Policy-Based Quality of Service Management in Wireless Ad Hoc Networks

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T-79.300 Postgraduate Course in Theoretical Computer Science

Outline

- Introduction
- Policy-Based Management Framework for Wireless Ad Hoc Networks
- Research Methodology
- Performance Evaluation
- Conclusion
- Comment

Introduction

- Managing mobile ad hoc networks (MANETs) presents new challenges due to the dynamic nature of these networks.
- In particular, provisioning and management of Quality of Service (QoS) in such networks represent a challenging as well.

Introduction ...

- In internet, QoS provisioning and management is the **Policy-Based Network Management (PBNM).**
- However, its application has been so far limited mainly to fixed high-bandwidth networks.

Introduction ...

- In this research, the PBNM concept is applied, for managing QoS in ad hoc networks.
- Research methodology focuses on both a prototype implementation and experimental analysis using wired and wireless testbed networks, and modeling and performance evaluation using simulation.

Introduction ...

- PBNM configures and controls the various operational characteristics (such as network security and quality of service) of a network as a whole, providing the network operator with a simplified, logically centralized and automated control over the entire network.

Introduction ...

- In general, policies can be seen as plans of an organization to achieve its objectives.
- *High-level policies* are those that express the overall goals of an organization.
- *Network level policies* are essentially high level policies mapped and expressed into networking terminology.
- *Node-level policies* are those that correspond to the objectives and requirements at the different network nodes,
- *Device-level policies* are device-specific instructions that facilitate implementation of algorithms,
- The node and device level policies typically constitute the *low-level policies*.

Introduction ...

- The Internet Engineering Task Force (IETF) and the Distributed Management Task Force (DMTF) define a policy framework.

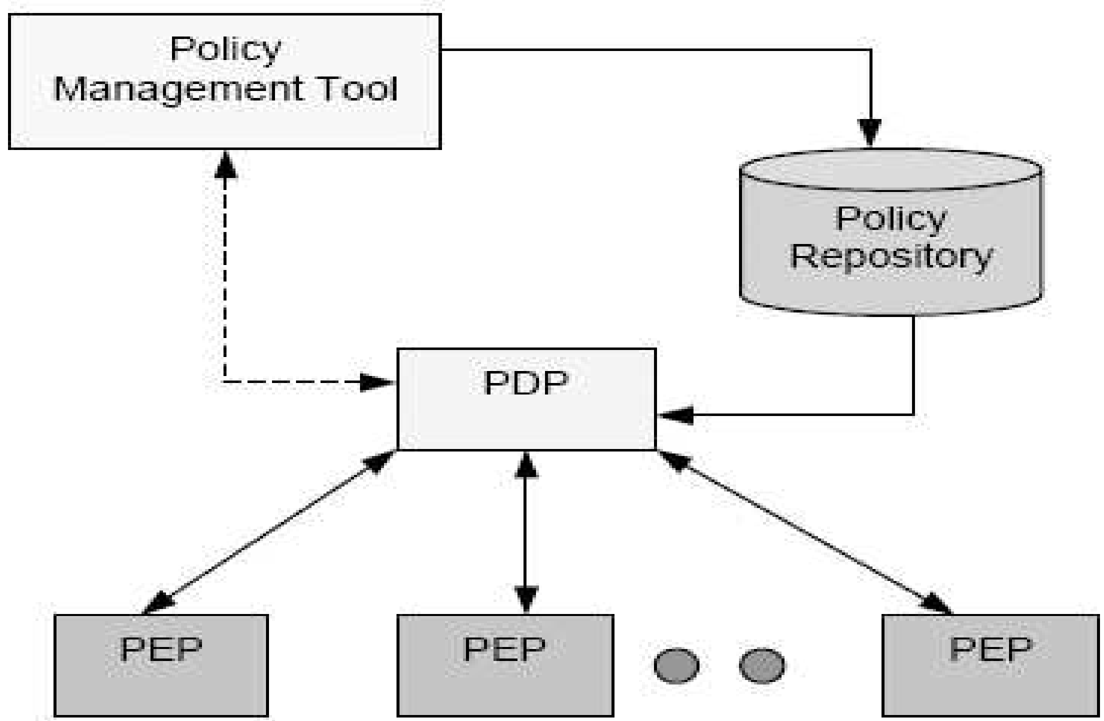


Figure ☐ Key architectural elements of a policy-based management system.

Introduction ...

- A *Policy Management Tool (PMT)*
  - provides the network administrator with an interface to interact with the network.
- *A policy Repository*
  - It is a data store or a model abstraction that holds policy rules, their conditions and actions, and related policy data

Introduction ...

- The *Policy Decision Point (PDP)*
  - retrieves the policies from the policy repository and performs complex policy interpretation and translation into a format that can then be used to configure one or more *Policy Enforcement Points (PEPs)*.
- The *PEP*
  - is a network device (e.g., end-host or router) where the policies are actually executed or enforced.

Introduction ...

- **Policy-Based QoS**
- The IETF Resource Allocation Protocol (RAP) group has defined:
  - QoS policy,
  - the policy-based admission control framework ,
  - the Common Open Policy Service (COPS) protocol and its extension – COPS for PRovisioning (COPS-PR).
- COPS is a simple query protocol that facilitates communication between the policy clients and remote policy servers.

Introduction ...

- Two policy control models have been defined:
  - outsourcing and
  - Provisioning.
- While COPS supports the outsourcing model, its extension COPS-PR integrates both the outsourcing and provisioning models.
- The outsourcing model is tailored to signaling protocols such as the resource ReSerVation Protocol (RSVP) which requires traffic management on a per-flow basis.
- On the other hand, the provisioning or configuration model is used to control aggregate traffic-handling mechanisms such as the Differentiated Services (DiffServ) architecture .

Introduction ...

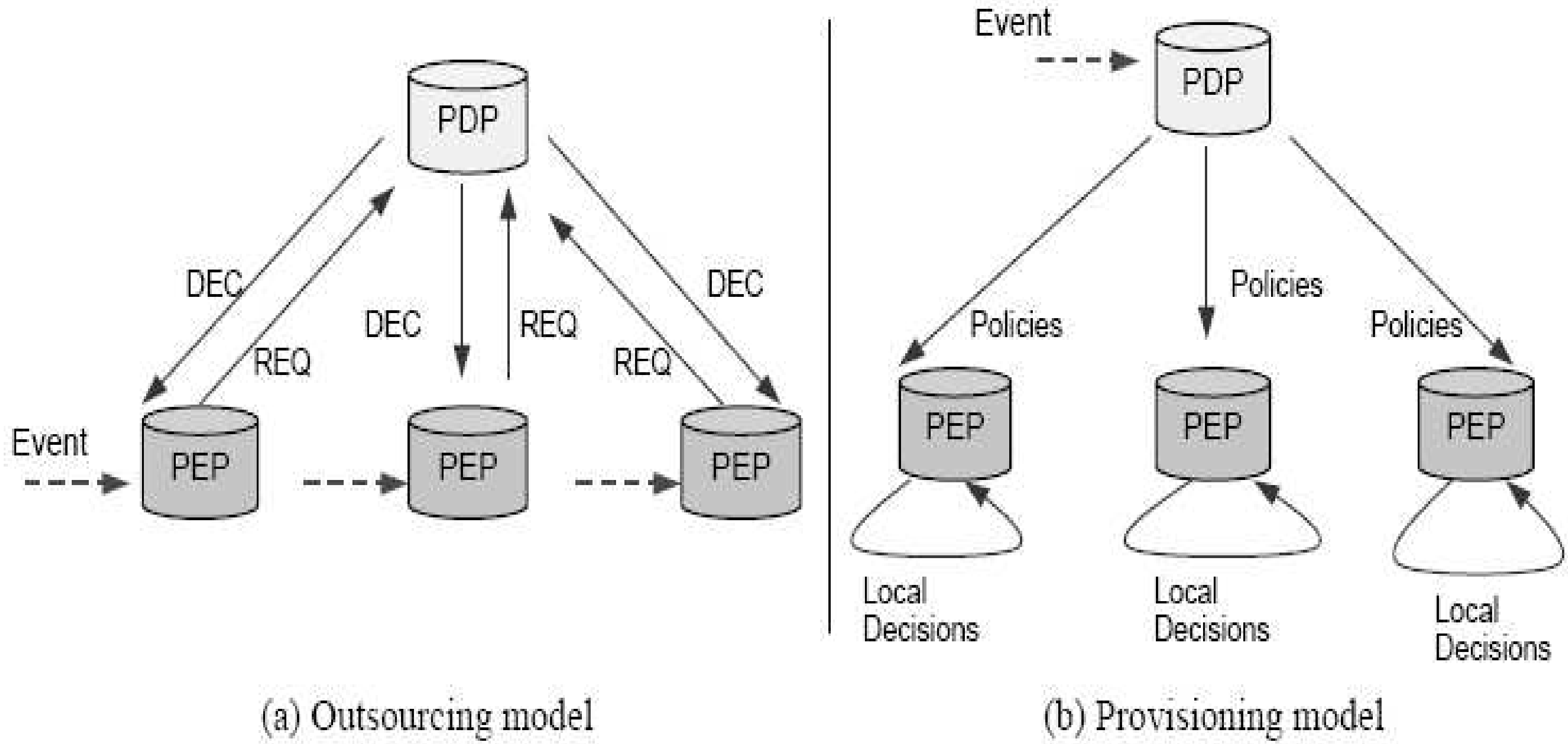


Figure Policy distribution models.

Policy-Based Management Framework for Wireless Ad Hoc Networks

- Our aim is to propose and implement a policy-based management framework for wireless ad hoc networks with focus on QoS management.

PBNM framework…

- Features of the managament policy:
  - Efficient Signaling Mechanism
  - Lightweight
  - Automated, Intelligent and Self-organizing
  - Secure and Robust

PBNM framework…

- **Adapting to the Decentralized Paradigm**
  - Policy-Based Network Management (PBNM) is conceptually an idea about centralized configuration and administration of a network as a whole.
  - This is contrary to the distributed, decentralized paradigm on which ad hoc networks are based.
  - Hence, the challenge is to adapt this centralized service to ad hoc networks – to take advantage of the automation and simplified abstraction of the policy-based approach, but at the same time make its deployment feasible in an ad hoc network environment.

PBNM framework…

- **Systems Approach**
  - policy-based management framework is presented as illustrated in next figure.

