Online QoS Management for Network-Centric Operations

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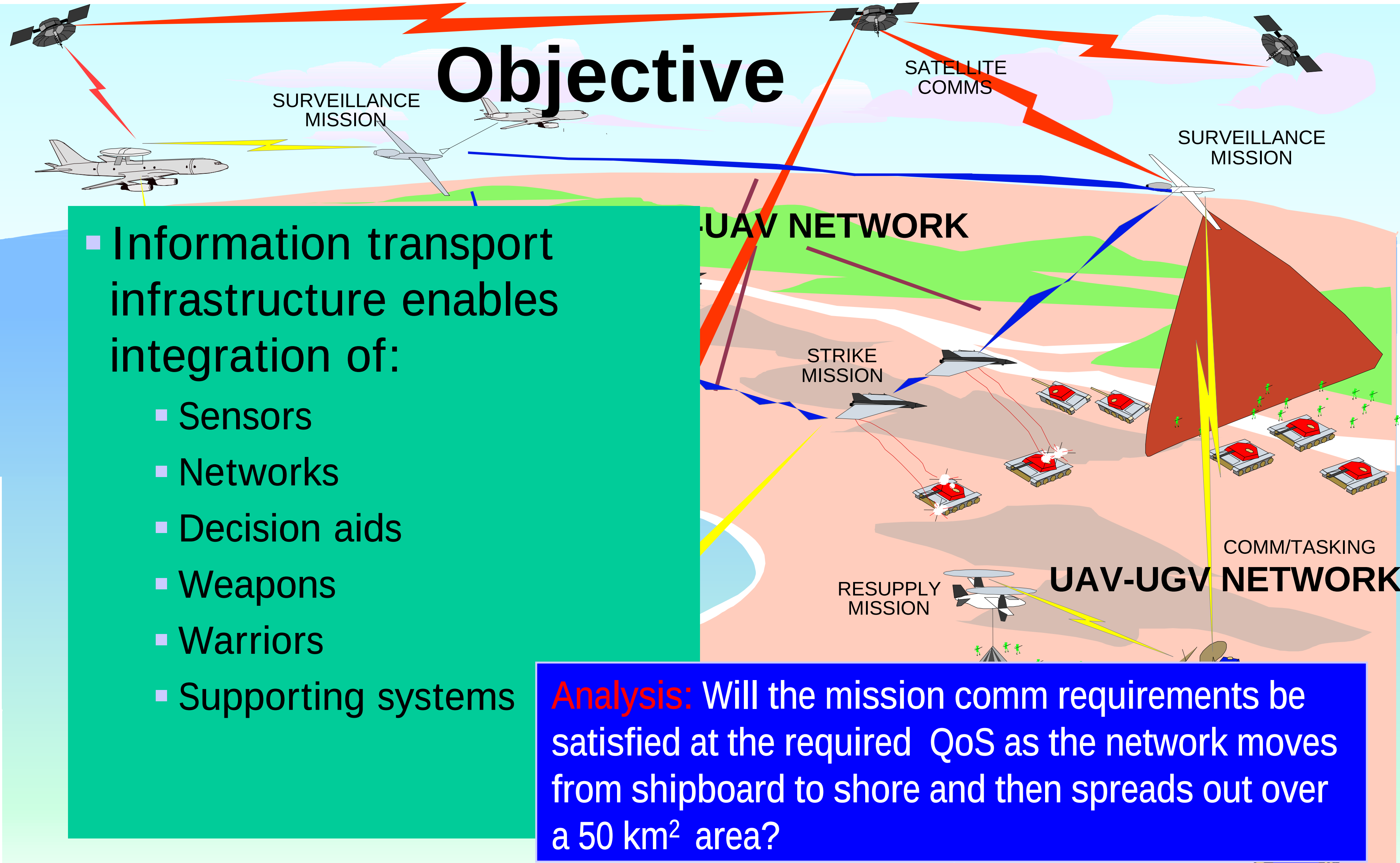
Objective



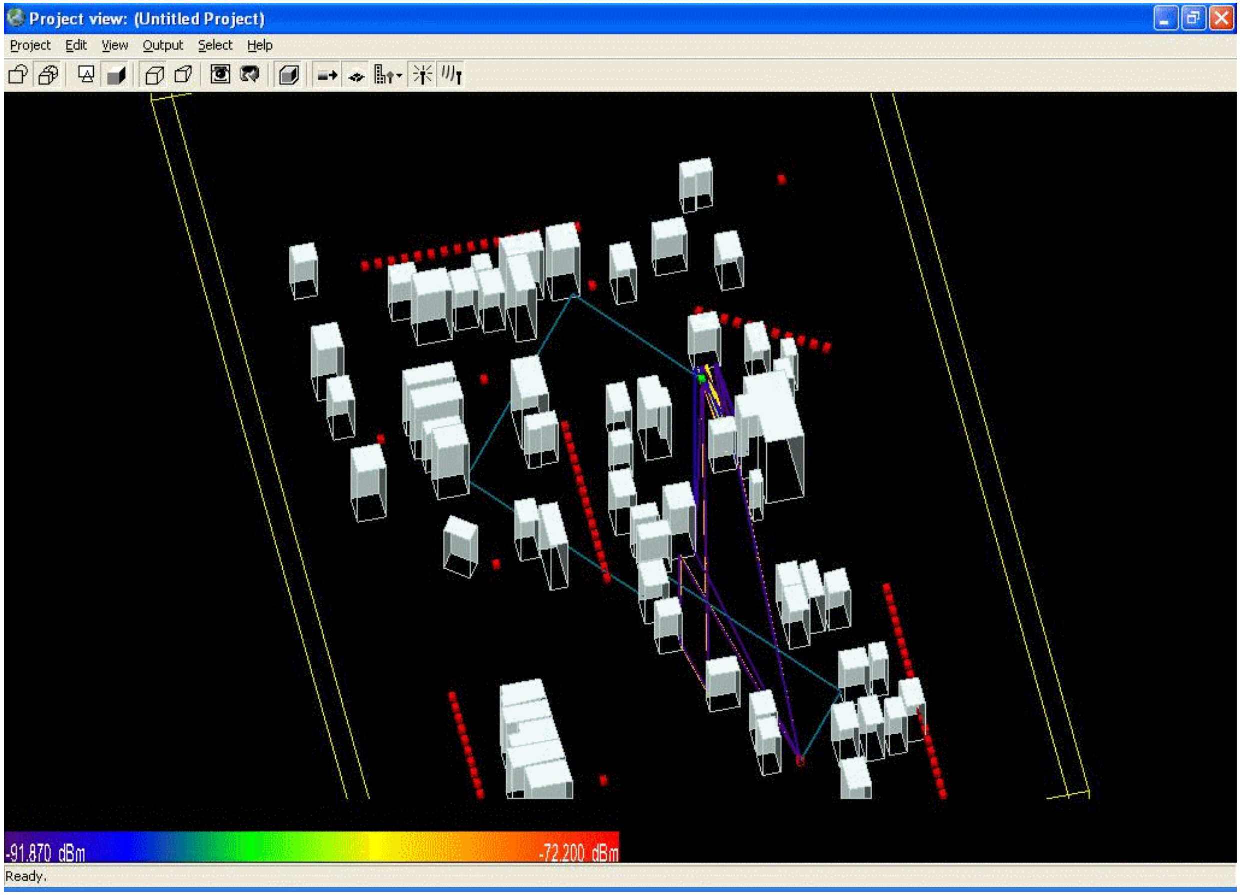
- Information transport infrastructure enables integration of:
  - Sensors
  - Networks
  - Decision aids
  - Weapons
  - Warriors
  - Supporting systems

Analysis: Will the mission comm requirements be satisfied at the required QoS as the network moves from shipboard to shore and then spreads out over a 50 km^2 area?

