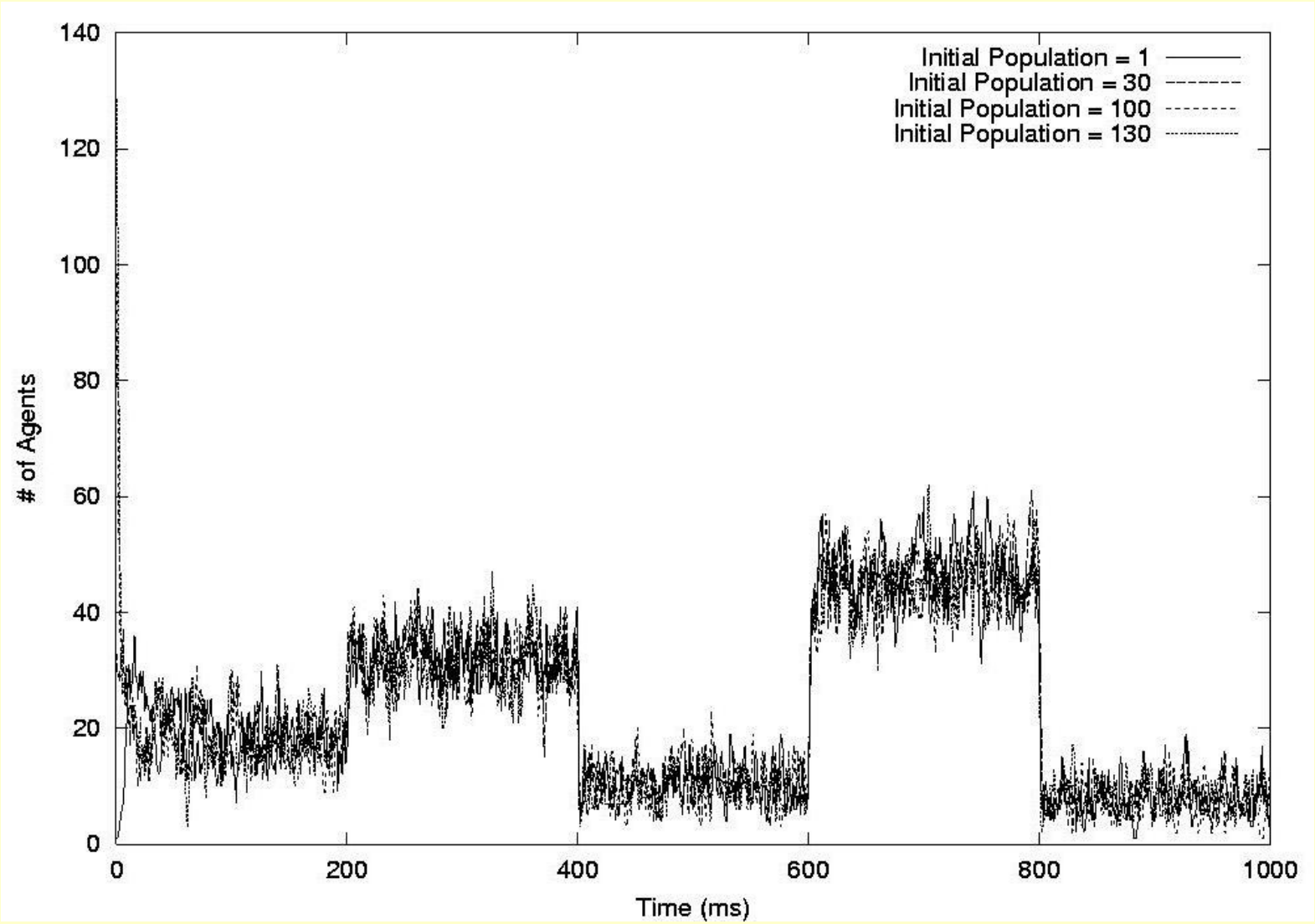
- The size of the agent population must adapt to:
  - Resource Availability
  - Changes in Topology
  - Traffic Dynamics

- ADVR can dynamically adjust the constituent population level by adjusting:
  - λ - the pheromone decay
  - Cloning threshold
  - Termination Threshold

- In a *static* network, the number of agents should be a minimum, yet sufficient to respond to sudden changes.