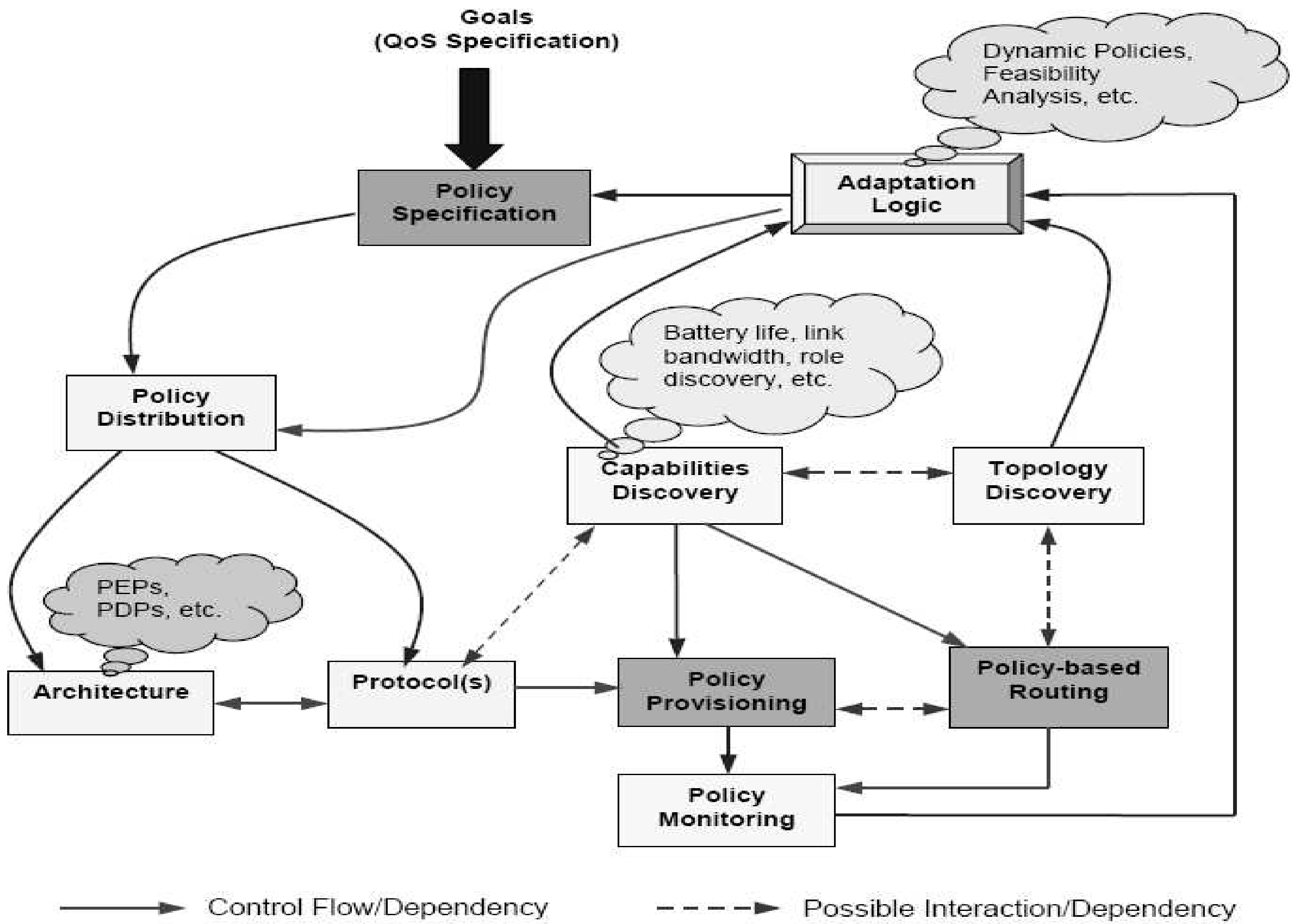


Figure Depiction of our proposed policy-based framework for wireless ad hoc networks, and its main components.

PBNM framework…

- **Policy Specification**
  - The policy specification is a mapping of the overall goals specified for a network into network-wide policies.
- **Policy Architecture and Distribution**

  This module is sub-divided into three major components:
  - **Types of Architectures**
    - see later
  - **Protocol for Policy Distribution**
    - COPS for PRovisioning (COPS-PR) protocol

PBNM framework…

- **Automated and Self-organizing Control Structure**

  This achieved through:

  - **Clustering**
    - we propose a k-hop clustering scheme to limit the number of wireless hops between a policy server and its clients.
  - **Service Adaptivity**
    - we use Dynamic Service Redundancy (DynaSeR).
  - **Service Location Discovery**
    - Locte the service in the network for nodes
  - **Topology Management**
    - Out of thesis scope

PBNM framework…

- **Resource Discovery**
  - A PBNM system translates the high-level policies (Policy Specification) into device-specific configuration to dictate the use of network resources.
  - Using the Optimized Link State Routing (OLSR) protocol, and the OSPF-MCDS protocol

PBNM framework…

- **Policy Provisioning**
  - Policy provisioning occurs after policies are distributed, and consists of installing and implementing the policies using device specific mechanisms

PBNM framework…

- **Policy-based Routing**
  - to control the flow of data traffic in the network based on pre-determined policies.
- **Policy Monitoring**
  - To provide robust management of the network, it is desirable to have an independent policy monitoring process to ensure that the network in fact meets the high-level goals or specifications.

PBNM framework…

- **Adaptation Logic**
  - Given the dynamic nature of ad hoc networks, it is necessary for a policy system to incorporate dynamic and state-dependent policies that allow the control structure to adapt to the current state of the network.

Research Methodology

- Most of the experimental work reported in this dissertation was done using a Linux-based testbed network.
- This testbed incorporates both wired and wireless networking capabilities.

Wired Testbed:

- The operating system used is Red Hat Linux (versions 7.0, 7.2 and 9.0)
- Up to nine of these machines can be used to form a mobile network, while the remaining computer operates as the Dynamic Switch
- The dynamic switch is a software application that allows emulation of a mobile wireless network environment over a wired network

Table Machines Used in the Testbed Network

Machine	RAM (MB)	Processor (MHz)
Desktop 1	128	Celeron 600
Desktop 2	128	Celeron 600
Desktop 3	128	Celeron 600
Desktop 4	128	Celeron 600
Laptop 1	256	Pentium III 1130
Laptop 2	256	Pentium III 1130
Laptop 3	256	Pentium III 1130
Laptop 4	256	Pentium III 1130
Laptop 5	256	Pentium III 833
Dynamic Switch	256	Celeron 600

Wireless Testbed

- The five laptops listed in the previous table constitute the wireless testbed.
- The laptops use Linksys wireless LAN (IEEE 802.11b) PC Cards:
- supports a maximum bandwidth of up to 11 Mbps.

Software components

- Intel® COPS Client SDK
  - It provides Common Open Policy Service (COPS) and COPS-PR protocol implementations for policy clients.
- Telia Research COPS API
  - Free implementation of the COPS and COPS-PR API used in some experiments.
- OLSR Routing Daemon
  - Provides the Optimized Link State Routing (OLSR)proactive protocol

SW components…

- OSPF-MCDS Routing Daemon
  - OSPF-MCDS is a mobile ad hoc routing protocol proposed and developed at Virginia Tech.
  - It is a link state routing protocol that maintains global topology information, simplifying topology discovery.
  - We integrated our PBNM software with the OSPF-MCDS routing daemon and demonstrated its operation.

SW components…

- DiffServ on Linux Tool
  - use the Differentiated Services on Linux tool, to implement IP QoS.
- Real-Time Application and Middleware
  - The real-time software includes a traffic generator and a middleware API.
  - the real-time performance is plotted on the choirGUI as shown next.
- Video Conferencing (VIC) Tool
  - can be used to stream video captured from a camera or alternatively, video captured from the desktop (screenshot).

SW components…

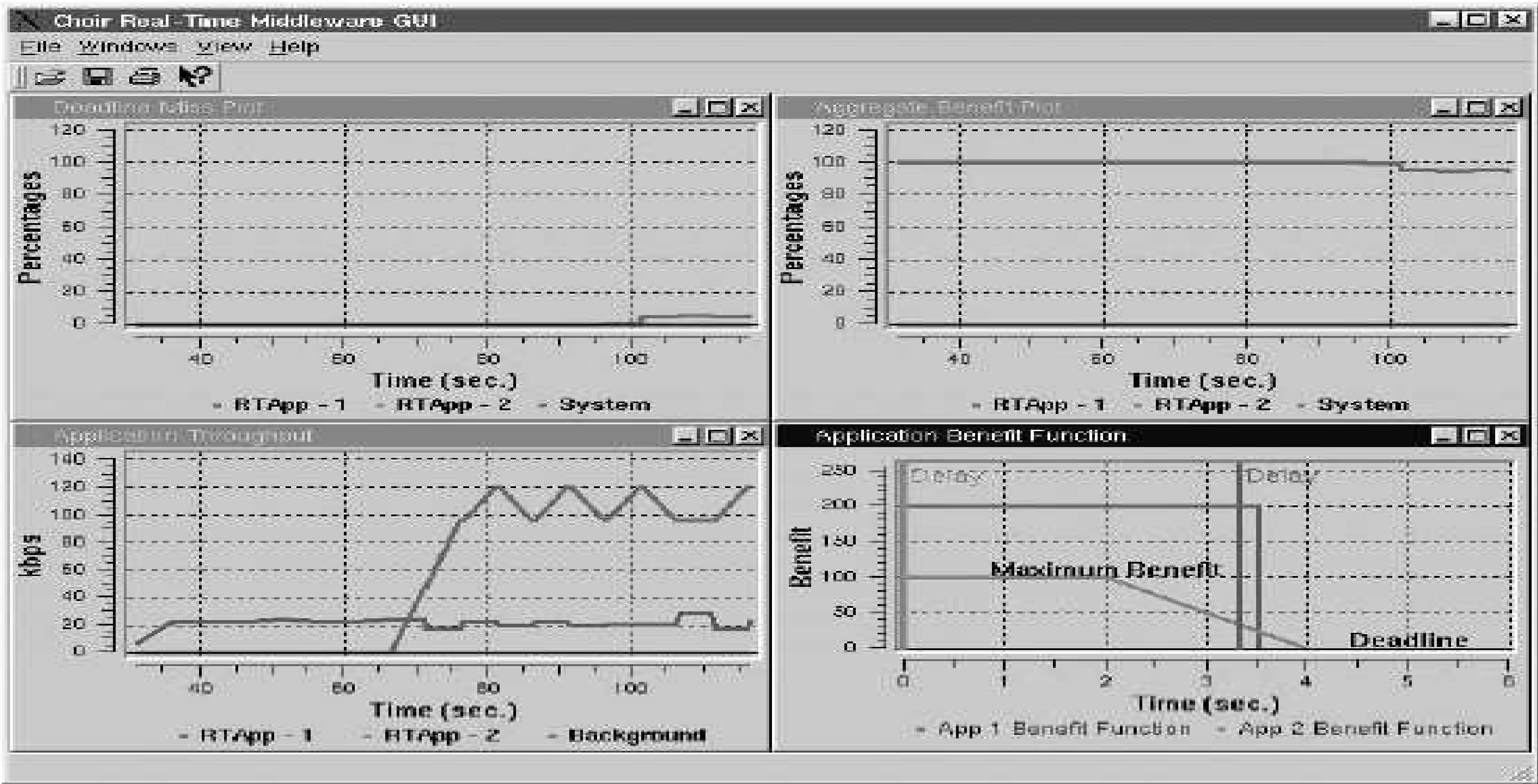


Figure GUI of the performance monitoring tool.

SW components…

- BonnMotion and Supplementary Programs
  - BonnMotion is a Java-based software developed and distributed by the University of Bonn.
  - It generates mobility trace files to simulate and analyze different mobility models.
  - It is known to support at least four mobility models: Random Waypoint, Gauss-Markov, Manhattan Grid and Reference Point Group Mobility (RPGM).
  - The generated trace files can be processed using certain utilities in-built in BonnMotion to study the mobility models themselves, or to generate trace files for network simulators – NS-2 and QualNet/GloMoSim

SW components…

- Traffic generators such as Iperf and Mtools
- *Tcpdump* is used to capture network traffic, and graphs were plotted using the *trpr* tool, which supports tcpdump and NS-2 traffic trace files.
- We use *Ethereal* to measure, debug and demonstrate our implementation.

Simulation Environment

- QualNet network simulator is used
- QualNet is a commercial version of the popular GloMoSim simulator.
- QualNet is a C-based simulator with a Graphical User Interface (GUI) as shown next.
- QualNet runs on different Microsoft Windows and UNIX (Solaris SPARC and Linux) platforms.