Efficient & scalable prediction of AINS technology for network-centric warfare

QoS Management in Urban Areas

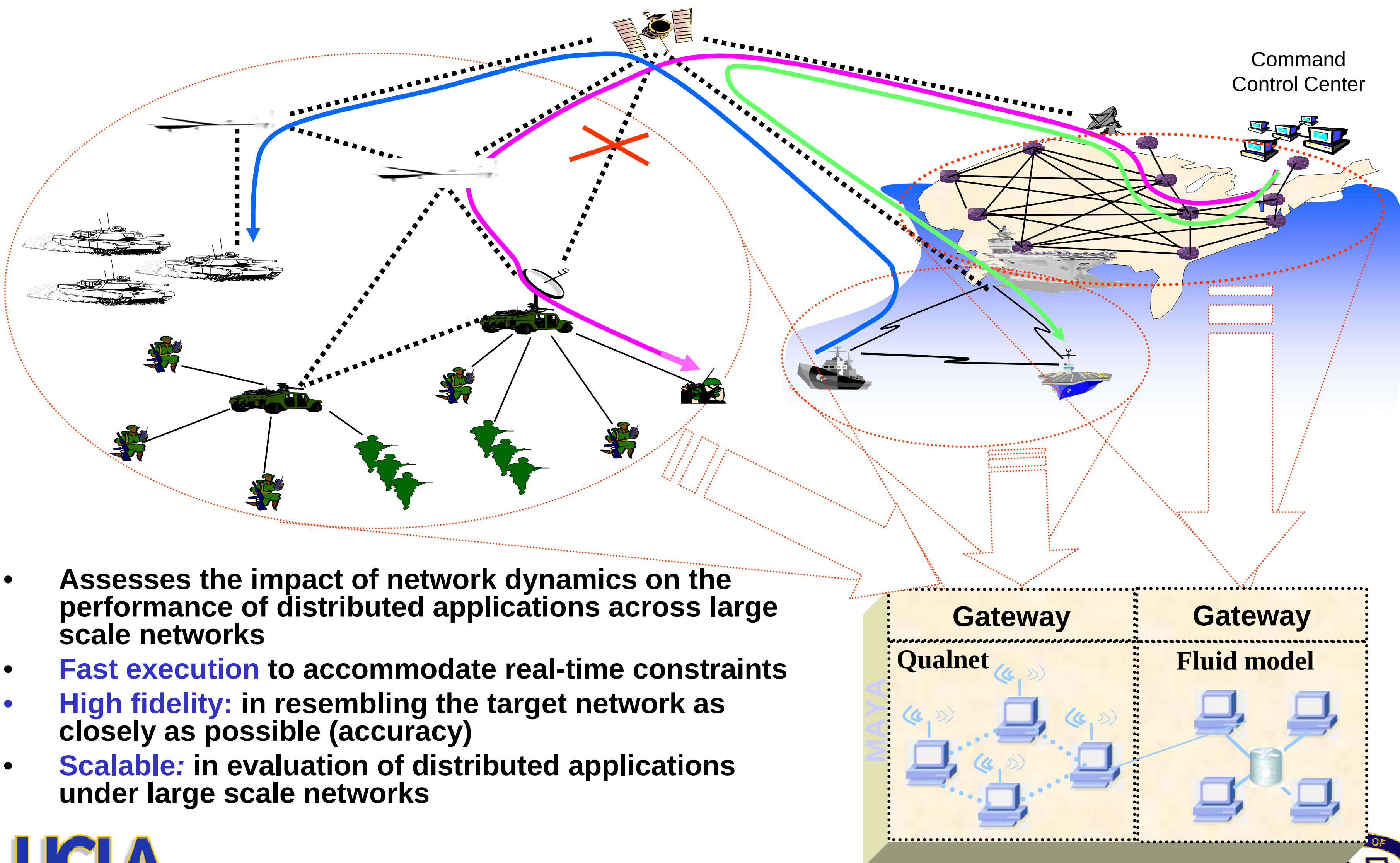
- Analysis of channel conditions due to terrain, buildings and mobility



Motivation

- Net-centricity is a force multiplier for the US military
- The next generation wireless communication technology being developed for this purpose will be adaptive (software-defined radios, smart antennas, programmable networks, …)
- There is substantial 'cross-layer interaction' among the technology solutions at multiple layers of the protocol stack (e.g., medium access, routing, and transport) to provision dynamic Quality of Service among the voice, video, and data traffics that must be carried by such networks
- There is limited experience, in the commercial or military arena, with large scale deployments and use of such on-the-move communication technology
- Static analysis and planning may not be adequate to achieve the dynamically varying Quality of Service requirements for the diverse applications
- Real-time network simulations can play a critical role in assessing the dynamic impact of net-centricity in the design and operation of such networks

A Multi-Paradigm Network Modeling Framework for Performance Prediction of Scalable Networks



- **Assesses the impact of network dynamics on the performance of distributed applications across large scale networks**
- **Fast execution to accommodate real-time constraints**
- **High fidelity: in resembling the target network as closely as possible (accuracy)**
- **Scalable: in evaluation of distributed applications under large scale networks**

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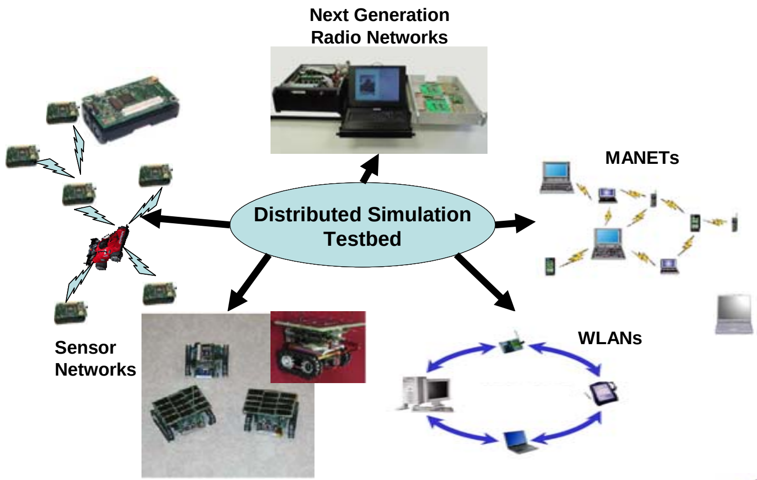
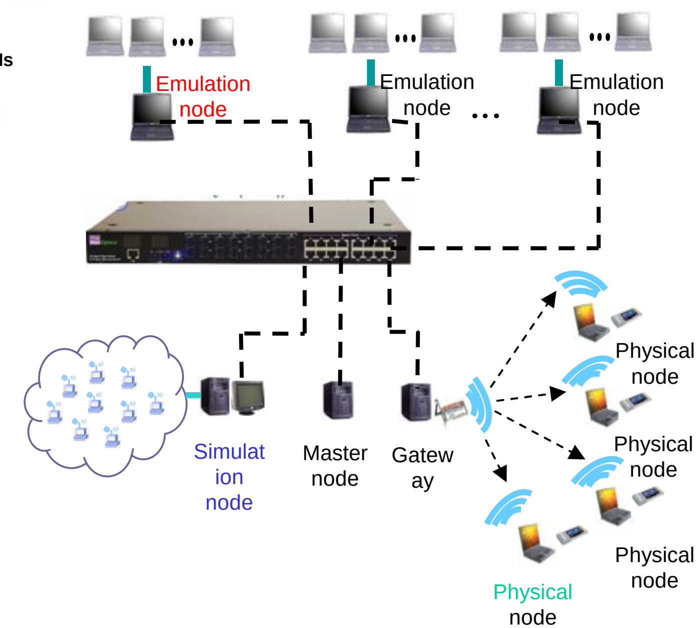
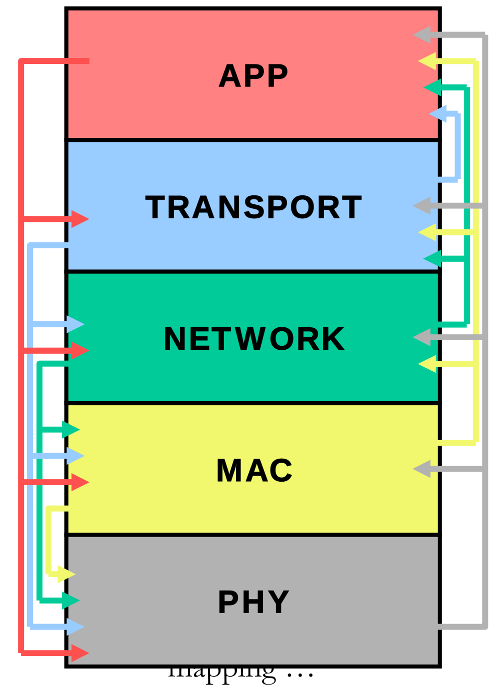
Multi-Paradigm Network Modeling

