
Realtime Multimedia Transport using Multiple Paths

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Sponsored by:

NSF, CATT, and WICAT

Outline

- Motivation
- Video transport over ad hoc networks
 - Using multistream video coding and multipath transport
 - A multipath video testbed for ad hoc networks
- Optimal traffic partitioning:
 - minimizing the end-to-end delay and resequencing buffer size
- The Multi-flow Realtime Transport Protocol
- Analyzing a GPS system

Motivation

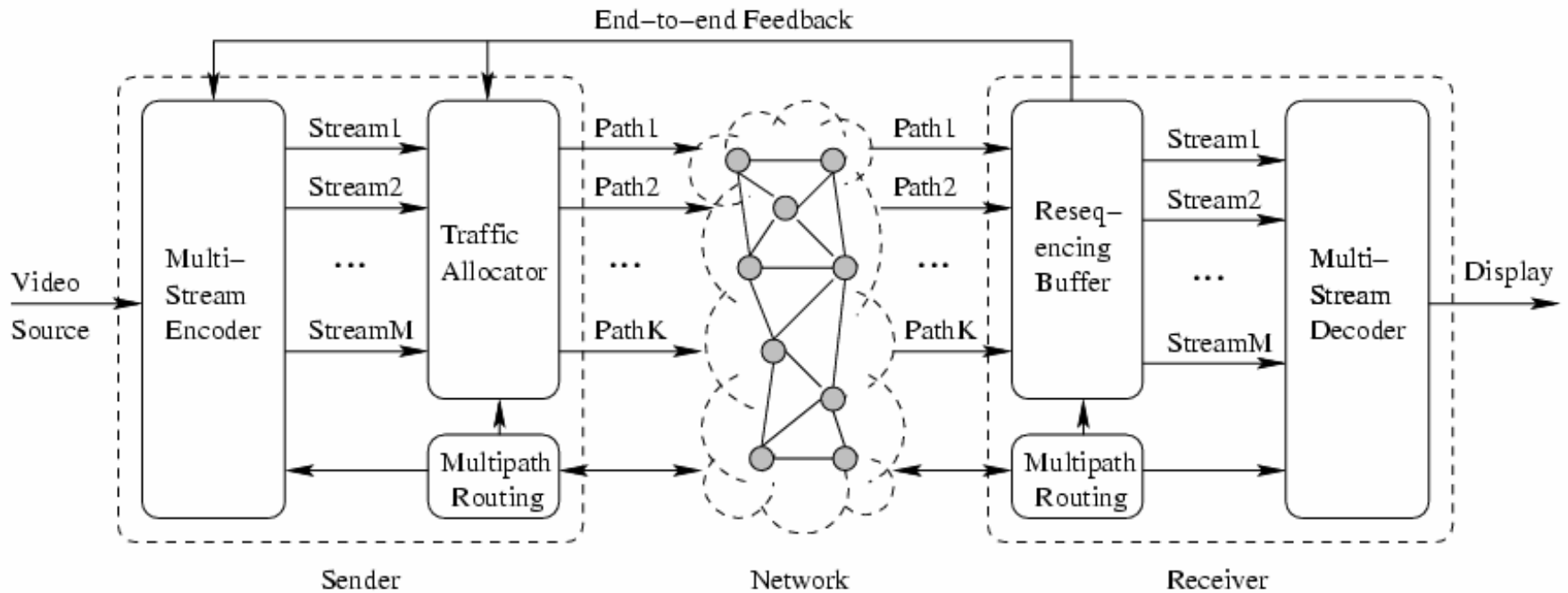
- Realtime multimedia services have stringent bandwidth, delay, and loss requirements:
 - receiver displays the received data continuously.
- The current best-effort Internet has no QoS guarantees
 - IP is best-effort
 - TCP is not suitable for realtime service,
 - UDP is non-adaptive, susceptible to congestion
- Wireless mobile ad hoc networks:
 - frequent link failures and topology changes
- Other types of networks (proxy servers and peer-to-peer networks):
 - Server failures, resulting in interrupted display

Motivation (ctd)

- Multipath Transport (MPT) provides a means to ameliorate the above problems:
 - ❑ Load balancing inside the network
 - ❑ Load balancing among the servers
 - ❑ A larger aggregate capacity for a video session
 - ❑ Path diversity, better error resilience
 - ❑ Robust to single server failure
 - ❑ Traffic partitioning reduces the short range correlation of the realtime flow, resulting in a better queueing performance
- Benefits obtained at limited costs on:
 - ❑ An increased computational complexity
 - ❑ Higher network traffic load