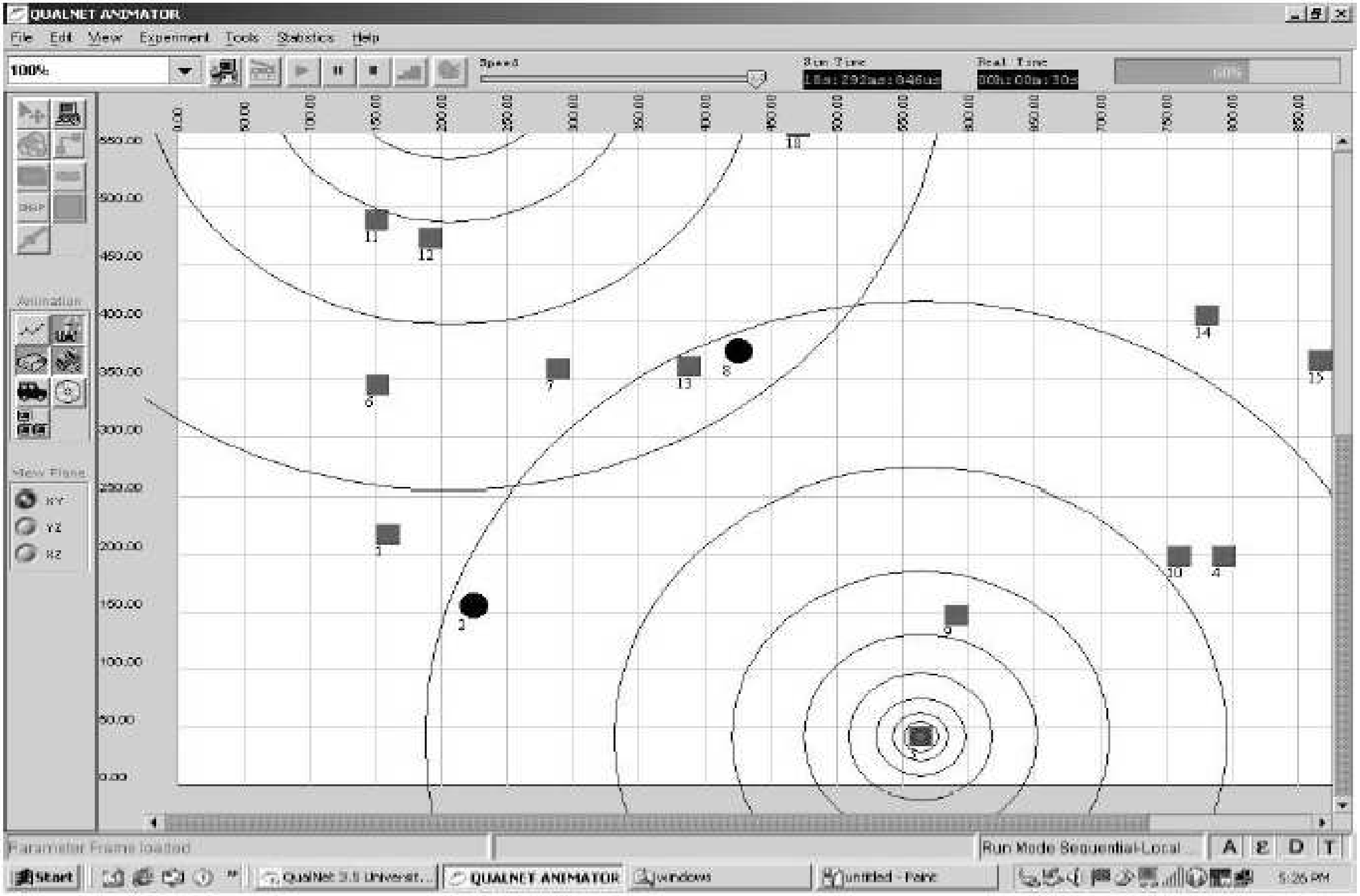


Figure QualNet Animator GUI.

Performance Metrics

- **Policy Response Time**
  - Policy response time is defined as the difference between the time at which a policy client (PEP) sends a policy request, and the time at which the corresponding policy decision is received back.
  - policy response time quantifies the round-trip delay
- **Inter-Decision Time**
  - Inter-decision time is the time difference between consecutive decisions received by the PEP.
  - the inter-decision time provides insight into the processing time spent behind every decision.

Performance Metrics…

- **Management Signaling Overhead**
  - A management framework generally results in additional control traffic or signaling.
  - Measuring the signaling overhead allows us to estimate how efficiently our management system operates.
  - We measured the management overhead in terms of two metrics:
    - Number of COPS Connections Handled Per Server
    - and Control Message Overhead (bytes).

Performance Metrics…

- **Percentage Service Availability**
  - It is the percent of the total network operation time that a policy client is able to receive service from the policy server.
  - This metric helps characterize the service coverage of the management servers.
- **Number of COPS Connection Timeouts**
  - This is the number of COPS connections that timeout.
  - This metric provides insight into how COPS performs in a MANET environment.

Performance Metrics…

- **Subjective Testing and Qualitative Assessment**
  - In addition to quantitative analysis using the above mentioned performance metrics,
  - we also use subjective testing or the quality perceived by the user(s) (e.g., quality of the received video stream) as one of our metrics.
  - This is useful in demonstrating the network performance as perceived by the end-user.

Performance Metrics…

- **Factors**
  - Bandwidth
  - Load (number of simultaneous policy requests)
  - Cluster Size (*k*)
  - Node Mobility or Speed
  - Network Density

Performance Evaluation

- **Simulation Environment**
  - 1000 x 1000 sq. meter flat area.
  - All simulations used the 802.11b MAC layer,
  - A statistical propagation model and two-ray path-loss model is used, leading to a radio range of about 370 meters.
  - The maximum COPS KA timer interval is set to 50 seconds and the service discovery timer interval is set to 20 seconds.
  - The Random Waypoint mobility model is employed.
    - the minimum speed (V*min*) =0.9V*max,* for all simulations.
  - Pause time for the mobility model is set to 10 seconds.

- Each simulation scenario is run for 1500 seconds; results were collected over 1000 seconds by disregarding data in the first 500 seconds of “warm-up” period.
- Nodes were uniformly distributed.
- During initialization, 10% of the nodes are randomly chosen to act as policy servers.
- Several runs of each simulation scenario are conducted to obtain statistically confident averages.

Simulation Results

- Here, simulation results are illustrated.
- First, we characterize the PBNM system performance as a function of cluster size, network mobility and network density, and show the effectiveness of our proposed time-based heuristic algorithm in minimizing service discovery broadcast overhead; these simulations do not incorporate our proposed delegation mechanism. Finally, we then compare the performance of the PBNM system with and without delegation.

- **Effect of Cluster Size and Mobility**
  - We consider a network of 20 nodes (with 2 nodes acting as policy servers).
  - The results are plotted as a function of the cluster size *k*, for three different mobility scenarios (V*max* = 5 m/s, 10 m/s, and 20 m/s).
  - Next figure shows the average number of new COPS connections handled by a policy server.
  - As cluster size (*k*) increases, the probability of a client moving in and out of a cluster decreases, thus reducing the number of new COPS connections being established and then being torn down due to the client moving out of the *k*-hop cluster; for low mobility.
  - As mobility increases, the probability of a client moving in and out of a cluster is high even for larger values of *k*. Hence, the number of new COPS connections being established does not reduce significantly with increase in *k*.

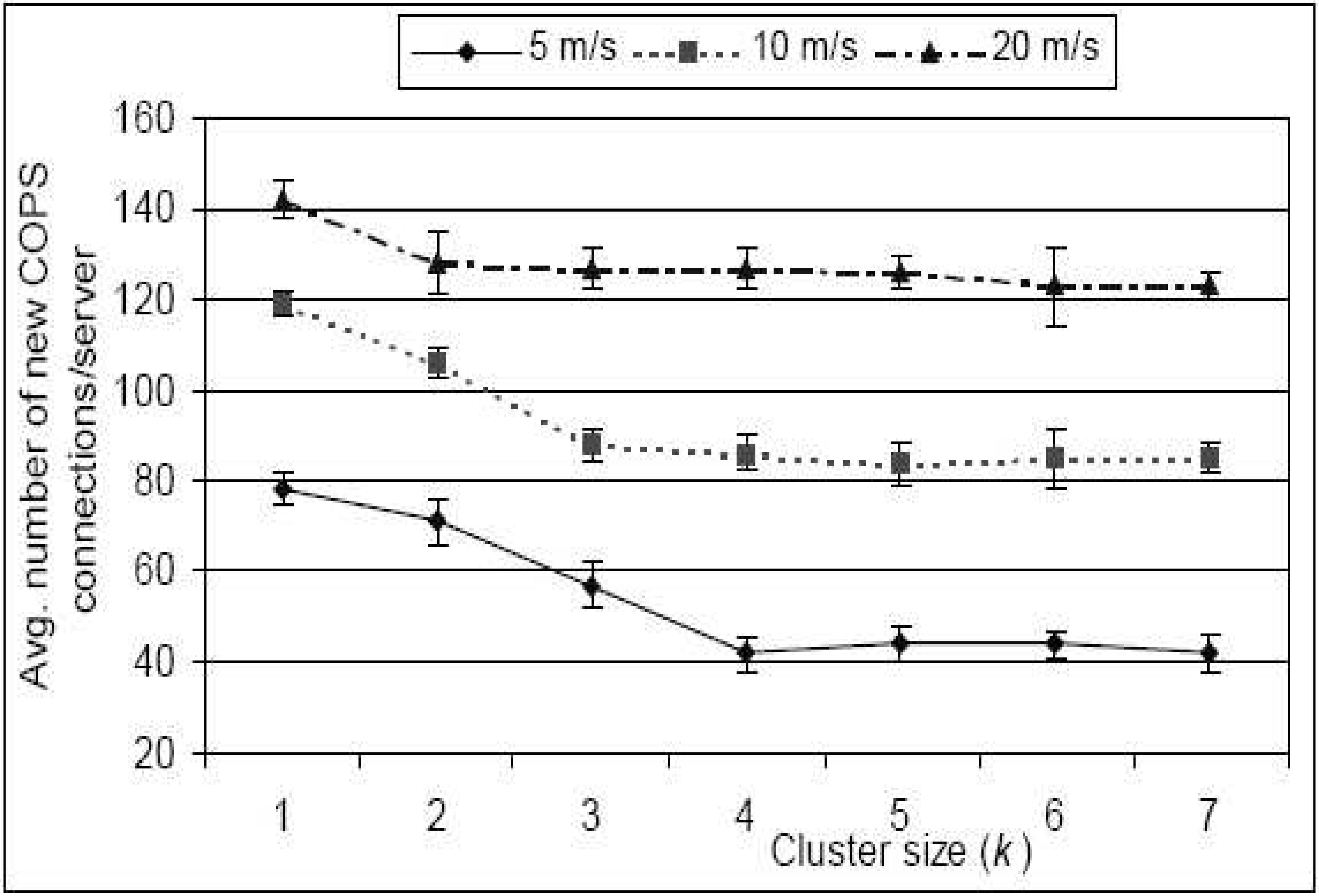


Figure Average number of COPS connections established per server as a function of mobility and cluster size.

- In next figure, we plot the average percent service availability for different values of *k* for three different speeds (5, 10, and 20 m/s).
- As the cluster size increases, the coverage area of each server increases, thus resulting in an increase in the service availability.
- The system typically performs much better at low mobility, except for *k* = 1, wherein the service availability actually improves with speed.

