Center for Satellite and Hybrid Communication Networks

Adaptive Hierarchical Network Modeling and Simulation

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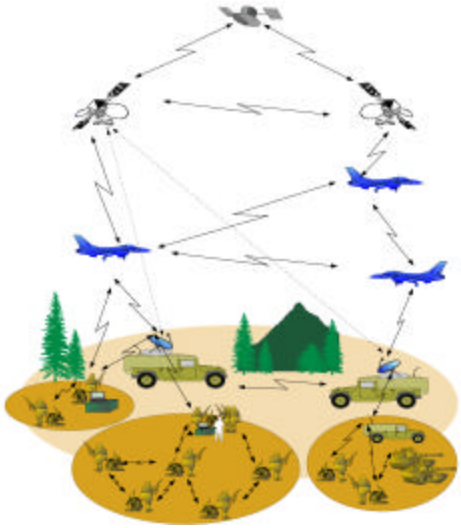
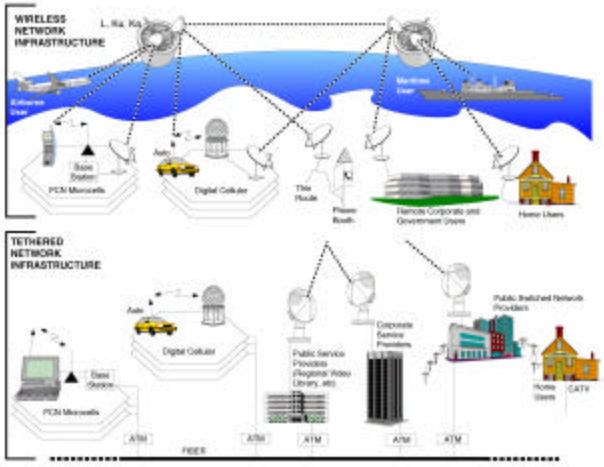




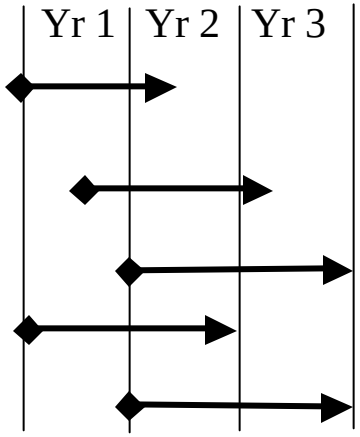
NEW IDEAS/METHODS

- Robust multi-scale traffic models and model complexity vs performance tradeoff
- Hierarchical loss network models and progressive estimates and control
- Self-configurable adaptive hierarchical traffic models linked to network management and control functions

IMPACT

- New network laws for new traffic types (fractal)
- Two to three orders of magnitude faster performance evaluation of large networks
- Enabler of intelligent network management via models
- Accurate network planning and dimensioning

SCHEDULE



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Main Goal

- **Realize the vision of hierarchical network models that can automatically adapt to traffic characteristics and network management needs**

- **Focus on new fundamental methods utilizing polymorphic models for traffic, analytical approximations, and hybrid multi-criteria optimization**

Innovative Ideas

- Develop robust multi-models of network traffic models of minimum complexity for network control and planning
- Assess the incremental utility of various network traffic models *wrt* speed, complexity, performance of function which uses them
- Evaluate the impact of various network traffic models (fitted to measured network traffic data) on
  - control performance (e.g. response time, fairness, priority fidelity, packet loss)
  - on allocation of network resources (e.g. buffer sizes, capacities)
  - on network performance predictability (e.g. QoS predictions *vs* actuals, proactive fault management, network availability)

Innovative Ideas (cont.)

- Model classes arranged in aggregation hierarchies
  - based on time scale, geography/topology scale, network state, distribution of values of performance metrics
  - finer and coarser representations are communicating as frequently as needed to maintain consistency
  - Network functions select and utilize automatically models of the needed granularity
- Use on-line measurements for both on-line and off-line model construction, adaptation and selection
  - validation/verification of models via robust control methods
  - combined model selection and validation problem (dynamic game)
  - sampling in the range space of variables (min overhead)

Innovative Ideas (cont.)