- Accurate, real time simulation of wireless networks with 00s of mobile nodes
- Comparative evaluation of wireless network performance in networks with 000s of nodes
- Integration of physical, simulated and emulated networks in a single modeling framework





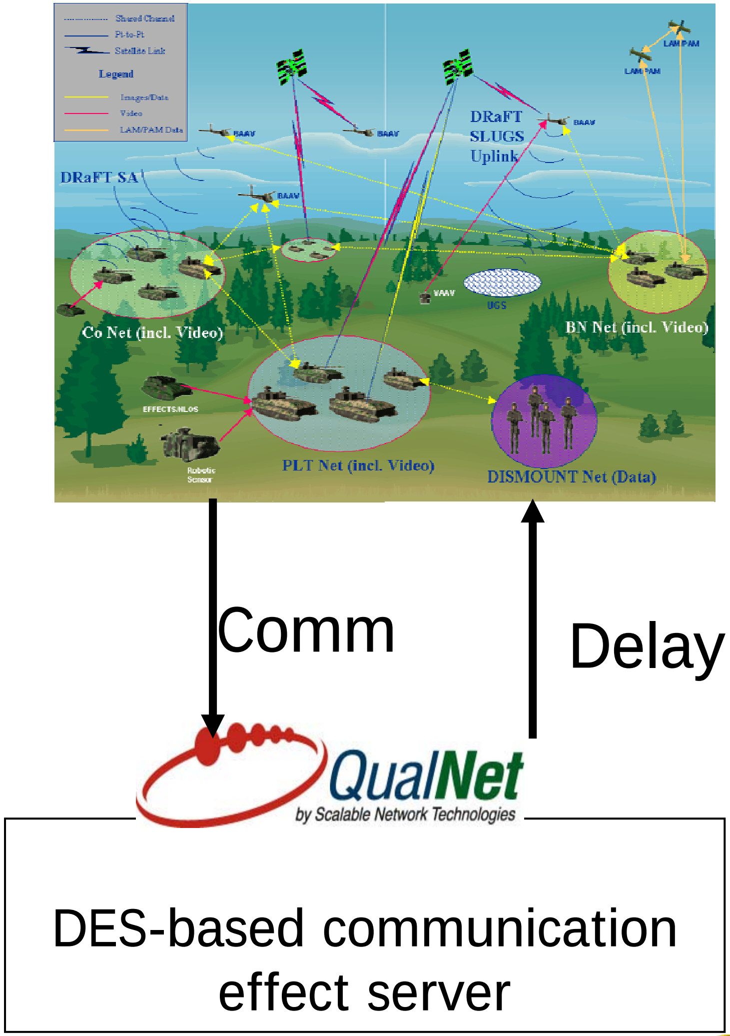


Our Contributions

- Framework for accurate analysis of QoS in scalable AINS networks
- Incorporation of next generation radio, antenna & protocol technologies into QoS planning
- Incorporation of real applications and hardware in analysis framework
- Evaluation of interoperability between heterogeneous wireless networks --legacy & future communications
- Demonstration
  - hybrid simulation capability to predict performance of heterogeneous wireless networks
- Technology transfer:
  - Simulator used as a key technology for communication effects simulation by the FCS LSI in Boeing Huntington Beach.
  - QualNet used for QoS evaluation by CERDEC, Ft Monmouth and SPAWAR, San Diego

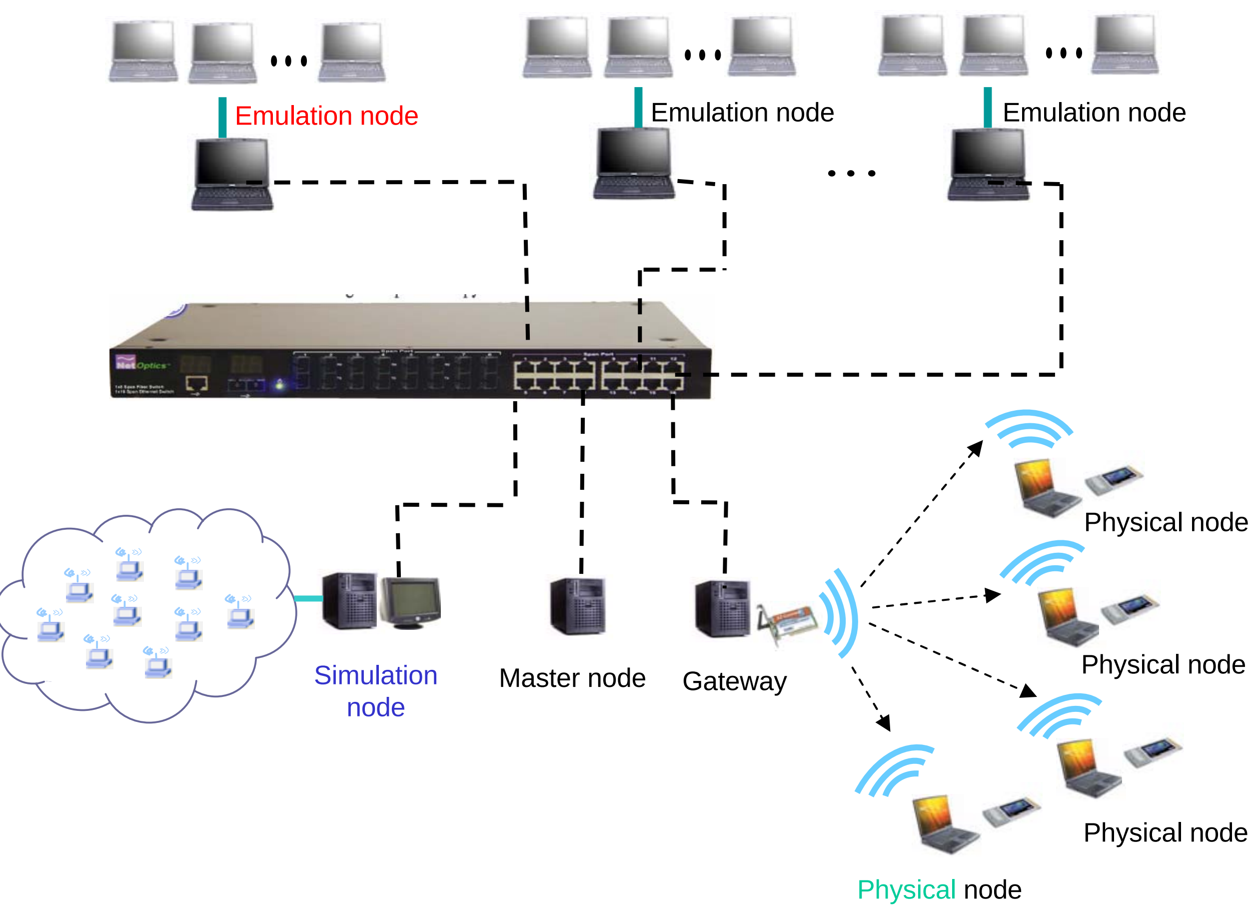
Analysis Framework Transition: FCS Communication Effects Server