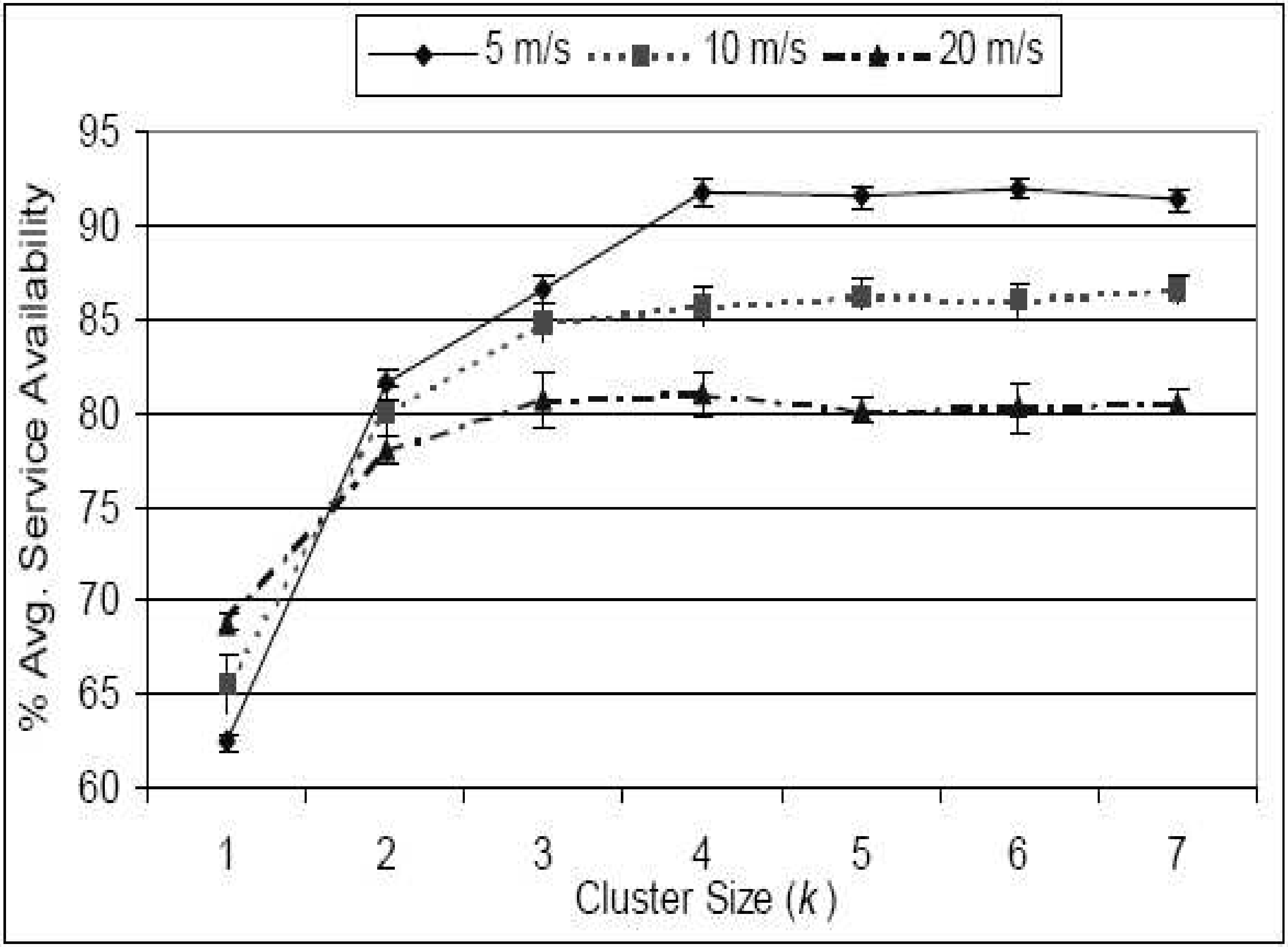


Figure Percentage average service availability as a function of cluster size and mobility.

- We considere different mobility scenarios (V*max* = 0, 2, 5, 10, 20, 50, and 100 m/s) for *k* = 1.
- As next figure shows, the service availability is founded to be the least when the network is static, since clients that are initially placed outside the *k*-hop clusters never get serviced.
- The service availability then increases with mobility, allowing clients to spend more time inside a *k*-hop cluster.
- Beyond a certain threshold speed (at 50 m/s and 100 m/s), mobility hampers the system performance, as clients move very quickly in and out of a cluster; resulting in a decrease in the overall service availability.

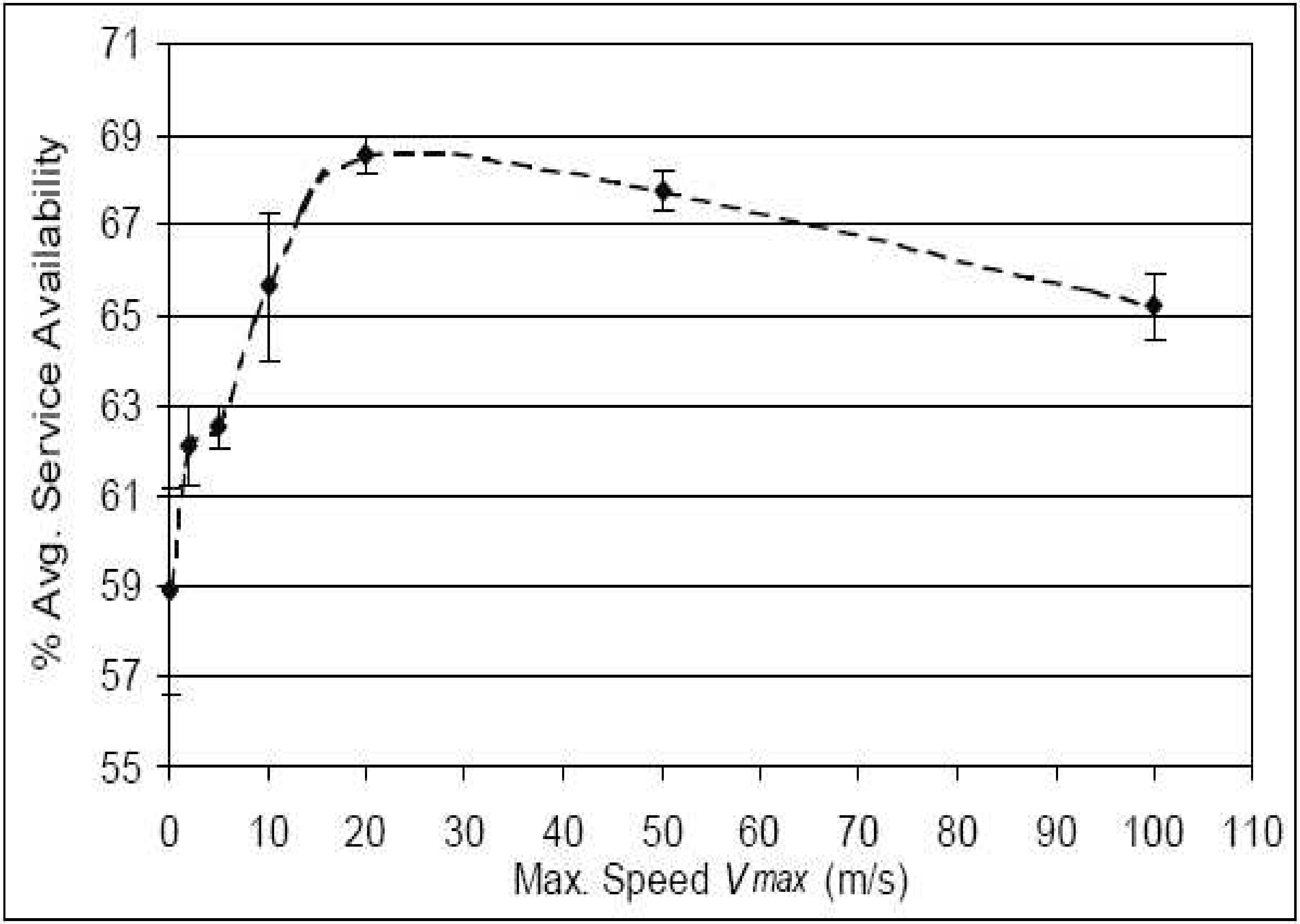


Figure Percentage average service availability at different speeds for cluster size *k* = 1.

- In general, we observe that increasing the cluster size improves the service availability and reduces the overhead (in terms of number of COPS connections).
- But, increasing *k* means that a greater number of intermediate nodes are involved in forwarding management traffic, leading to expenditure of expensive resources such as bandwidth and energy. Here, we characterize how COPS performs with increase in the cluster size.

- As shown in next figure, it is founded that increasing number of COPS connections are timed out as *k* increases, due to the COPS Keep-Alive (KA) message sent by a client not reaching the server, or the server's response not reaching the client in a timely fashion.

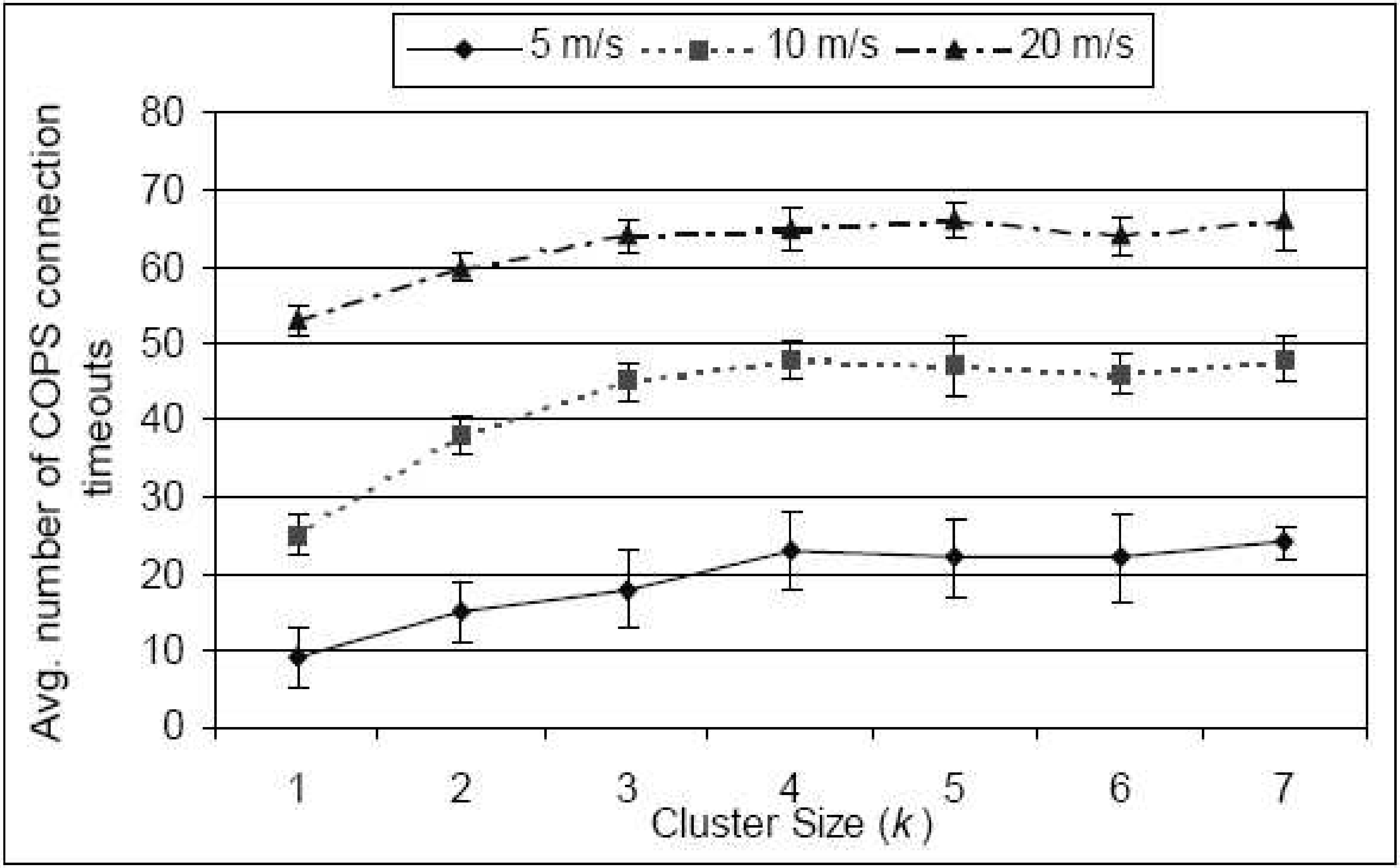


Figure . COPS connection timeouts as a function of cluster size and mobility.