- Self-organized algorithms and systems that automatically select appropriate models and scale for the function
  - both on-line and off-line processing
  - learning and adaptation
  - learn patterns, models, strategies

Thrusts

- Network Traffic Models for Control and Planning
- Adaptive Hierarchical Modeling Incorporating On-Line Measurements
- Simulation Experimentation and Validation

Network Traffic Models for Control and Planning

- Self-similar and multi-fractal models
  - understand the “laws”
  - “fast” and “slow” time scales
    - < 100 ms, protocol dynamics, queue control
    - 100 ms to 10 min, user dynamics, aggregate flow control
    - > 10 min, network planning and dimensioning
- Deeper investigation of self-similar and multi-fractal models
  - ON/OFF, aggregations, FBM, M|G|∞
  - Causes and “new network laws”
  - Queuing analysis

Network Traffic Models for Control and Planning (cont.)

- Statistical Methodologies for Network Traffic Data Analysis
  - analysis of measured traffic traces
  - traffic model fitting and parameter estimation
  - model parameter tuning and adaptation
  - wavelet and multiresolution methods
  - properties of estimators (bias, confidence intervals, consistency)
  - discrete operations with uniform and non-uniform sampling
  - tests for fractality and multi-fractality
  - Minimum Description Length (MDL) complexity analysis of models, tests and parameter estimators

Network Traffic Models for Control and Planning (cont.)

- Model Selection and Fitting to Traffic Traces
  - MDL selection of models of "minimum complexity"
  - evaluation of different models types fitting the same trace from an MDL perspective
  - models parameter estimation via matching specific traffic descriptors, or via model identification techniques (M|G|∞, FGN, MMB, MMP, ARIMA, HMM, Petri Nets, etc.)
- Queuing Theory and Control
  - large buffer asymptotics for packet loss and more
  - for fractal and multi-fractal models
  - impact of short-time fluctuations
  - fast approximations
  - performance of RED and variations, impact on MAC design, impact on dynamic bandwidth allocation

Network Traffic Models for Control and Planning (cont.)

- Incremental Utility of Models for Control and Management
  - key challenge in linking network modeling and simulation to network management
  - fit different type models to the same traffic trace
  - derive best model based control and/or management strategy using fitted model
  - compare relative performance of resulting strategies via detailed simulations and real experiments
  - seek “laws” that govern buffer, schedule and queue dynamics based on performance metrics
  - “fast” time scale: model based prediction, dynamic queue service scheduling, dynamic bandwidth allocation in wireless, buffer and packet drop policies
  - “slow” time scale: network resource planning, design and dimensioning
  - analysis of traffic shaping controls

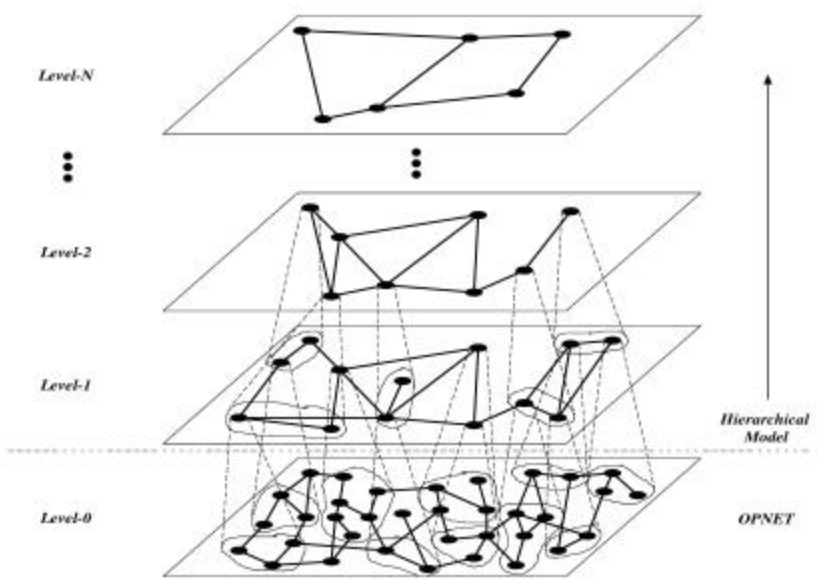
Adaptive Hierarchical Modeling Incorporating On-Line Measurements