- **Technology transitioned into COTS simulator – QualNet**
- **QualNet is being used to develop a Communication Effects Server (CES) for the FCS Program**
  - A discrete-event simulation based CES to incorporate *realistic* communication effects into *virtual* and *constructive* wargaming software environments.
- **FY2004-2006 Objectives**
  - Accurate representation of FCS communication architecture & its interaction with external networks
  - Integration into constructive & virtual simulation frameworks
  - Accurate, real-time simulation of an FCS Unit of Action with 10,000 communicating devices



Steven Goldman, Boeing, IS&T IPT, FCS

Hybrid Testbed: Architecture



Zhou et al, ACM TOMACS Apr 04

Emulation Node
- Emulates multiple wireless hosts

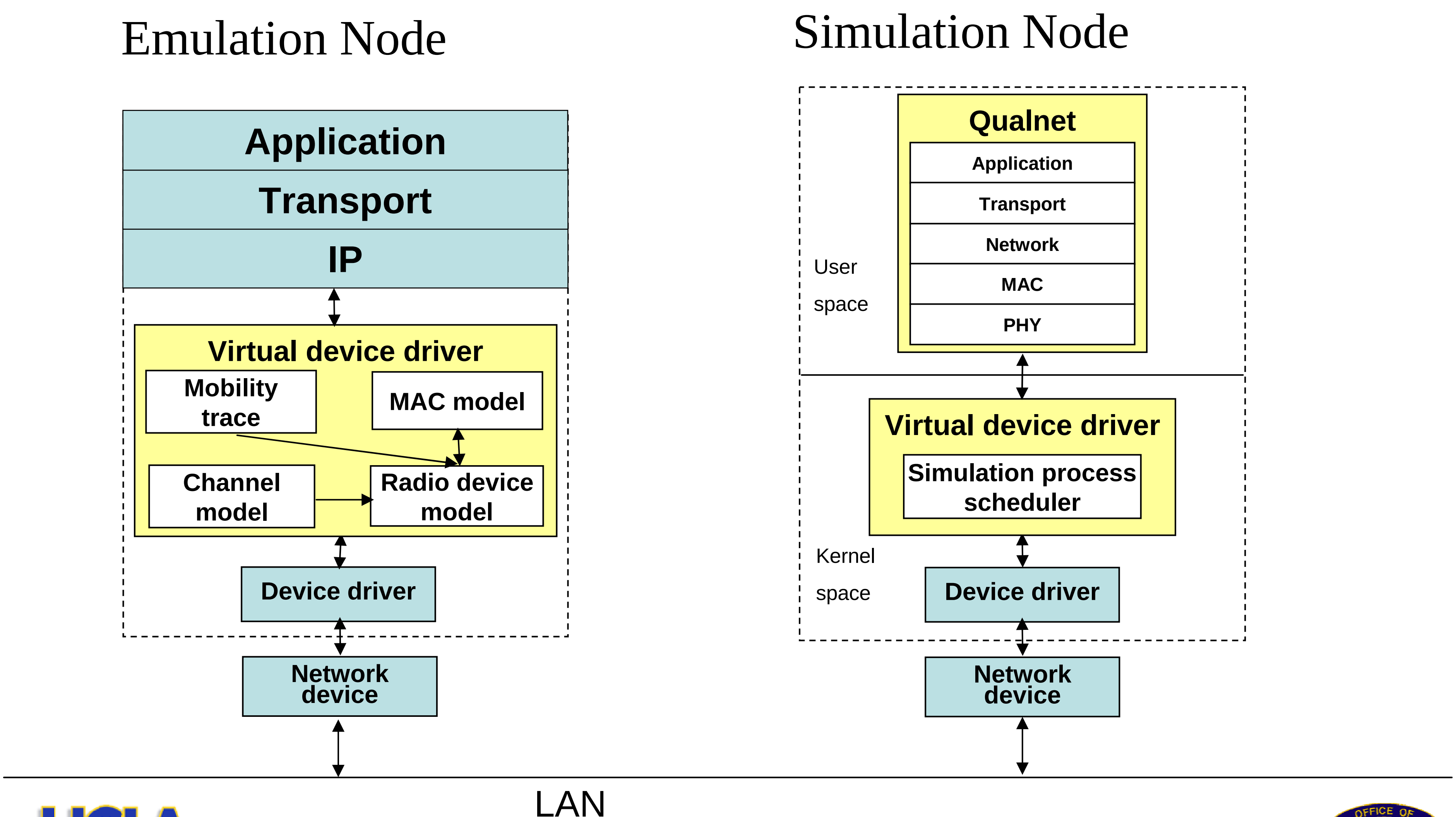
Simulation Node
- Parallel simulation for high-fidelity modeling of a wireless subnet