- **Effect of Network Density**
  - Here, we vary the network density – changing the number of nodes and keeping the simulation area constant.
  - The aim is to address scalability of the management system in larger networks
  - Three different scenarios are considered: 20, 50, and 100-nodes/simulation area;
  - *Vmax* is set to 10 m/s.
  - The PBNM service availability is plotted in next figure.
  - The service availability is found to improve with increase in network density, attributed to the improved connectivity

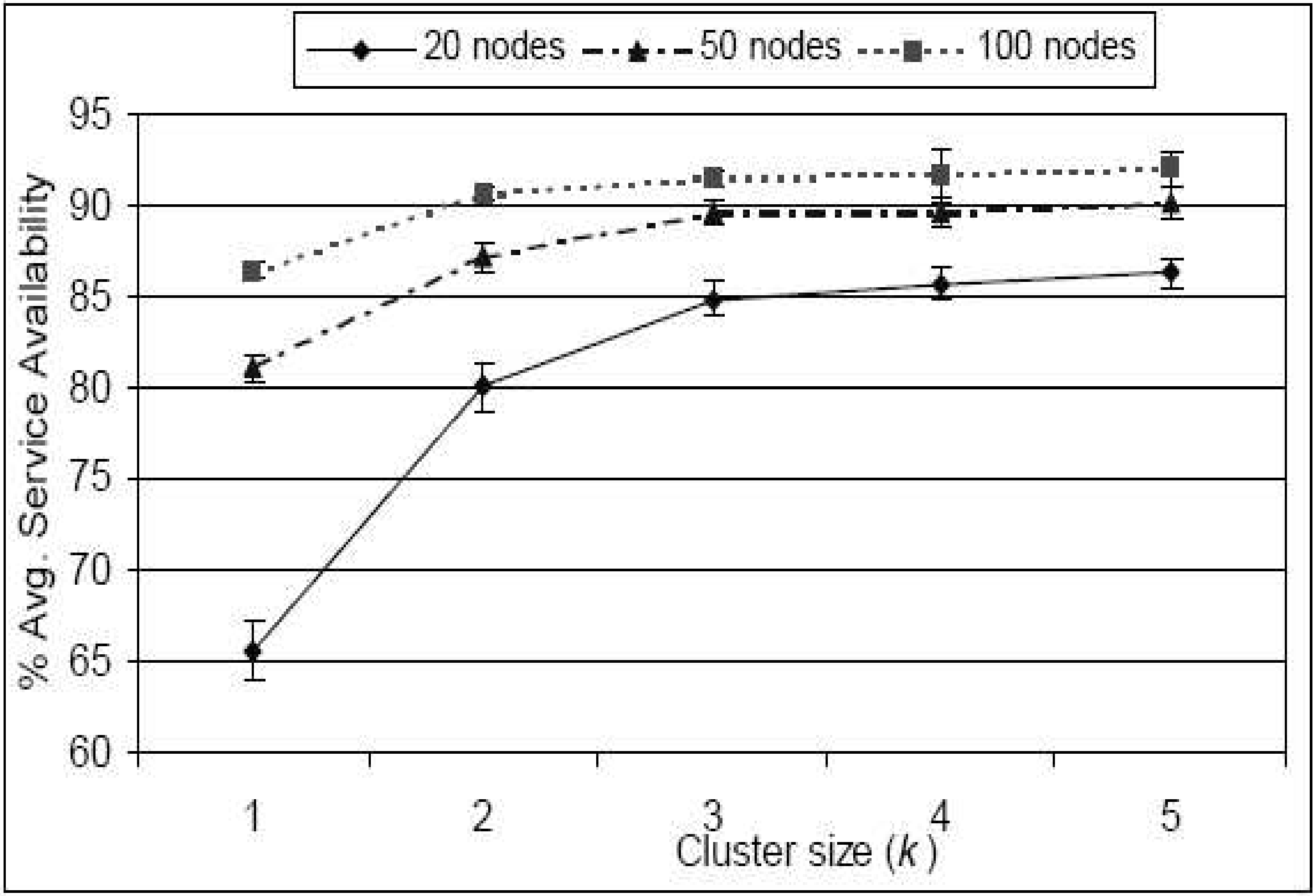


Figure Percentage average service availability as a function of cluster size and network density.

- **Service Discovery Overhead Minimization**
  - Here, we observe the improvement obtained by using our proposed time-based heuristic algorithm to minimize service discovery broadcast overhead.
  - As shown in next figure, the proposed mechanism considerably reduces the broadcast overhead by minimizing unnecessary broadcasts, as compared to the case with blind *k*-hop limited broadcasts.

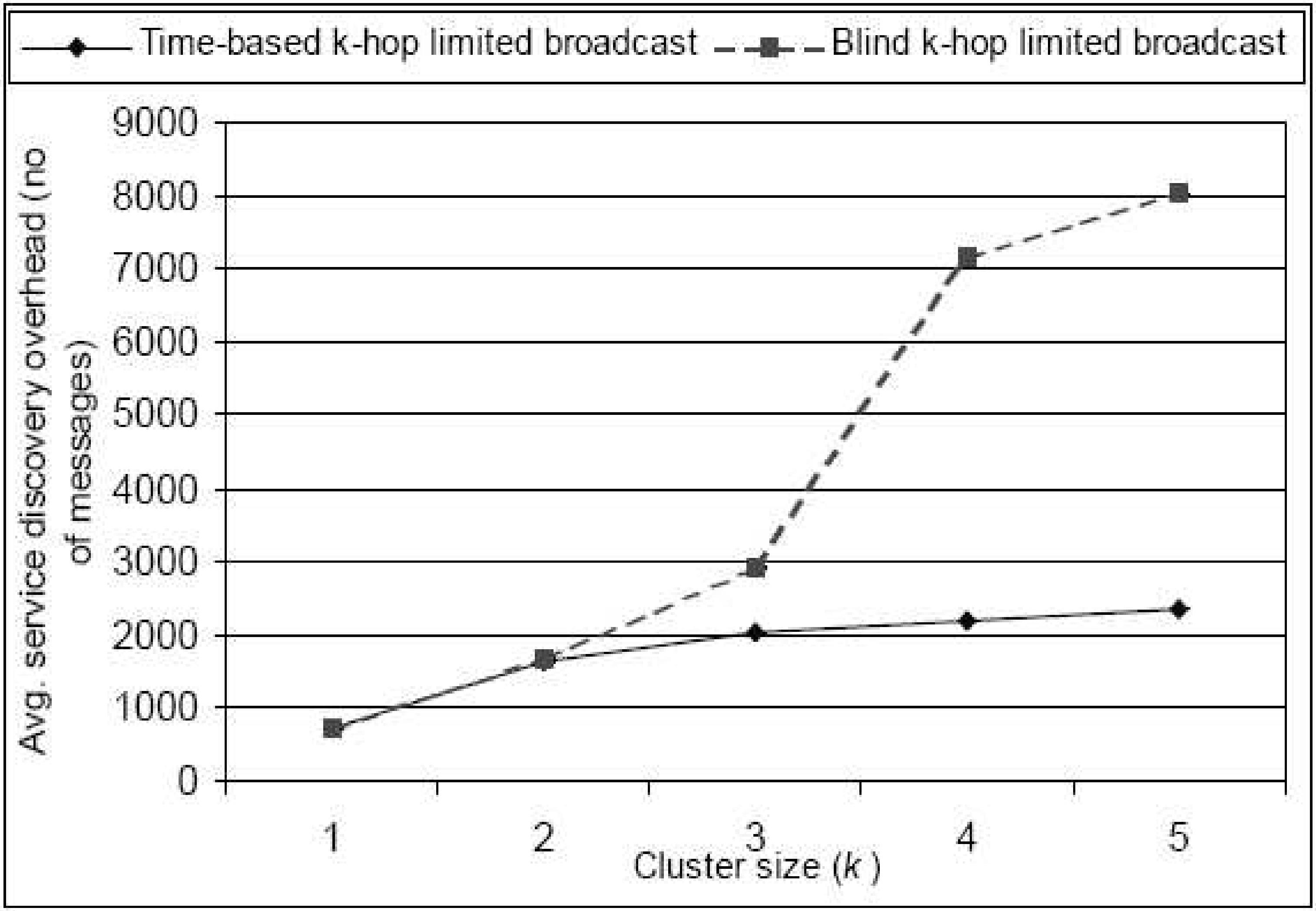


Figure Average service discovery broadcast overhead as a function of cluster size, in presence and absence of our proposed time-based heuristic.

- **Delegation**
  - Distributed Management by Delegation (MbD) is introduced to achieve decentralized management through dynamic distributed computing. Wherein, instead of retrieving collected data from a remote location for processing, the analysis program is dispatched to where the data is.
  - Here, we quantify the improvement in system performance (% service availability) through delegation.
  - We consider a 20-node network with, initially, two policy servers present.
  - Three nodes are randomly chosen to be capable of acting as delegated servers.
  - A node may volunteer to act as a delegated server based on certain resource management criteria such as processing load, battery life, and connectivity.

- With two policy servers initially deployed, and three servers that may get elected as delegated servers, there are a maximum of 5 servers operating in the network at any given time.
- Considerable increase in service availability is observed with delegation, as shown in next figure.

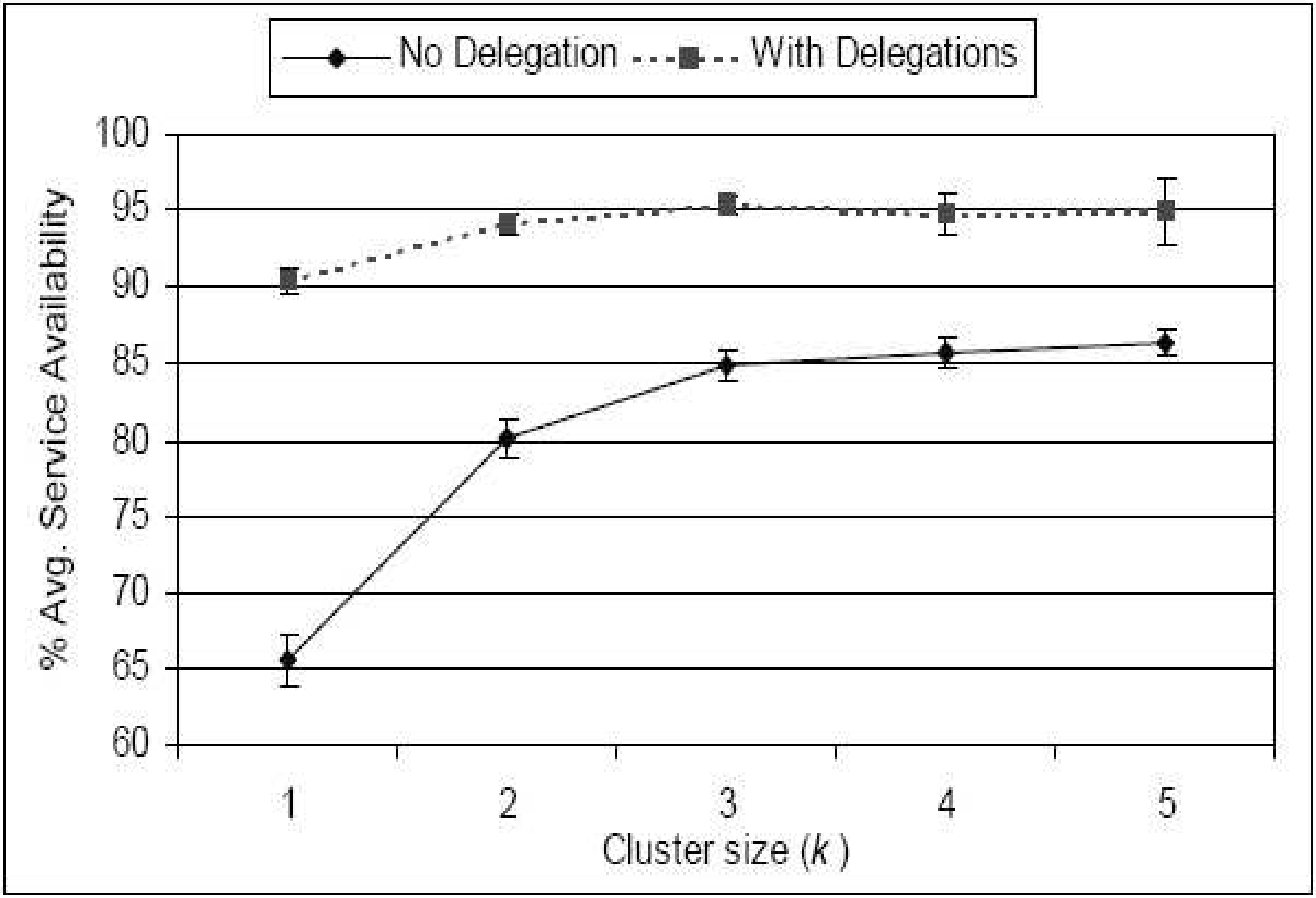


Figure Improvement in service availability using our proposed delegation scheme.