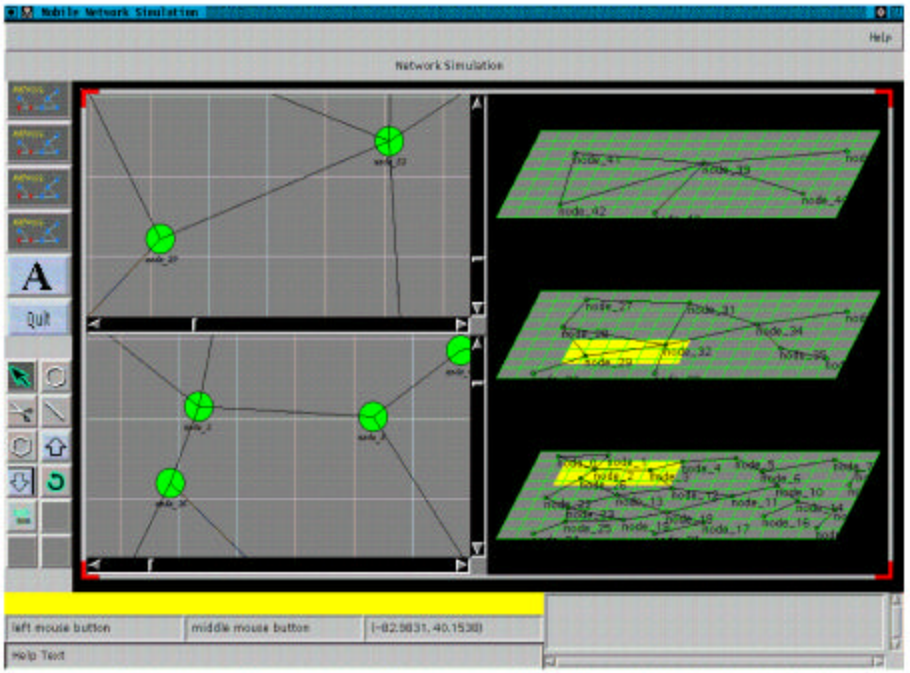
- Large networks $\Leftrightarrow$ complex systems $\Leftrightarrow$ hierarchies $\Leftrightarrow$ adaptation and self-organization
- Aggregation due to topology, routing, time scales, size
  - adaptive aggregation methods
  - prediction/estimation accuracy *vs* aggregation level/resolution
  - convergence, robustness, domain of validity in relation to specific control and/or management function
- Minimum Complexity Hierarchical Traffic Modeling
  - refinement/coarsening and "updating" in the ladder
  - extensions of MDL to hierarchies
- Hierarchical Loss Network Model
  - validity, convergence, performance
  - new traffic models impact

Adaptive Hierarchical Modeling Incorporating On-Line Measurements (cont.)

- Multi-Objective Design and Sensitivity Analysis
  - use of automatic differentiation techniques for sensitivity analysis
  - trade-off analysis via multi-objective optimization
  - linkage to traffic models and simulations
- Network Control, management and resource allocation
  - progressive representations using hierarchies
  - complex systems and learning/adaptation
- Multiple Performance Metrics and Hierarchical Models
  - multi-performance trade-offs within the hierarchical framework
  - adaptivity: different subnetworks use different model types in the hierarchy

Adaptive Hierarchical Modeling Incorporating On-Line Measurements (cont.)





Topology
Traffic pattern
Routing policy
Call admission control (CAC)

AD processor

Model and its sensitivities

Performance Models

Multi-objective designer/optimizer

Design parameter

QoS estimates:
End-to-end delay
Call blocking
Throughput

Simulation, Experimentation and Validation

- Importance Sampling
  - rare events and change of probabilities
  - beyond large deviations due to LRD
  - evaluation of blocking probabilities in M|G|∞ fractal or multi-fractal
  - evaluation of blocking probabilities for problems involving aggregation of many ON/OFF processes
- Model Validation
  - formal verification methods and extensions
  - hierarchical models
  - combined model selection and validation, robust control, dynamic games
- Software Implementation
  - COTS +: MATLAB, SPLUS, OPNET, ILOG SOLVER and CPLEX
  - CORBA-JAVA and UML
  - Experimentation, testing and validation of models, algorithms, methods