Physical Node
- Executes entire operational protocol stack

Gateway
- Inter-connects physical networks with simulated and emulated networks

Master node
- Provides global reference time

Interfacing Multi-Paradigm Models

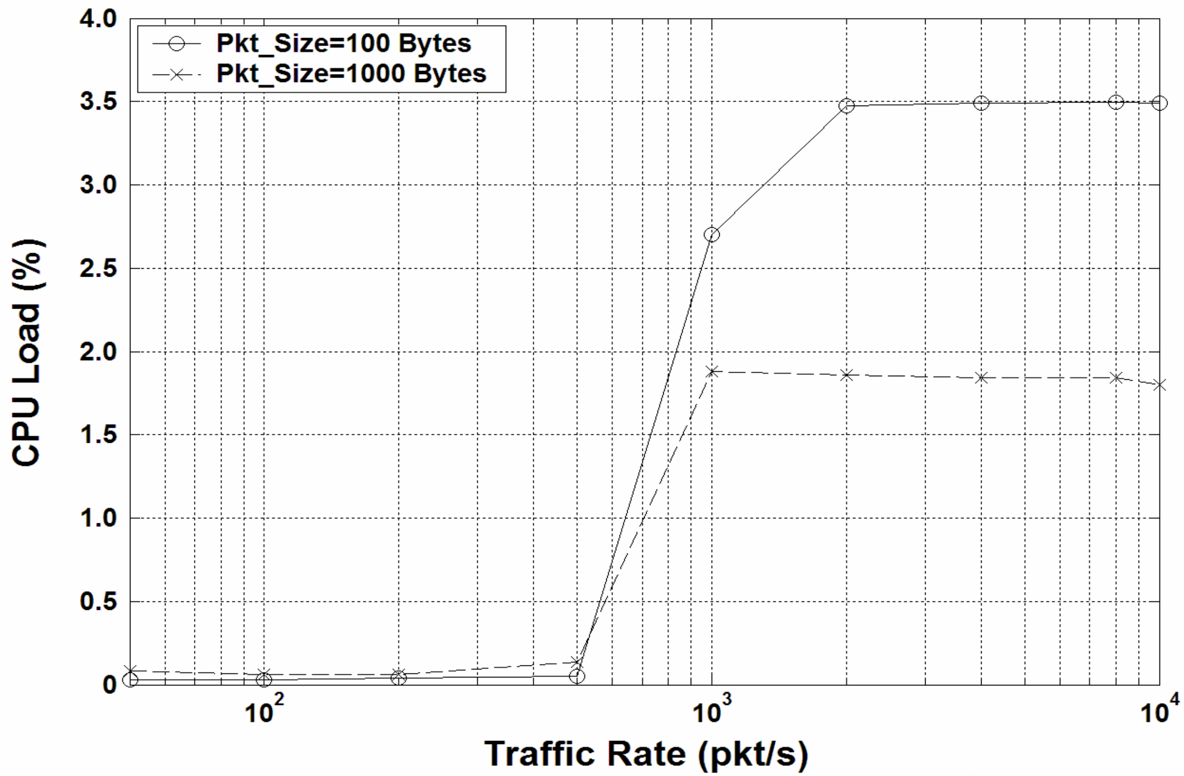


Performance evaluations

- Goals
  - Evaluate CPU overhead of emulation layer
  - Validate application throughput of emulated wireless nodes
  - Evaluate scalability of emulation/simulation entities
- Experiment setup
  - One physical wireless link
  - One emulated wireless link
  - Both links use the following configurations:
    - PHY: 802.11b DSSS, 1,2,5.5, 11Mbps, 2.462GHz
    - MAC: CSMA/CA, RTS required for all data pkts
  - Traffic type: UDP or TCP

CPU overhead of emulation layer (1)

- Setup:
  - Traffic: one backlogged UDP traffic session (fixed pkt length)
  - Data rate: 11Mbps



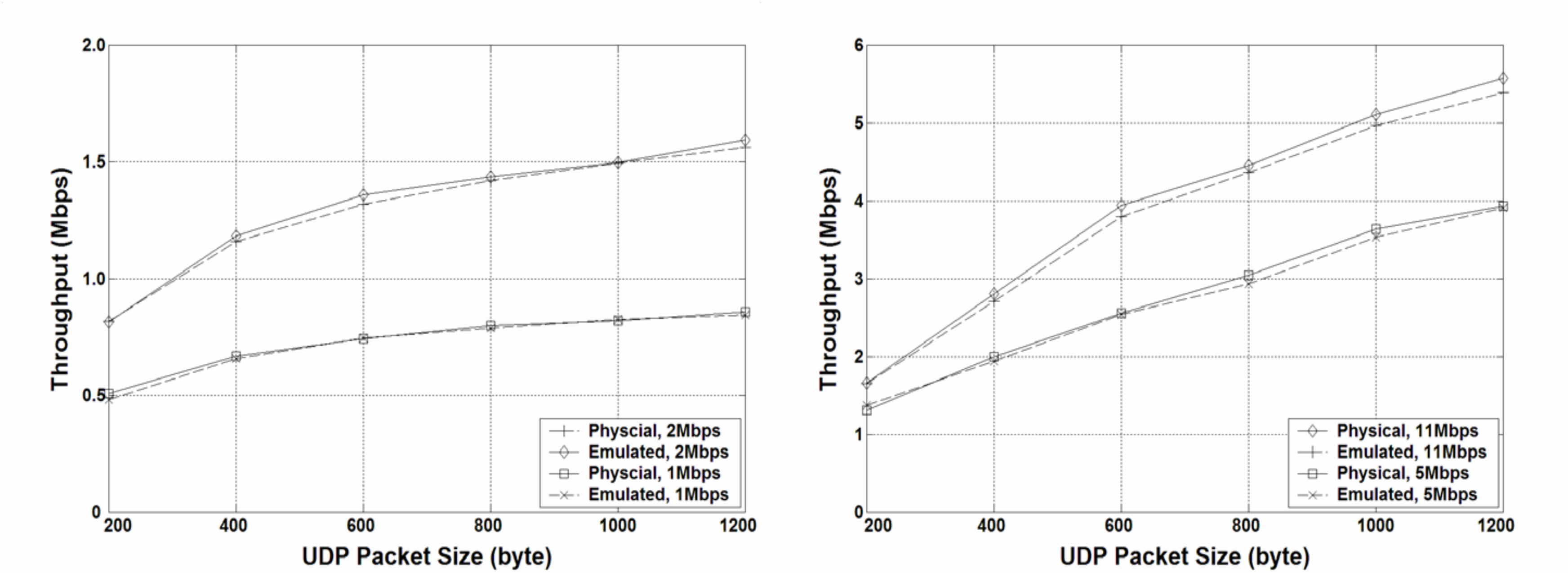
CPU load peaks at 2% or 3.5% with packet size of 1000 or 100 Bytes

CPU overhead of emulation layer (2)

- CPU load peaks at 2% or 3.5% with packet size of 1000 or 100 Bytes
- CPU load stabilizes after the emulated wireless link is saturated
- Small packets incur more processing overhead and result in higher CPU load when the emulated wireless link is saturated

Validation of UDP throughput

- Setup:
  - Traffic: one backlogged UDP traffic session (fixed pkt length)
  - Data rate: 1, 2, 5.5, 11Mbps



- UDP throughput of emulated wireless node closely matches real measurements with less than 5% difference

Validation of TCP throughput

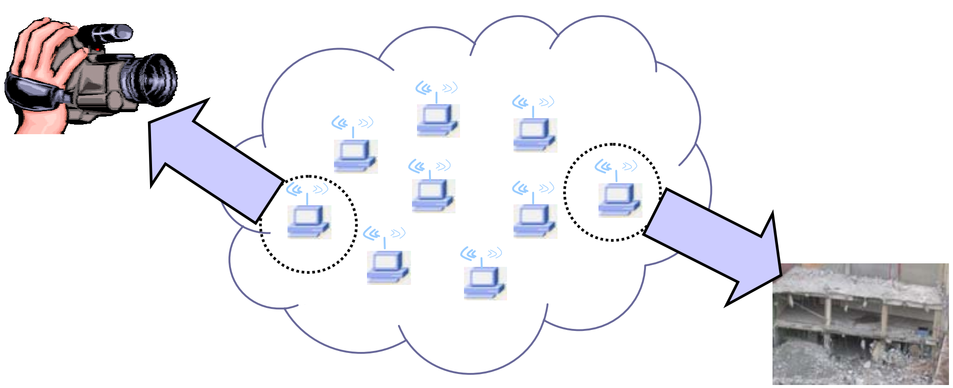
- Setup:
  - Traffic: one file transfer session using scp (secure copy)
  - Data rate: 1, 2, 5.5, 11Mbps