Experiments

- **Results**
  - Here we present a comparison of the results obtained from our experiments and simulations.
  - Plots for the percentage average service availability and the number of COPS connections per server as a function of cluster size are shown in next two figures.
  - The general trend in the average service availability obtained from the experiments is similar to that observed in the simulations.
  - Both exhibite increase in service availability with increase in the cluster size as expected.
  - In general, much fewer COPS connections are observed in the experimental results as compared to the simulations, while the resulting service availability is equal to or greater (except for k = 1) than that obtained from the simulations.

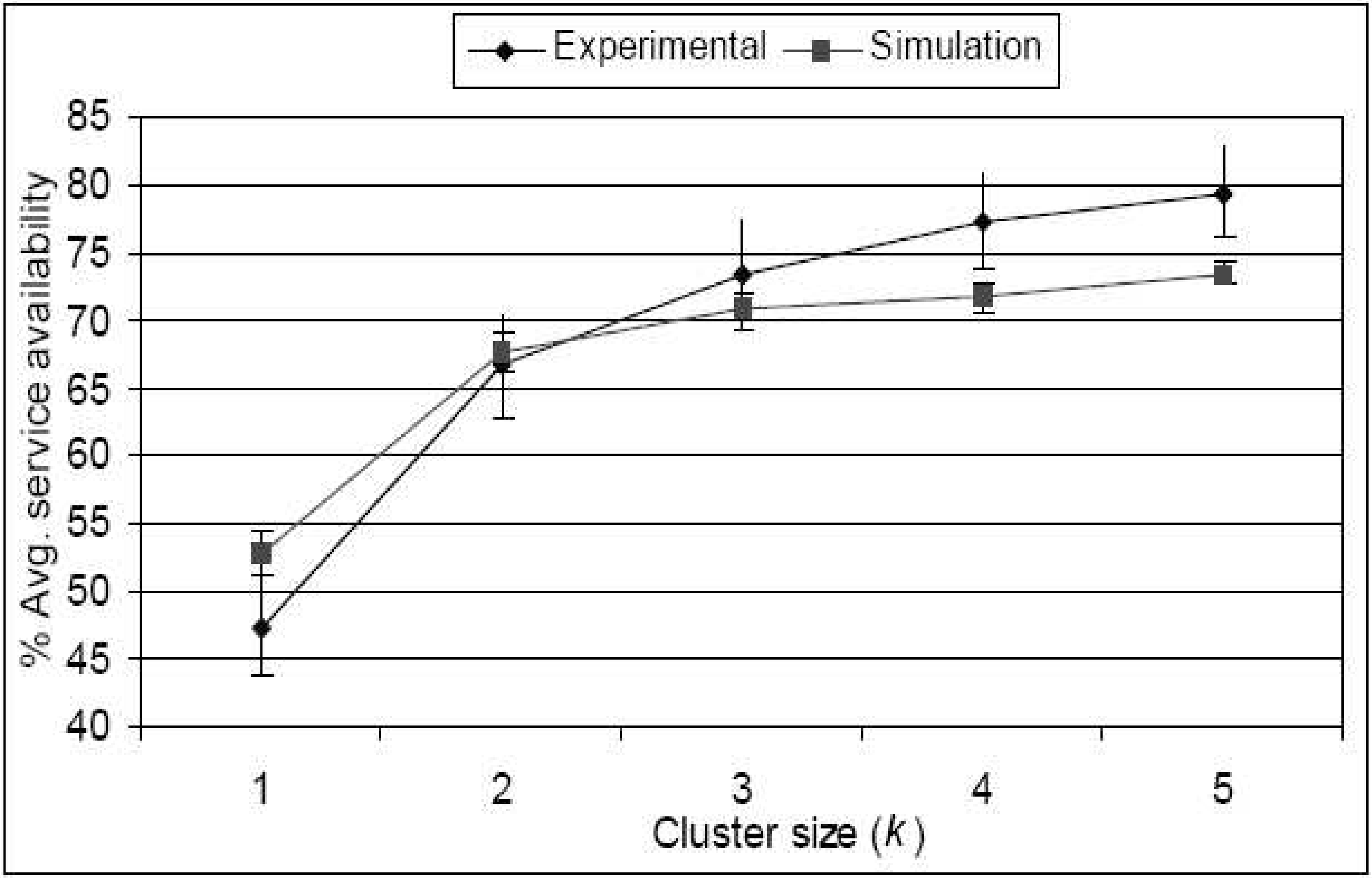


Figure Comparison of average service availability obtained from the experiments and simulations.

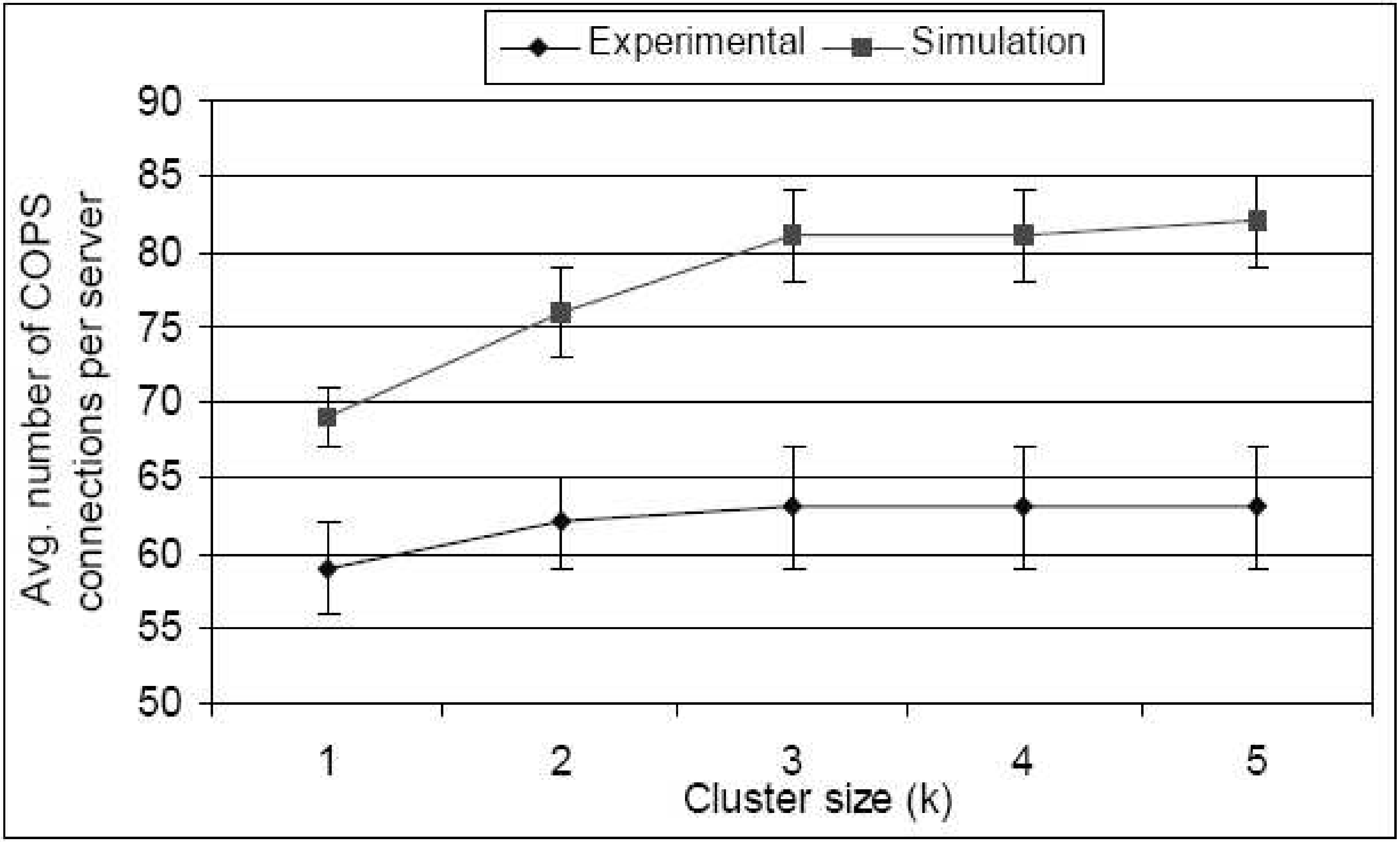
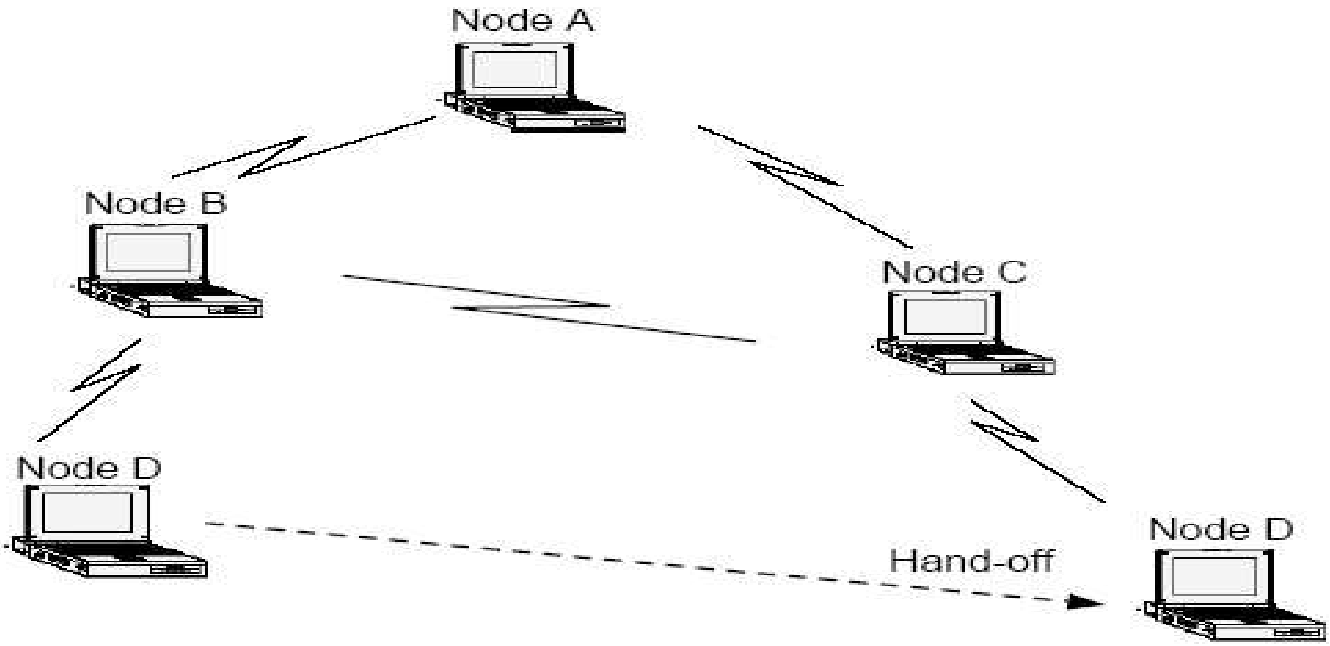


Figure   Comparison of average number of COPS connections obtained from the experiments and simulations.