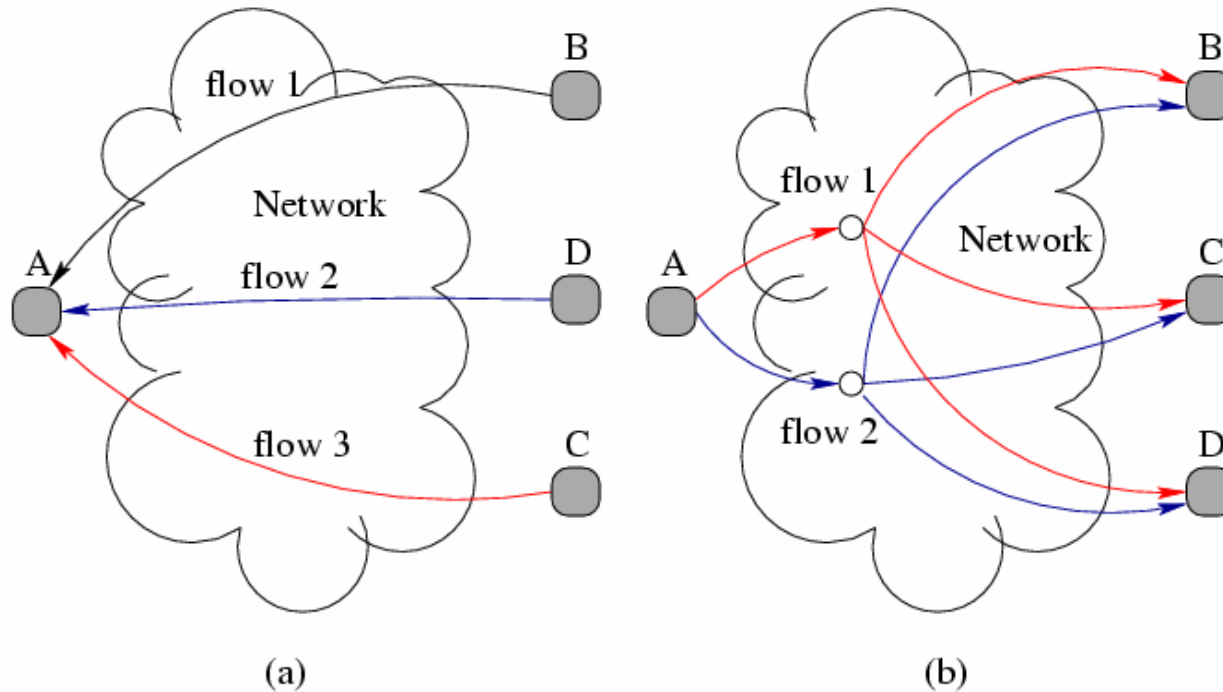
Reference Architecture

- Four key components: (i) multistream video coding, (ii) traffic allocator, (iii) resequencing buffer, and (iv) multipath routing



Reference Architecture (ctd)

- Generalized multipath transport:
 - Parallel downloading,
 - Live multicasting using multiple multicast trees





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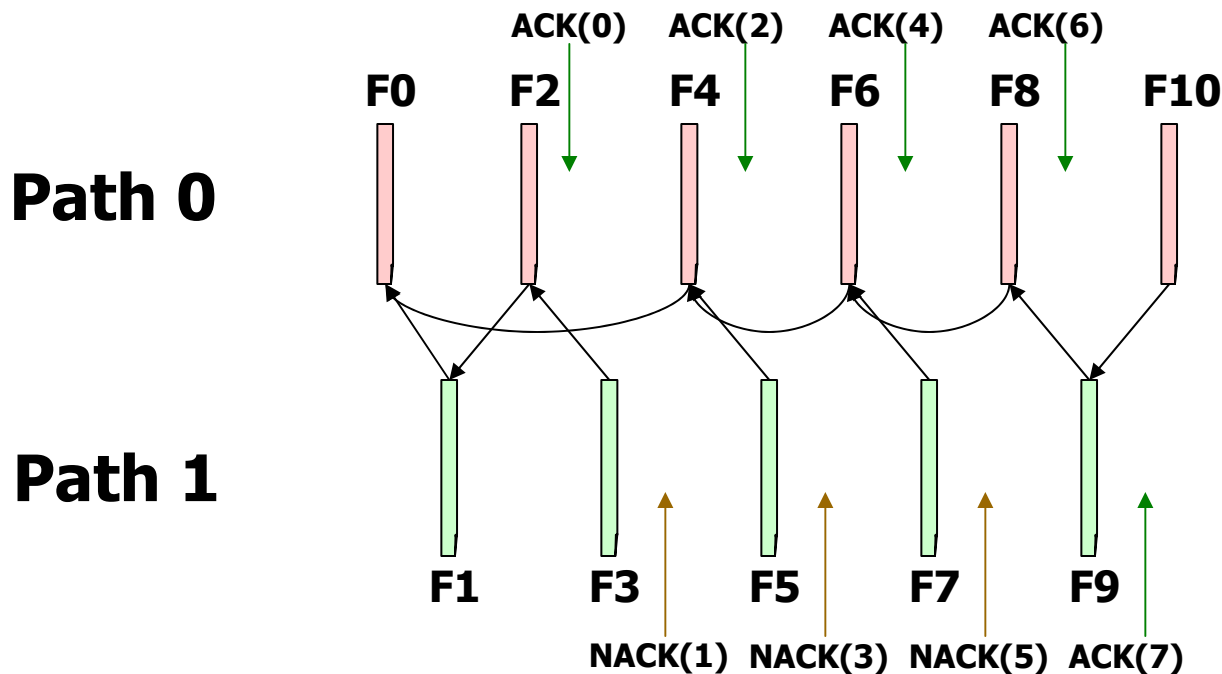
Part I: Video over Ad Hoc Networks