Node type	1Mbps	2Mbps	5.5Mbps	11Mbps
Physical	90.4KB/s	162.4kB/s	332.3kB/s	483.4kB/s
Emulated	89.9KB/s	158.1kB/s	329.5kB/s	480.2kB/s

- TCP throughput difference between emulated and physical wireless nodes is less than 3%
- Contentions between scp source and destination are accurately emulated

Adaptive Video Streaming Performance in Ad Hoc Networks

- Evaluate adaptive video streaming performance in presence of channel fading, congestion and node mobility in ad hoc networks
- Use QStream as a representative *adaptive media application*
  - Optimizes two quantitative measures of video quality along temporal and spatial dimensions
  - Relies on TCP for rate control and drops low priority data during congestion to maintain video quality and timeliness



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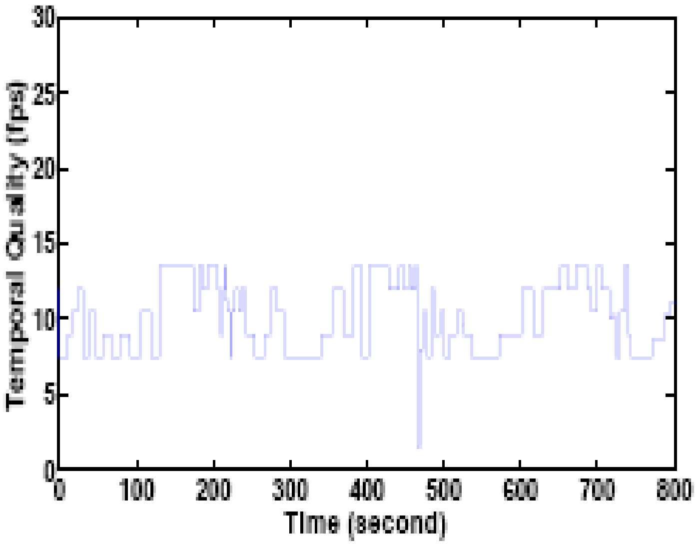
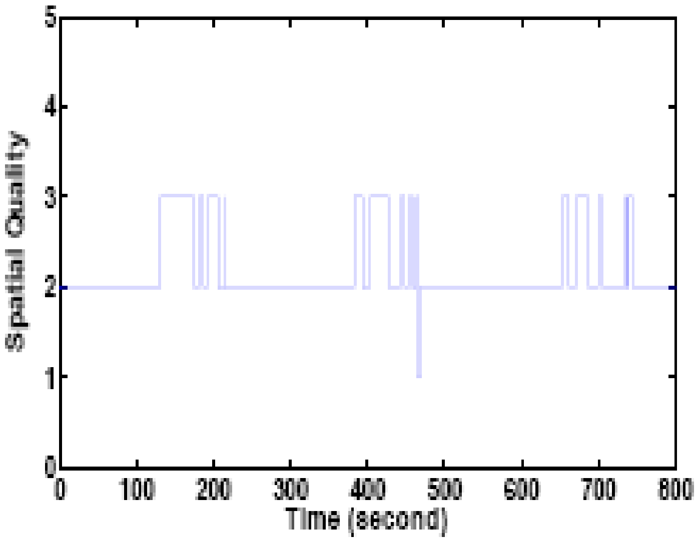
Adaptive Video Streaming Performance in Ad Hoc Networks

- Hybrid testbed usage – emulated wireless hosts running QStream communicating with each other over a simulated ad hoc network
- Observed complete *lack of correlation between perceptual and quantitative metrics*, especially with node mobility



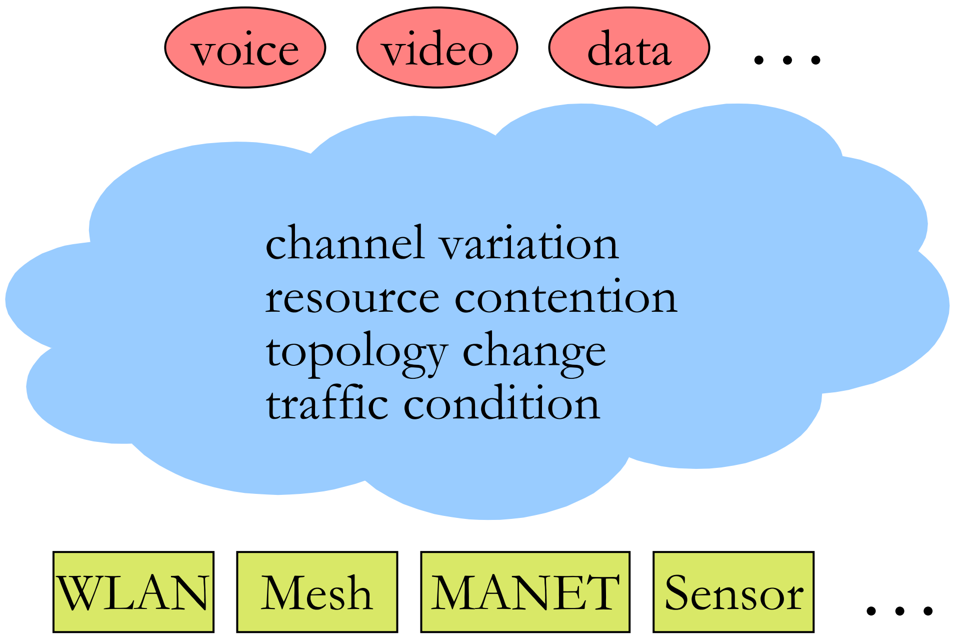


QoS Techniques

Wireless QoS

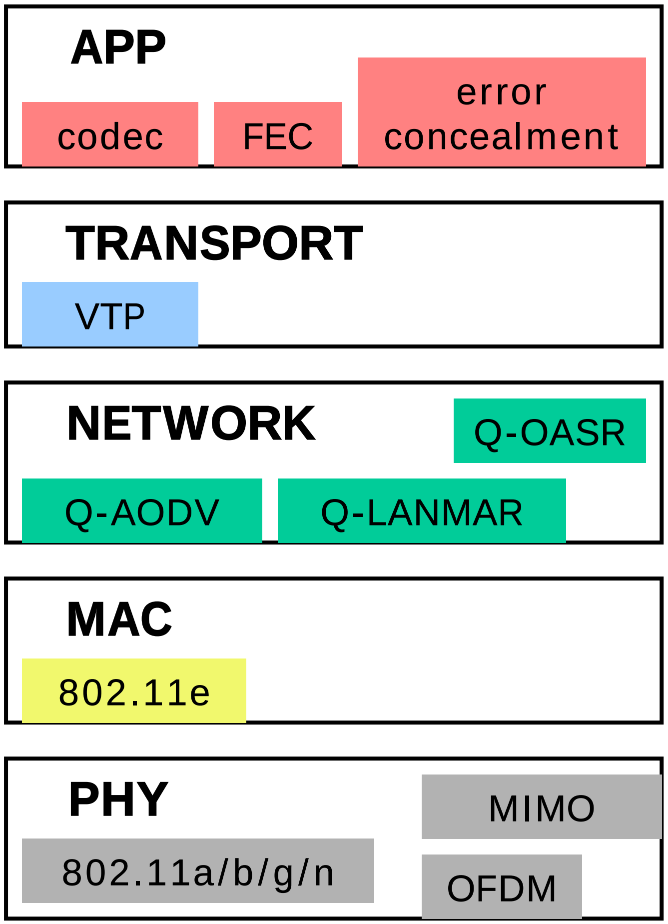
- Support Quality of Service (QoS) communication in wireless environments