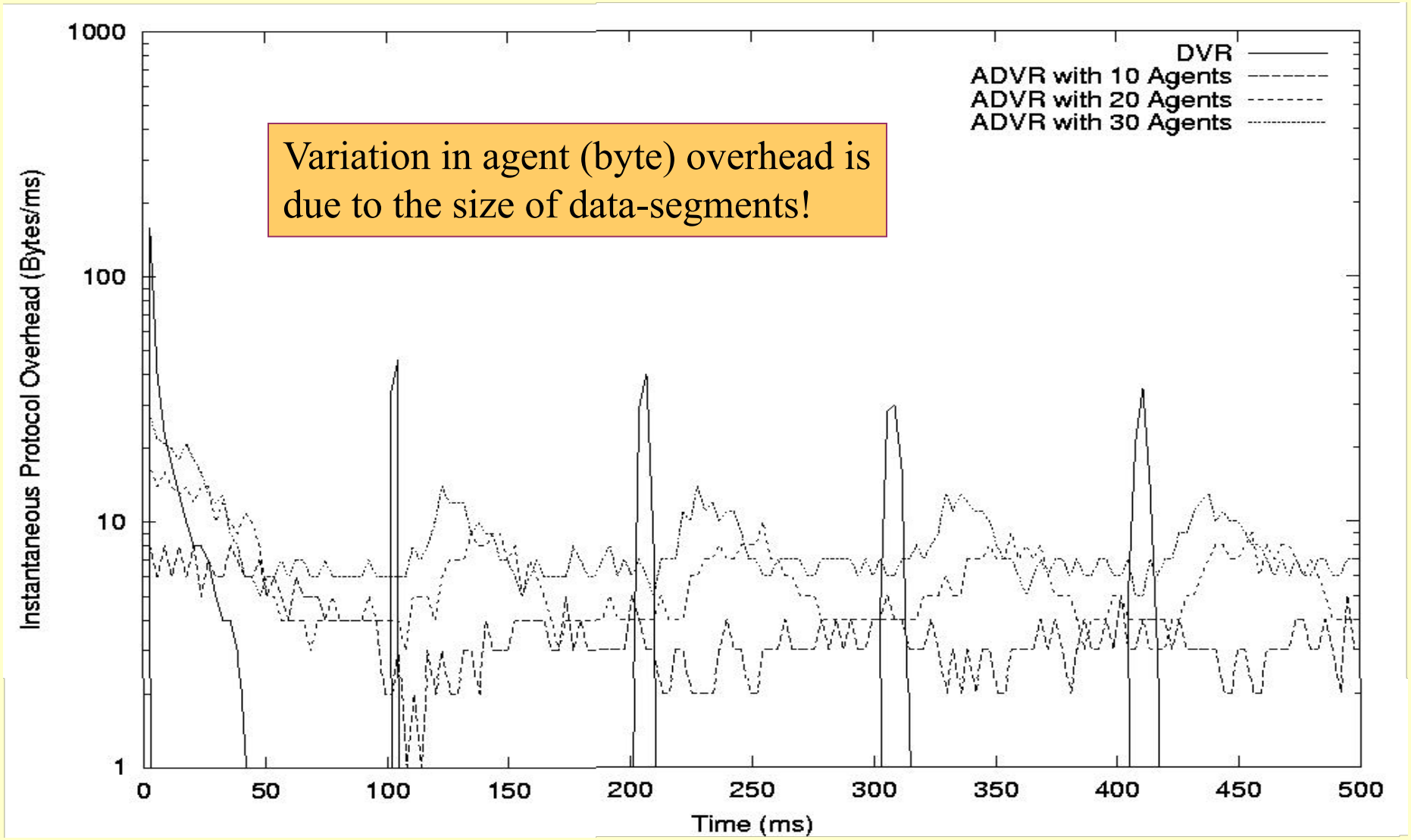
- Issues / Questions:
  - What is "minimum"?
  - What are suitable network/performance parameters.
  - What is an appropriate feedback function?

Analysis of Agent Population …



(Ψ, Ω):: (75,25) (90,40) (60,10) (95,45) (55.5)

Bounded Resource Overhead



ADVR Summary

- A new routing algorithm using mobile agents: ADVR.
- Routing messages are replaced by an active population of mobile agents.
- Biological Inspired Control
  - Stigmergy
  - Pheromones
- Routing table selection algorithm.
- Dynamic Agent population control mechanism
- Experimental analysis

- ADVR is:
  - Robust
  - Scalable
  - Fault Tolerant
  - Resource efficient
- Performance Analysis:
  - Cost Convergence
  - Route Discovery
  - Aggressive Control
  - Effect on Packet Delay

Publications

- Journals:
  - Kaizar A. Amin, Armin R. Mikler, and Prasanna Venkatesan Iyengar, **Modeling Dynamic Agent Population in Agent-based Distance Vector Routing**. Special issue on Advances in Intelligent Systems in the Journal of Neural Parallel and Scientific Computing, Volume 11, issues 1 & 2 2003, pages 127 to 143.
  - Kaizar A. Amin and Armin R. Mikler, **Agent-based Distance Vector Routing: A Resource Efficient and Scalable Approach to Routing in Large Communication Networks**. Accepted for publication in the Journal of Systems and Software, Elsevier Publications.

- Conferences:
  - Kaizar A. Amin and Armin R. Mikler, **Dynamic Agent Population in Agent-based Distance Vector Routing**. ISDA 2002: Second International Workshop on Intelligent Systems Design and Applications, Atlanta, USA, August 2002.
  - Kaizar Amin, John Mayes, and Armin Mikler, **Agent-based Distance Vector Routing**, IEEE/ACM MATA 2001: 3rd International Workshop on Mobile Agents for Telecommunications Application, Canada, August 2001.