- Wireless mobile ad hoc networks:
 - ❑ Lack of infrastructure
 - ❑ Multi-hop wireless paths
 - ❑ Mobility makes links continuously broken and established
- Link failures:
 - ❑ Cause packet losses
 - ❑ Interrupt the continuous video display
- Congestion:
 - ❑ buffer overflow
 - ❑ False link failures, trigger route discovery, which intensifies the congestion



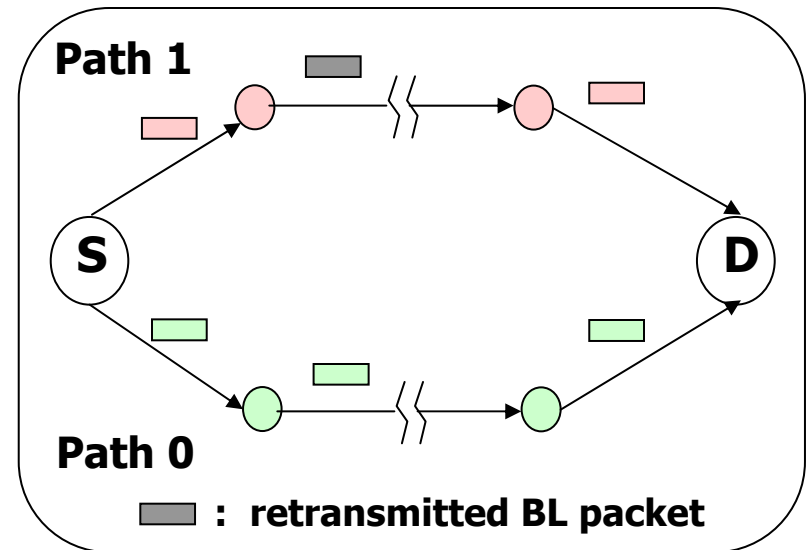
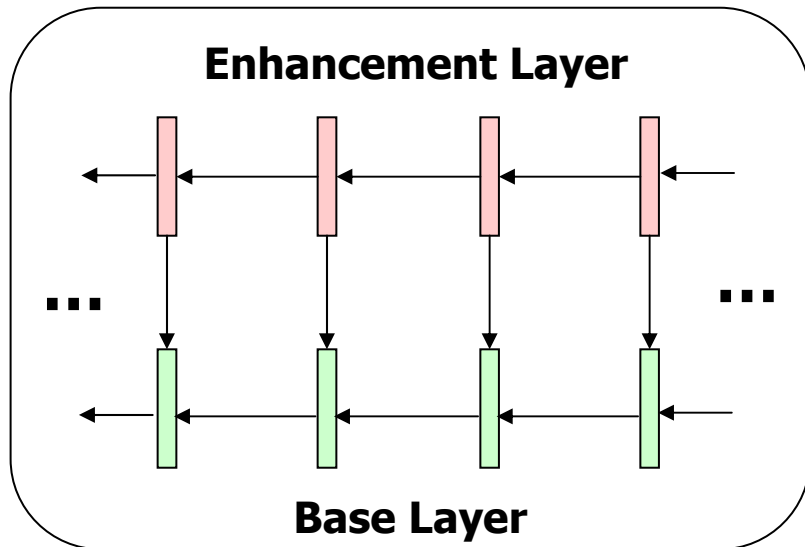
Video Transport Scheme 1: RPS

- Reference picture selection [ICME01]
 - Even/odd frames sent on separate paths
 - The encoder keeps K recently encoded frames
 - Predict damaged frames based on NACK on each path
 - Use undamaged frames as reference pictures