QoS Management in Multi-domain Ad Hoc Networks

- The goal is to illustrate the use of our proposed COPS-based policy negotiation mechanism to guarantee seamless QoS in such networks.

- **Illustration 1: Video Streaming**
- Here, we illustrate the effectiveness of our proposed policy negotiation scheme in provisioning QoS for a video-streaming application.
- Our demonstration network consists of four laptops: A, B, C, and D, as shown next two figures.
- The result is shown after them.



Node	Description
A	Video stream application sink
B	Policy server for domain 1
C	Policy server for domain 2
D	Video stream application source

Figure Demonstration scenario depicting a multi-domain wireless ad hoc network; hosts B and C are policy servers in distinct administrative domains.

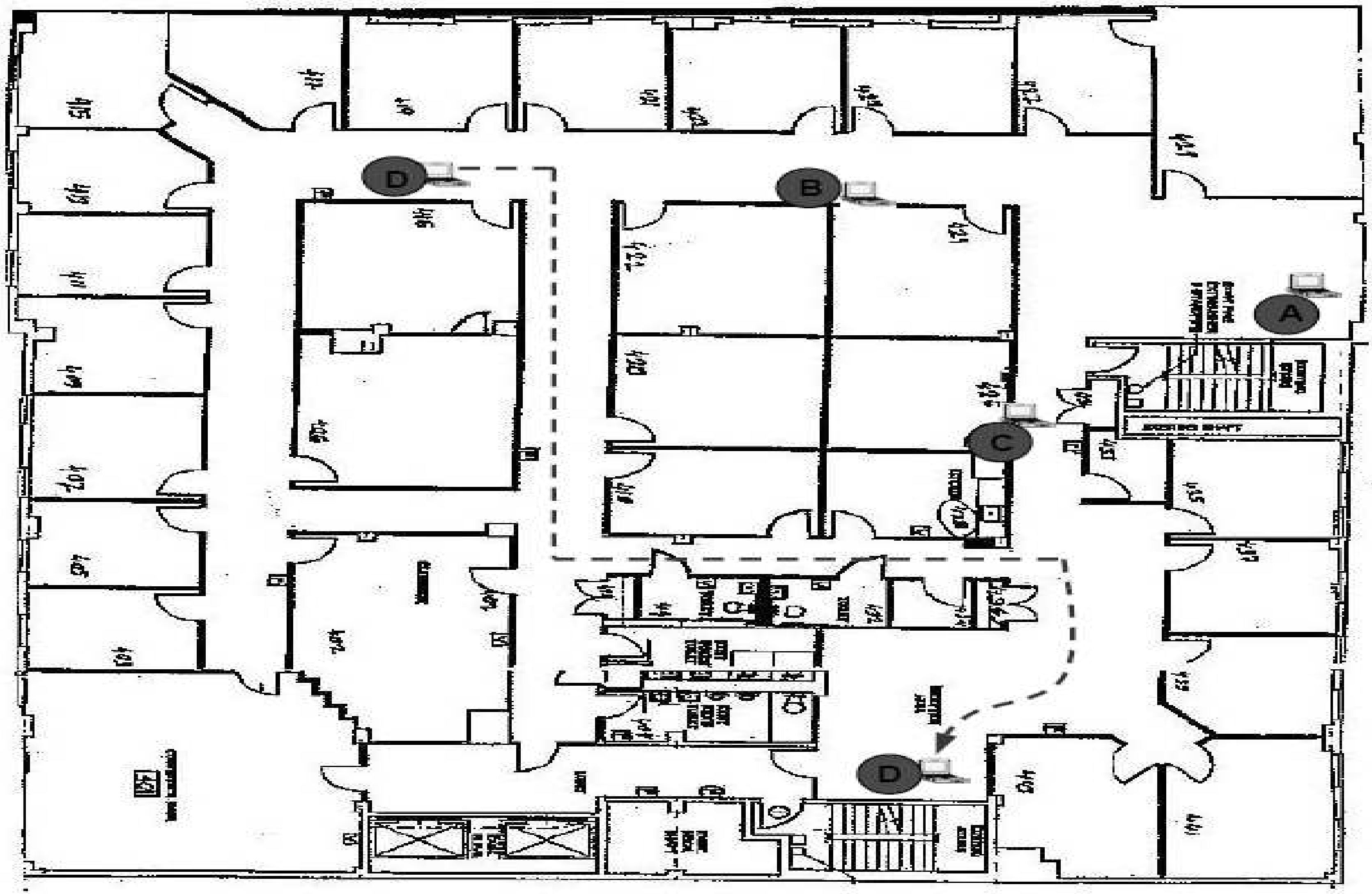
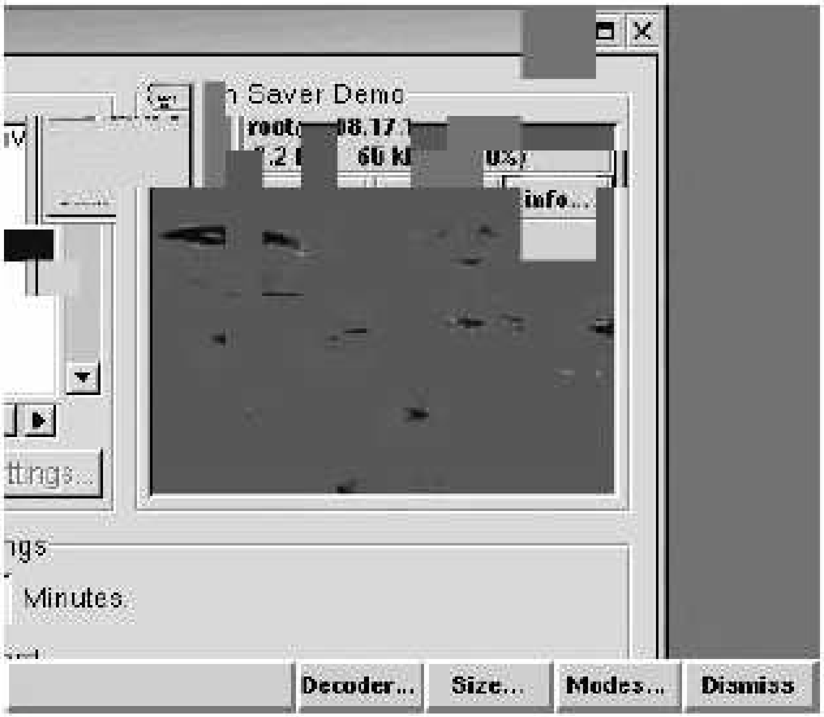
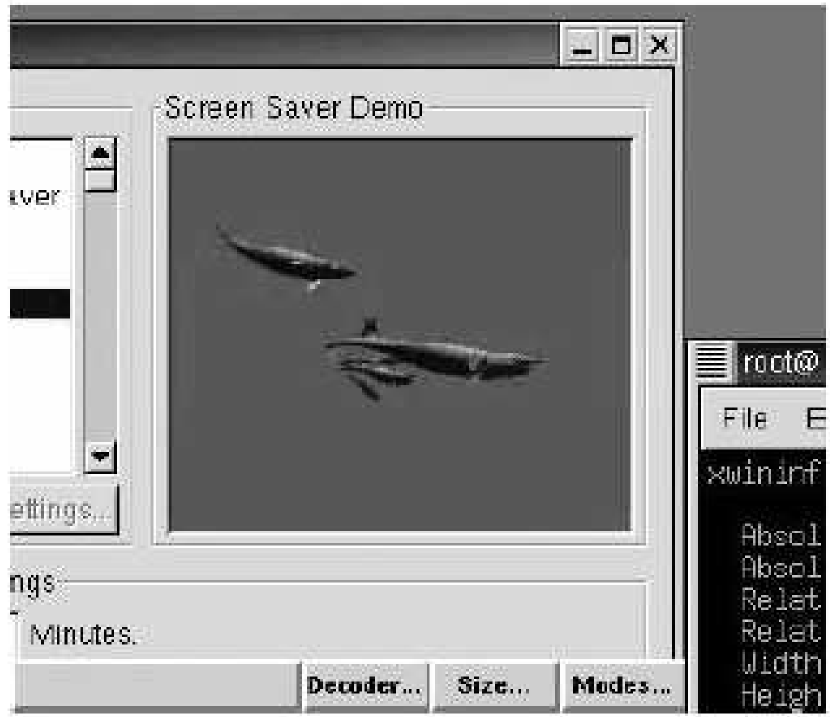


Figure **Layout of the area where we conducted the demonstration; nodes A, B and C are static, while the movement of node D is shown with dotted line. Node D is the policy client that "hands-off" from policy server B to policy server C.**



(a)



(b)

Figure (a) Degraded video quality without policy negotiation (allocated bandwidth is 12 kb/s); (b) Acceptable video quality (bandwidth in the range 64 kb/s to 128 kb/s allocated) after policy negotiation.

- **Illustration 2: Real-Time Application**
  - This illustration is conducted using the wired testbed.
  - We again considered a mobile ad hoc internetwork; however, this time four different administrative domains were setup.
  - The real-time application software used here.
  - Results are shoen in next two figures.