- Challenges
  - Differing application requirements
  - Different types of networks
  - Dynamic network behavior



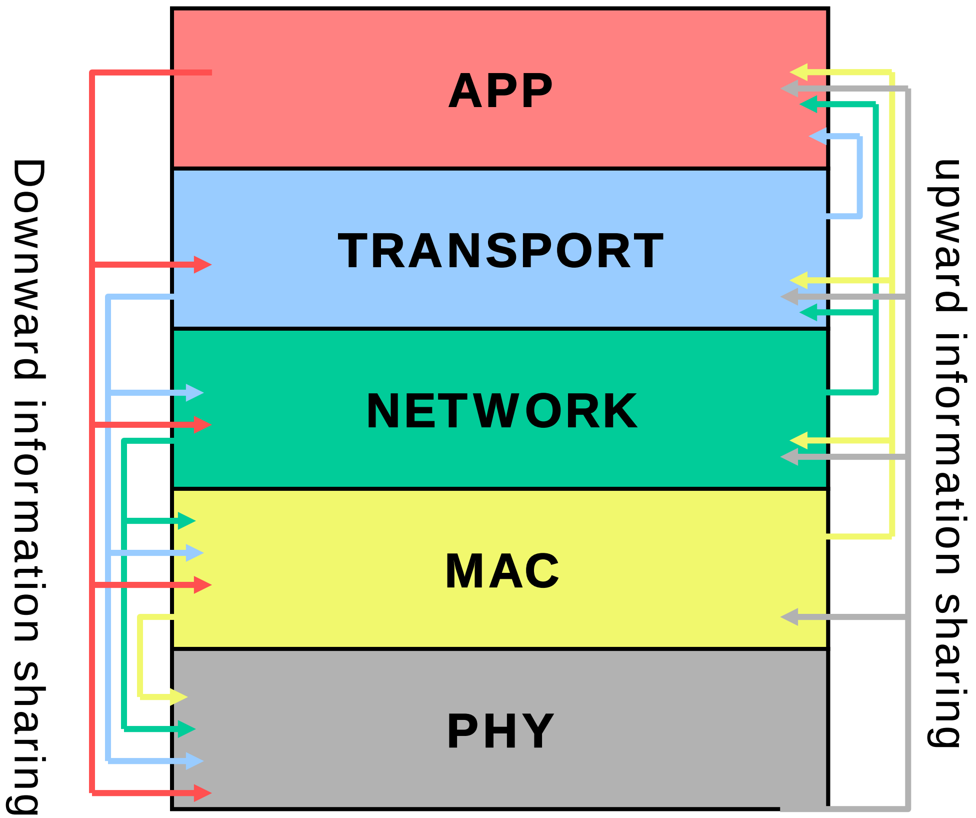
Traditional Paradigm

- Each layer is independently designed
  - Lack of information sharing
  - Assume worst conditions
- Network runs in a less than optimal mode



Design Methodology
Cross-Layer Optimization

- Information is shared among application and lower layers
- QoS control is addressed at all layers
  - Network responds to different QoS requirements
  - Application and network adapts to channel quality, traffic conditions, topologies, …



Experimental Evaluation of 802.11 Rate Adaptation Algorithms

Motivation

- Wide adoption of 802.11-based wireless LANs (WiFi)
  - 802.11b,g,a,e,n,…
- Two emerging trends leveraging 802.11 success
  - Community wireless mesh networks (e.g., MIT Roofnet) for low-cost Internet access everywhere
  - High performance next-generation WLANs based on MIMO, driven by interest in multimedia distribution and data networking in the home
- A key challenge: higher throughput and wider reliability for greater QoS
- PHY rate adaptation in 802.11-based networks has a large influence in meeting this challenge
  - Adapt to varying channel conditions as per application requirements
  - Left to the equipment manufacturers in 802.11 MAC/PHY specification; same applies to 802.11n proposals
- Our motivating application – wireless IPTV for live/stored video programming to the home

802.11 Rate Adaptation Algorithms

- FER-based schemes (e.g., Onoe, SampleRate)
  - Indirectly estimate channel based on frame error rate measurements (or a related measure)
  - Depending on aggressiveness, can be inefficient or unreliable
    - Unreliability leads to packet losses; hurts multimedia performance, especially with ARQ
    - Can misinterpret collision losses for channel losses
- SNR-based schemes (e.g., RBAR, OAR)
  - Use more direct channel quality estimation such as SNR; so can be efficient and reliable if the channel is well-characterized
  - May not be robust across channel environments since thresholds for rate selection are based on a channel model chosen *a priori*
  - Only simulation-based evaluations
- Our goal: Evaluate real-world performance of FER-based and SNR-based schemes in a common setting
- Present initial results for comparison of two representative FER-based schemes: Onoe and SampleRate