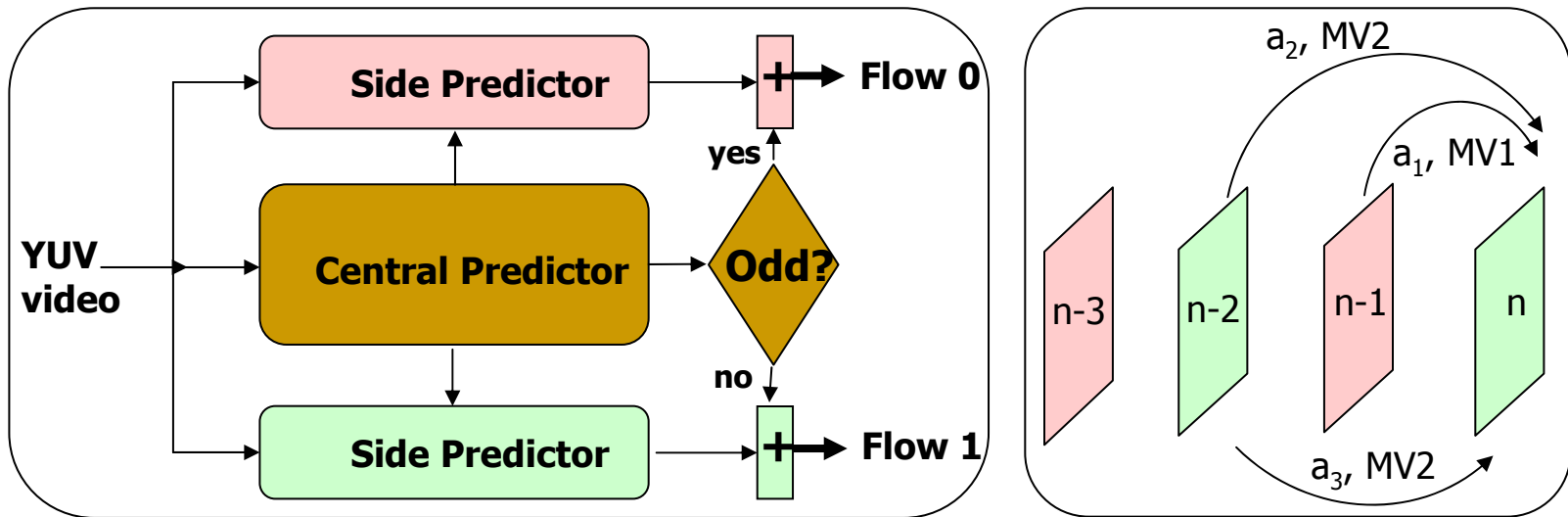
Video Transport Scheme 2: LC with ARQ

- Layered coding with constrained ARQ [VTC-F01]
 - Video is coded into two layers: base layer and enhancement layer
 - Base layer is sent on the better path, enhancement layer the other
 - Lost packets in the base layer are retransmitted over the enhancement layer path
 - A simple rate control on the enhancement layer



Video Transport Scheme 3: MDMC

- Multiple description Motion Compensation (MDMC) [CSV02]
 - Even/odd frames sent on separate paths
 - Each frame is predicted from the previous two frames
 - Mismatch in prediction (when only a single description is received) is coded explicitly
 - Redundancy controlled by the predictor and the quantizer for mismatch signal and can be adjusted based on channel loss statistics

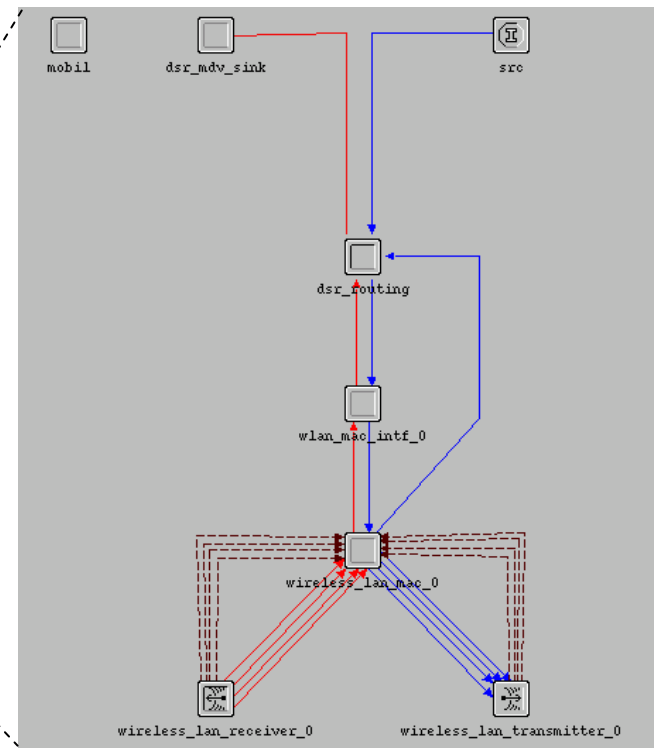
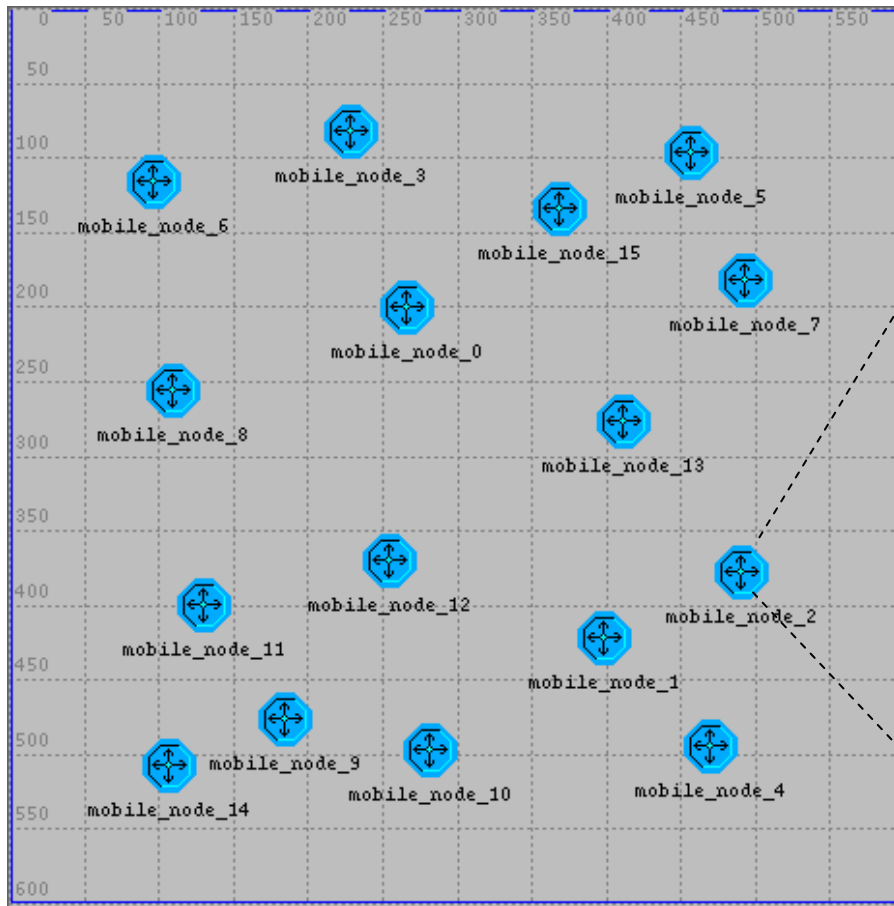