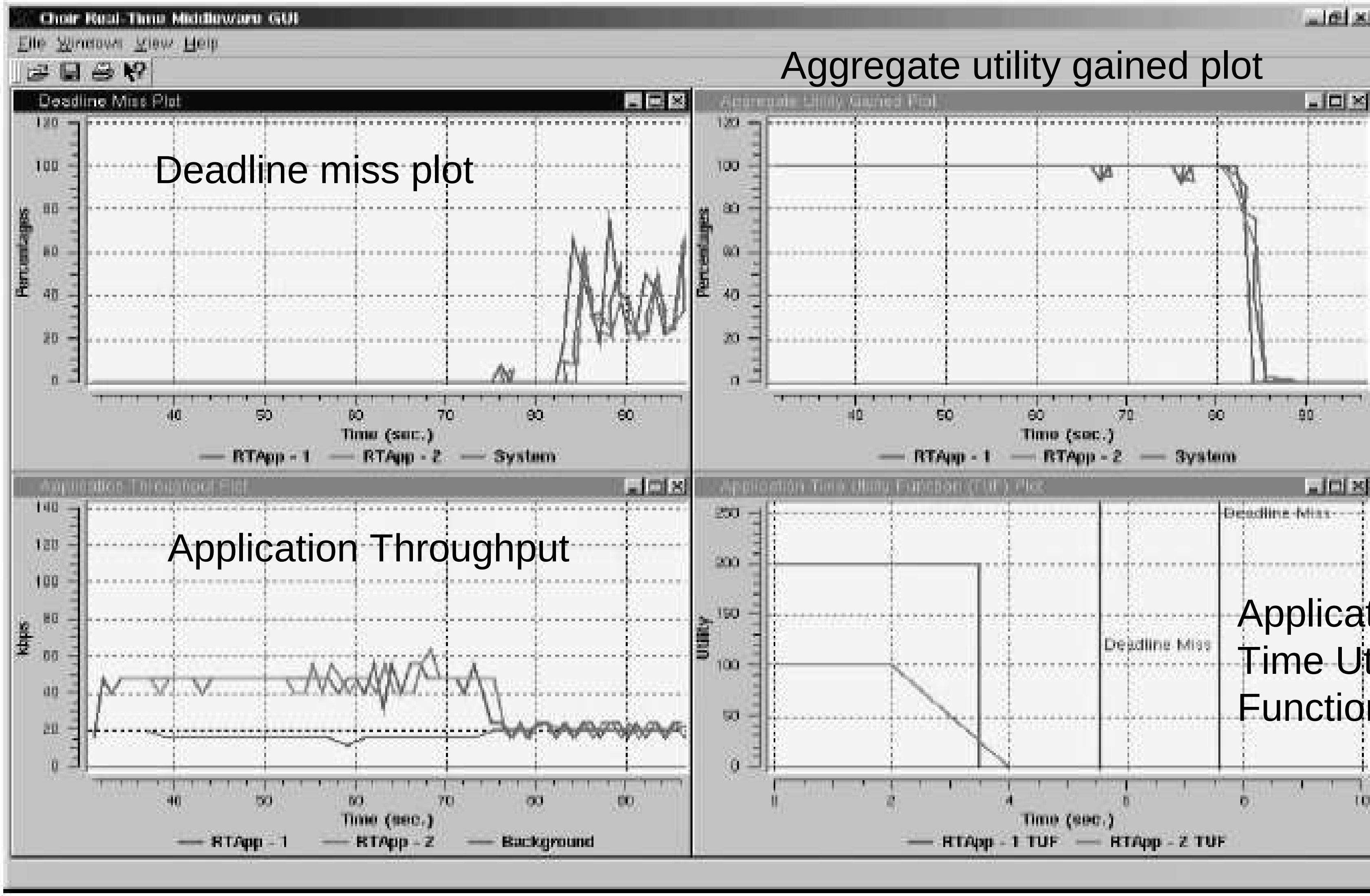


Figure Without policy negotiation, the real-time mission critical applications are treated as best-effort along with background traffic as the source node moves into foreign domains.

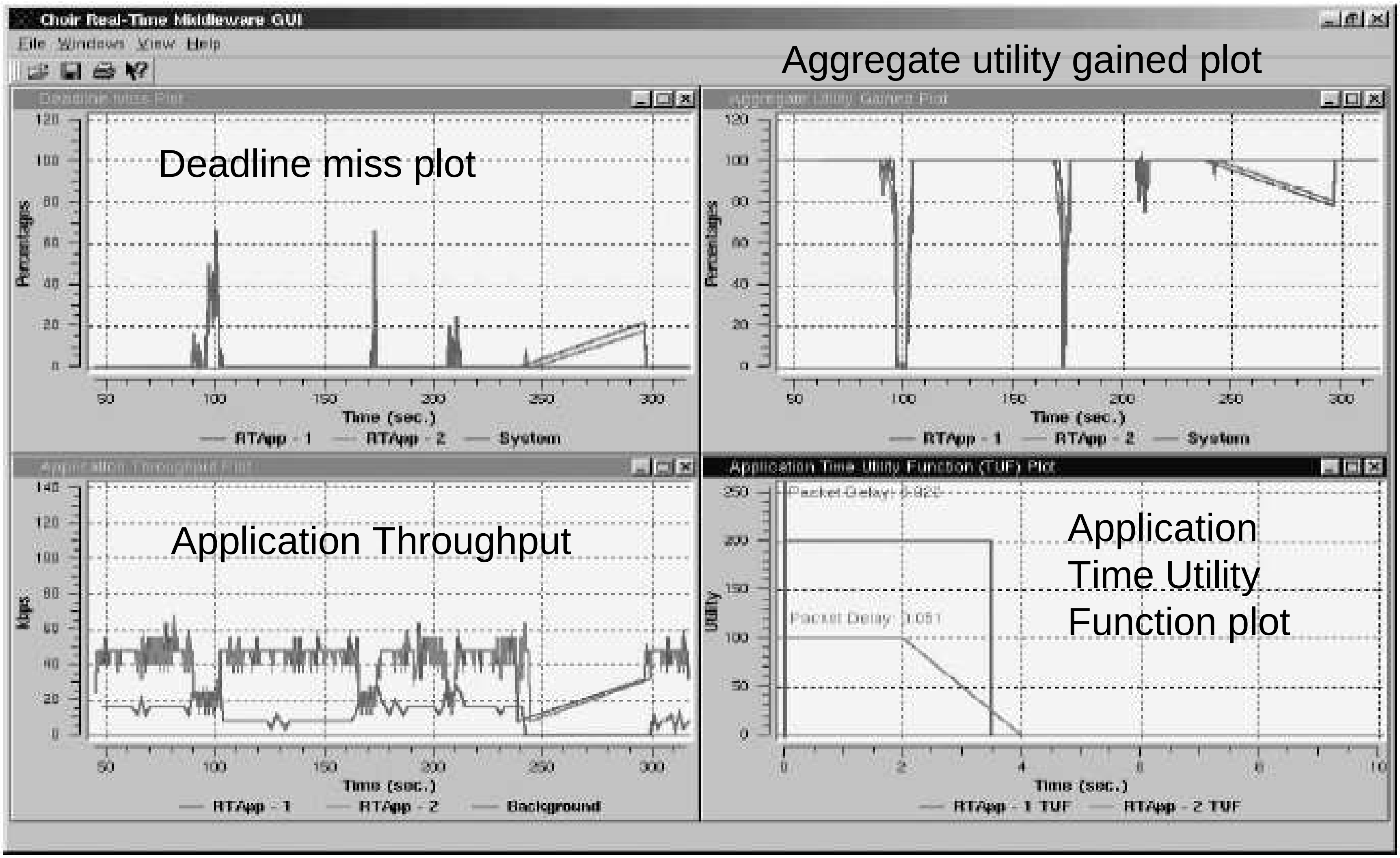


Figure Almost seamless QoS is achieved for real-time mission critical applications in presence of policy negotiation even as the source node moves across different network domains.

Conclusion

- The various constraints imposed by ad hoc network environments make Quality of Service (QoS) provisioning and management in such networks a challenging task.
- We identify policy-based management as a promising approach for managing QoS in ad hoc networks.
- Policy-Based Network Management (PBNM) provides a logically centralized, simplified and automated control of the network as a whole, making management of complex network operational characteristics such as QoS, access control, and network security easier.

Conclusion…

- We propose and implement an automated, intelligent, efficient, and robust policy-based management framework for MANETs, and demonstrate its application for Quality of Service (QoS) management.
- The main contributions of this research are:
  - **PBNM framework**
    - The framework provides insight into the interdependencies among the various components, and helps formalize the complex functional tasks that need to be carried out.

Conclusion…

- **Solution Suite**
  - We propose a suite of solutions to achieve a self-organizing, robust and efficient PBNM system.
  - The four components of the solution suite are:
    - k-hop Cluster Management
      - Our proposed k-hop clustering helps limit the number of hops between a policy client and server.
      - Doing this considerably improves the predictability of the PBNM system, reduces the number of COPS connection timeouts, and bounds the policy response time.

Conclusion…

- Dynamic Service Redundancy (DynaSeR)
  - We proposed the DynaSeR solution to adapt to clients that are outside or have moved out of a k-hop cluster and thus improve the service coverage of the system.
- Policy Negotiation
  - We proposed and implemented another extension to the COPS-PR protocol to facilitate inter-PDP communication and hence to allow negotiation of policies between network domains administered by different organizations.
- Service Discovery
  - A time-based heuristic was developed to reduce the service discovery broadcast overhead

Conclusion…

- **Real-Network Implementation and Experimental Analysis**
- **Simulation-based Study**
    - to address performance, effectivness, and scalability of the proposed PBNM framework, and to understand its behavior under different networking conditions.

Comment

- Well organized work
- Easy to understand
- Every thing well defined
- Based on both simulated and experimental analysis.
- New topics applied to new technology
- In general, it is a very good research.

Glossary

- **ACG:** Automated Code Generation
- **ANMP:** Ad hoc Network Management Protocol
- **API:** Application Programming Interface
- **ARI:** Alexandria Research Institute
- **CBQ:** Class-Based Queuing
- **CCO:** Centralized-Centralized-Outsourcing
- **COPS:** Common Open Policy Service
- **COPS-PR:** COPS for PRovisioning
- **CORBA:** Common Object Request Broker Architecture

Glossary…

- **CSRQ:** Client Service Request
- **C-WAN:** Coalition Wide Area Network
- **DCO:** Distributed-Centralized-Outsourcing
- **DDO:** Distributed-Distributed-Outsourcing
- **DDOP:** Distributed-Distributed-Outsourcing-Provisioning
- **DDOP-H:** Hierarchical DDOP
- **DDP:** Distributed-Distributed-Provisioning
- **DDP-H:** Hierarchical DDP
- **DiffServ:** Differentiate Services architecture

Glossary…

- **DMTF:** Distributed Management Task Force
- **DynaSeR:** Dynamic Service Redundancy
- **FSM:** Finite State Machine
- **GUI:** Graphical User Interface
- **HMAC:** key-Hashed Message Authentication Code
- **HTB:** Hierarchical Token Bucket
- **IEEE:** The Institute of Electrical and Electronics Engineers
- **IETF:** Internet Engineering Task Force
- **IP:** Internet Protocol

Glossary…

- **IPSec:** IP Security protocol
- **ISM:** Industrial Scientific and Medical
- **ISO:** International Standards Organization
- **ISP:** Internet Service Provider
- **KA:** Keep-Alive
- **LAN:** Local Area Network
- **LARTC:** Linux Advanced Routing and Traffic Control
- **LBNL:** Lawrence Berkeley National Laboratory
- **LDAP:** Lightweight Directory Access Protocol
- **LPDP:** Local Policy Decision Point

Glossary…

- **LTU:** Lulea University of Technology
- **MANET:** Mobile Ad hoc NETwork
- **MARE:** Mobile Agent Runtime Environment
- **MbD:** Management by Delegation
- **MCDS:** Minimal Connected Dominating Set
- **MD:** Message Digest
- **MIB:** Management Information Base
- **NAVCIITI:** Navy Collaborative Integrated Information Technology Initiative
- **NTP:** Network Time Protocol
- **OLSR:** Optimized Link State Routing

Glossary…

- **ONR:** Office of Naval Research
- **OSPF-MCDS:** Open Shortest Path First routing protocol using MCDS
- **PAM:** Policy Advisor Module
- **PBNM:** Policy-Based Network Management
- **PDP:** Policy Decision Point
- **PEP:** Policy Enforcement Point
- **PIB:** Policy Information Base
- **PMT:** Policy Management Tool
- **PRC:** Policy Rule Class
- **PRI:** Policy Rule Instance

Glossary…

- **QoS:** Quality of Service
- **RAP:** IETF Resource Allocation Protocol working group
- **RPGM:** Reference Point Group Mobility
- **RSVP:** resource ReSerVation Protocol
- **SA:** Service Advertisement
- **SHAMAN:** Spreadsheet-based Hierarchical Architecture for MANagement
- **SDK:** Software Development Kit
- **SLA:** Service Level Agreement
- **SLS:** Service Level Specification

Glossary…

- **SMI:** Structure of Management Information
- **SNMP:** Simple Network Management Protocol
- **tc:** Traffic Control
- **TCP:** Transmission Control Protocol
- **TLS:** Transport Layer Security
- **TTL:** Time To Live
- **UMTS:** Universal Mobile Telecommunications System
- **VIC:** VIdeo Conferencing tool

Reference

- **Policy-Based Quality of Service Management in Wireless Ad Hoc Networks**
  - Kaustubh S. Phanse
  - Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Electrical Engineering
  - August 22, 2003
  - Alexandria, Virginia

Questions

Thank you