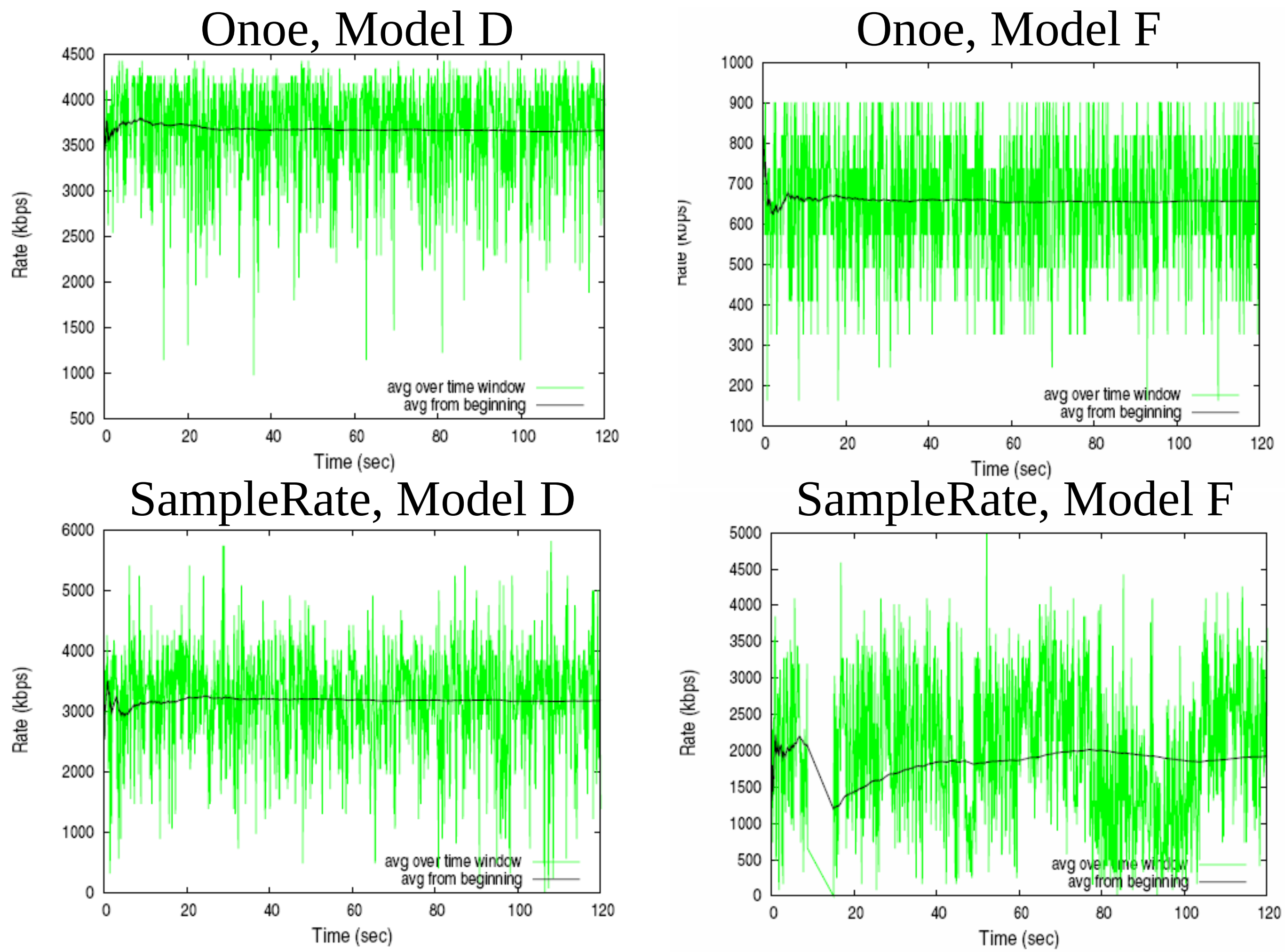
Representative FER-Based Schemes

- Onoe (default in atheros cards)
  - Find the highest rate with less than 50% loss rate
    - Maintain credits for the current rate on each link – incremented in absence of frame loss, decremented on retransmissions
    - Move to next highest data rate, when "sufficient" credits accumulated
    - Move to next lowest data rate on persistent frame losses
- SampleRate (Bicket, MIT Master's Thesis 2005; Mobicom 2005)
  - Find the rate with the smallest average packet transmission time
    - Periodically probe data rates other than current rate to estimate average transmission time; only promising subset of alternate rates are probed to keep overhead low
  - For high throughput in lossy environments, exploits the fact that rate giving highest throughput may also incur significant losses
- Both Onoe and SampleRate optimize throughput, but with different levels of aggressiveness

Experimental Methodology

- Channel emulator for application-level performance evaluation
  - Repeatable & real-time experimentation with different channel environments
  - Allows use of real applications running on wireless devices with real 802.11 network interfaces
- 802.11 TGn channel models
  - Model B (15 ns rms delay spread) – home environment
  - Model D (50 ns rms delay spread) – indoor environment, non-line-of-sight (NLOS) conditions
  - Model F (150 ns rms delay spread) – large open space (indoor and outdoor), NLOS conditions
- 802.11 cards based on Atheros chipsets, and open source madwifi driver
- MGEN/DREC for UDP traffic generation and statistics logging

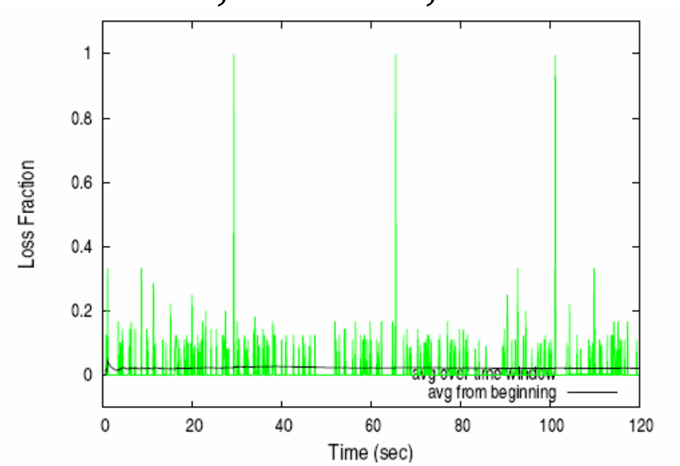
Impact of Channel Environment



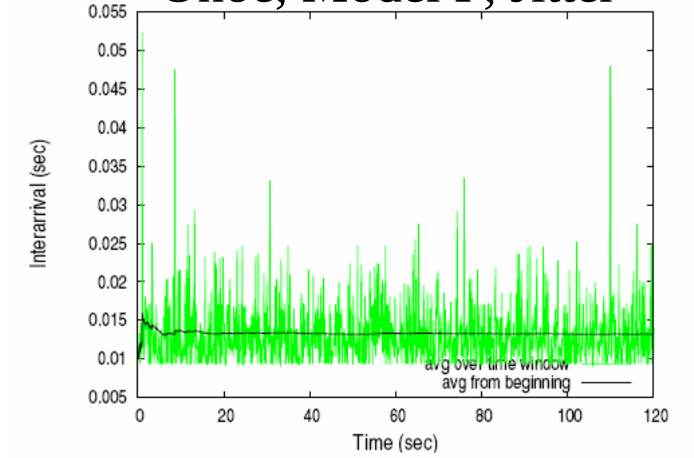
- Throughput with SampleRate 15% lower than Onoe for model D, but 3x greater for model F.

Loss Rate and Jitter Performance

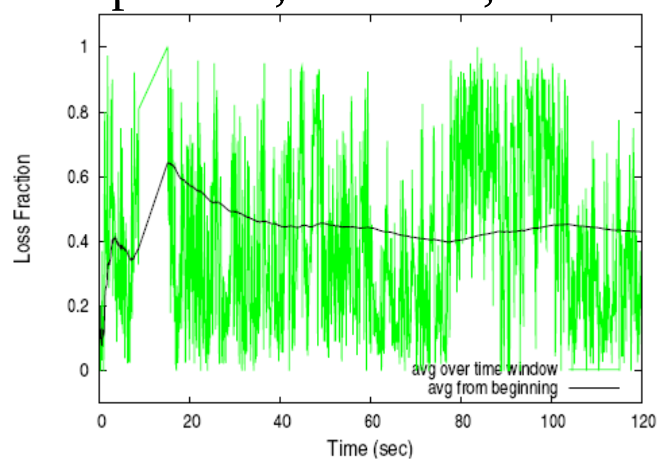
Onoe, Model F, Loss Rate



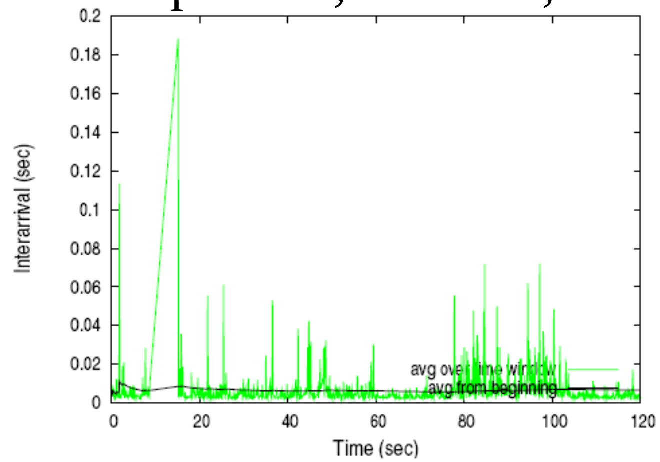
Onoe, Model F, Jitter



SampleRate, Model F, Loss Rate



SampleRate, Model F, Jitter



- Loss rate with SampleRate 20x worse than Onoe for model F; it also has larger jitter (~4x difference in scale)

Challenge

Online mission-level QoS management

- faster than real time analysis o target network via multi-paradigm models

- Replicated & distributed model instances for analyzing multiple target network configurations