OPNET Models

- Parameters
 - 16 nodes, 600m by 600m
- Multipath routing DSR (MDSR):
 - An extension of the Dynamic Source Routing (DSR) protocol, maintains two maximally node-disjoint routes
- IEEE 802.11 MAC:
 - No RTS/CTS, 7 retransmissions if there is collision
 - Transmission range=250m, 1Mbps channel
- Mobility model:
 - Random Waypoint model, but with constant speed (no convergence problem)

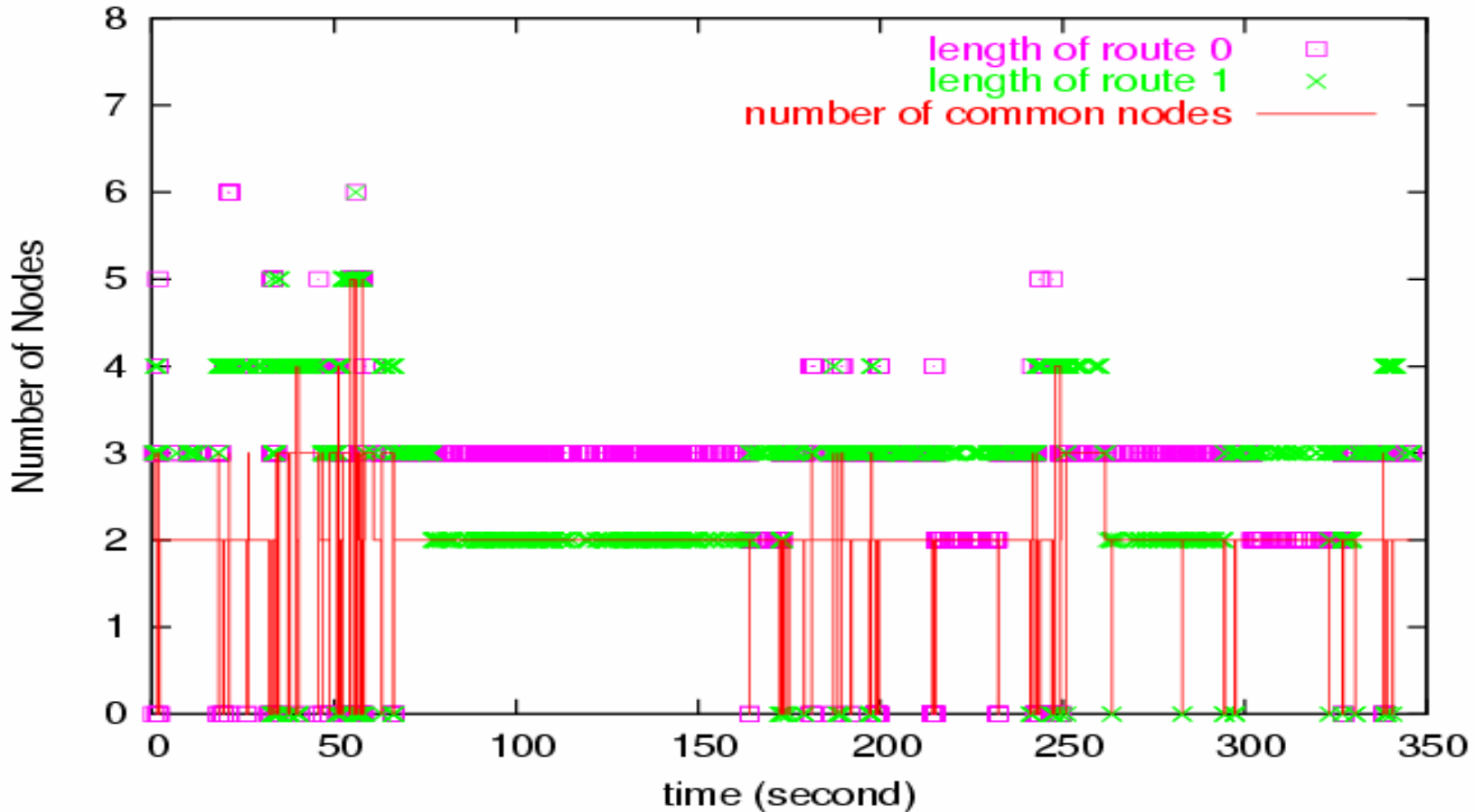
OPNET Models (contd)

- A 16-node wireless ad hoc network:



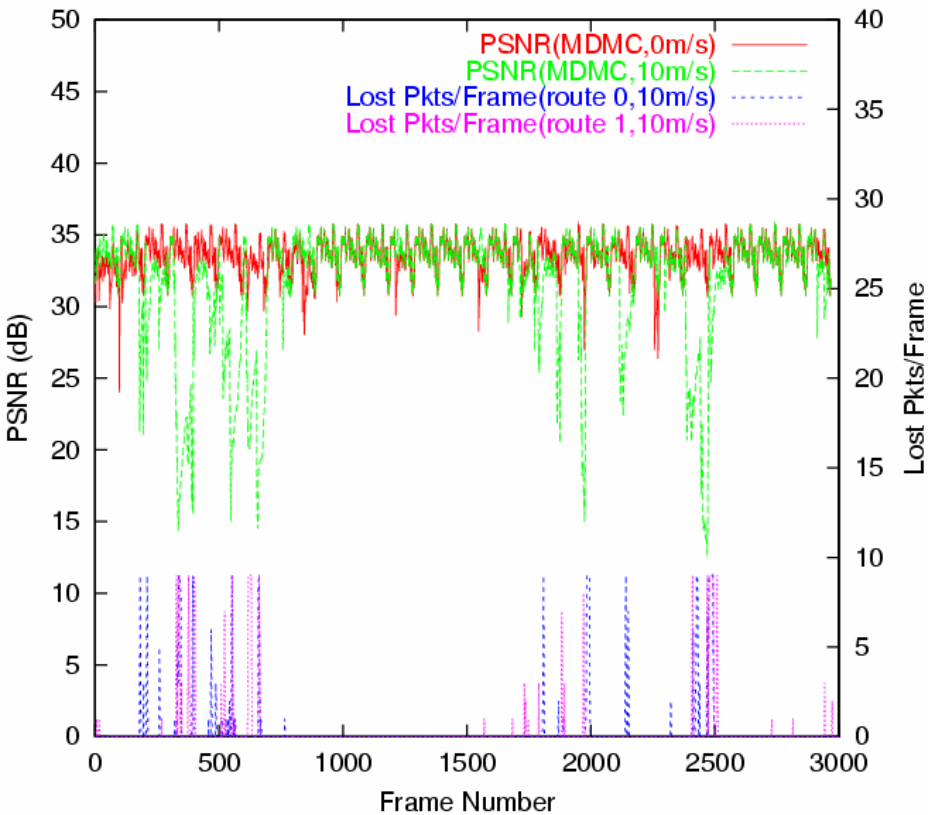
MDSR Performance

- 16 nodes, 600m by 600m, 10m/s, trans. range=250m:

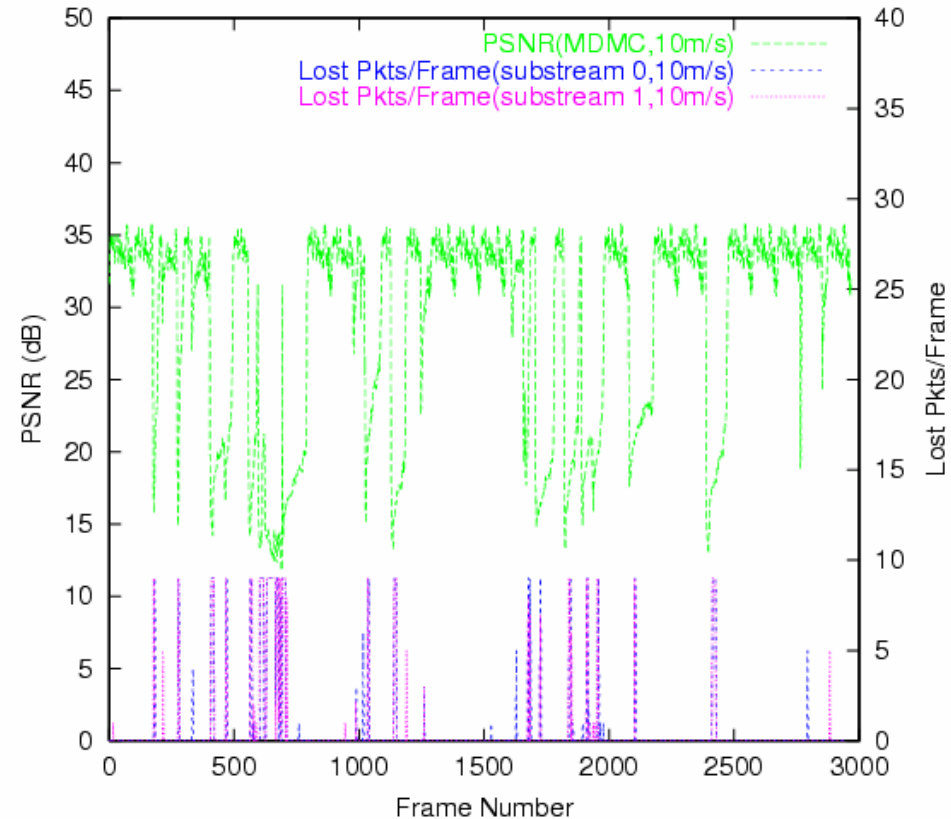


OPNET Simulation Results

- 16 nodes, 600m by 600m, 0 or 10m/s, trans. range=250m, MDMC codec:



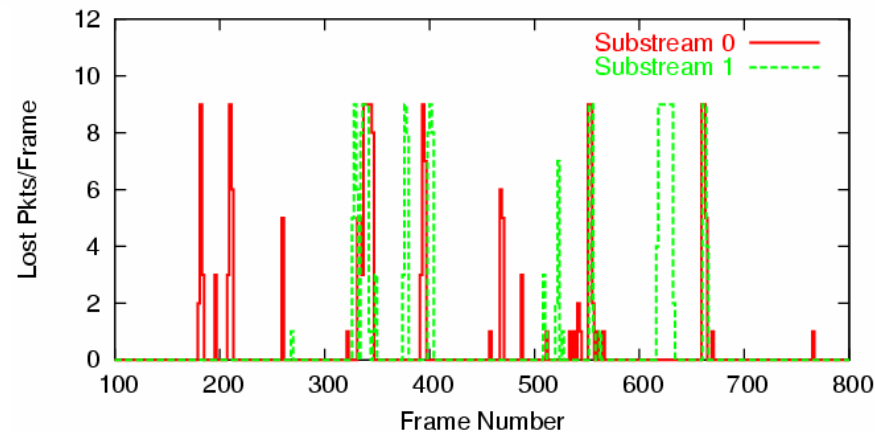
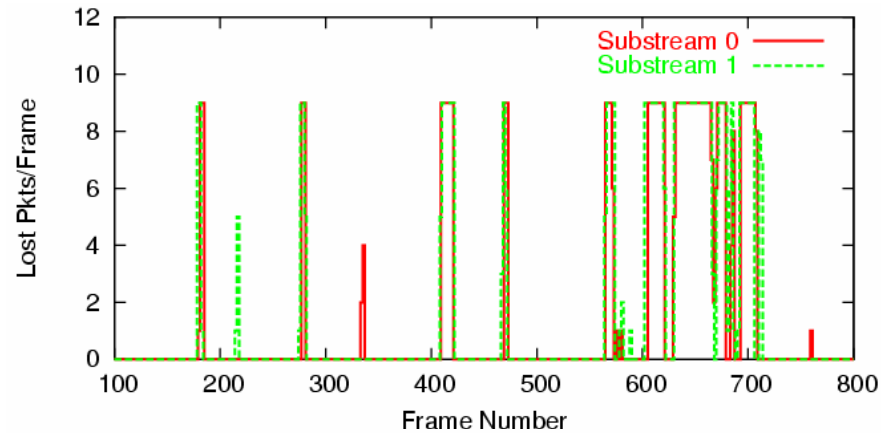
Multipath Routing DSR



Single Path Routing DSR

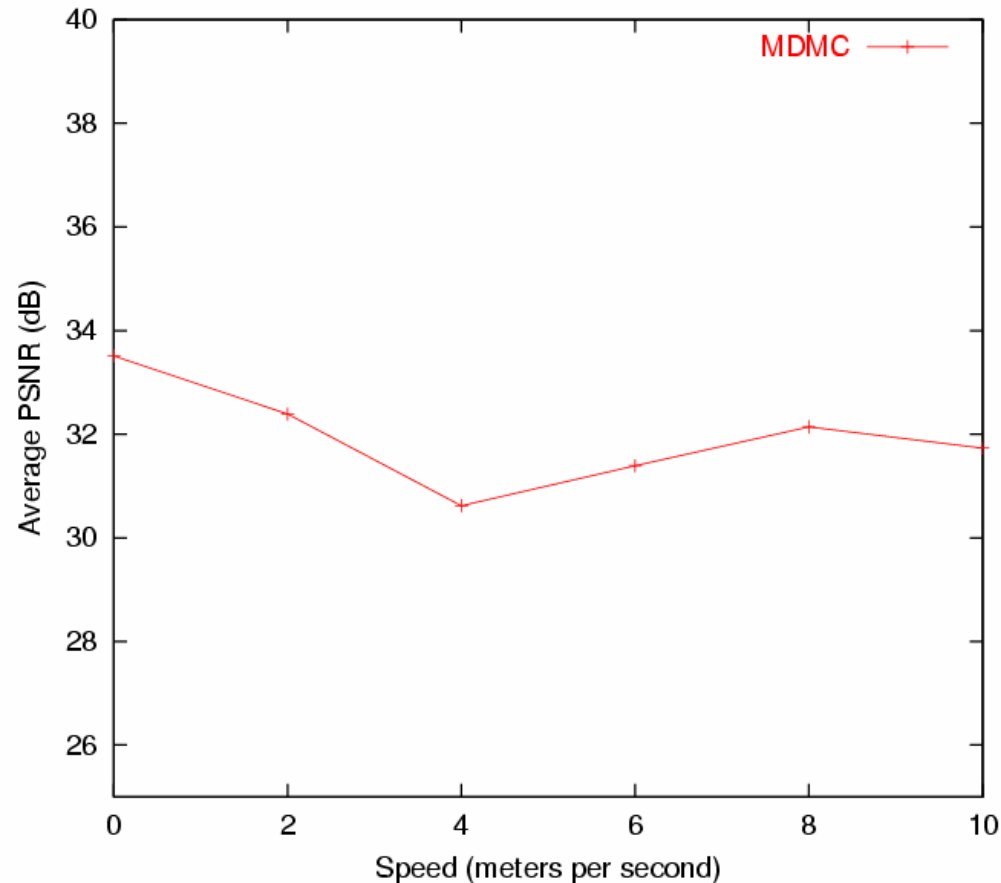
OPNET Simulation Results (contd)

- The error traces of the DSR simulation and the MDSR simulation:



OPNET Simulation Results (contd)

- 16 nodes, 600m by 600m, 0-10m/s, trans. range=250m, multipath routing DSR, MDMC codec:





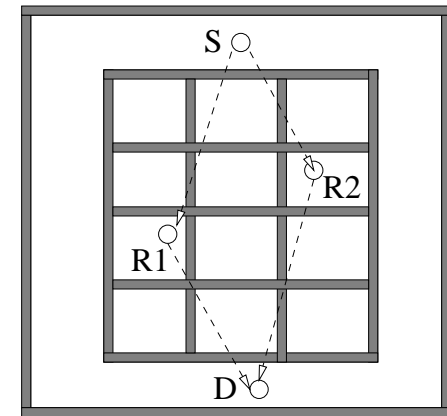
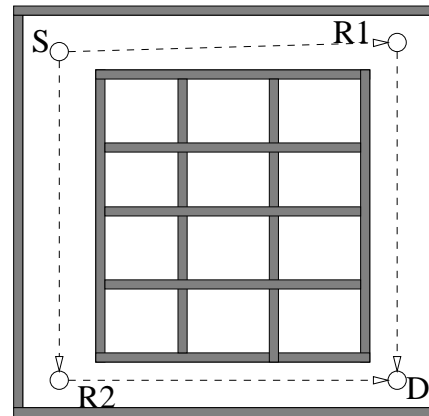
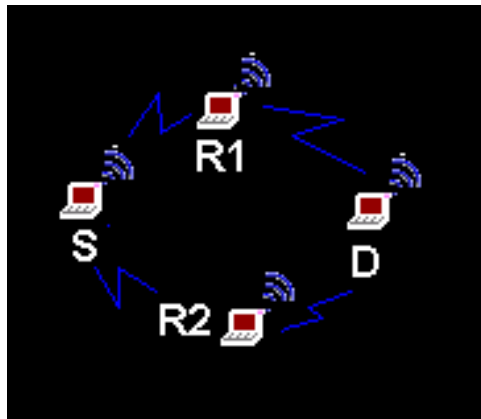
A Multipath Video Streaming Testbed

- Objectives
 - Demonstrate the viability of the schemes
 - Further investigate the pros and cons of the proposed schemes
- Approach:
 - Use off-the-shelf devices
 - Notebook computers
 - IEEE 802.11b cards
 - Microsoft Windows



Testbed: Network View

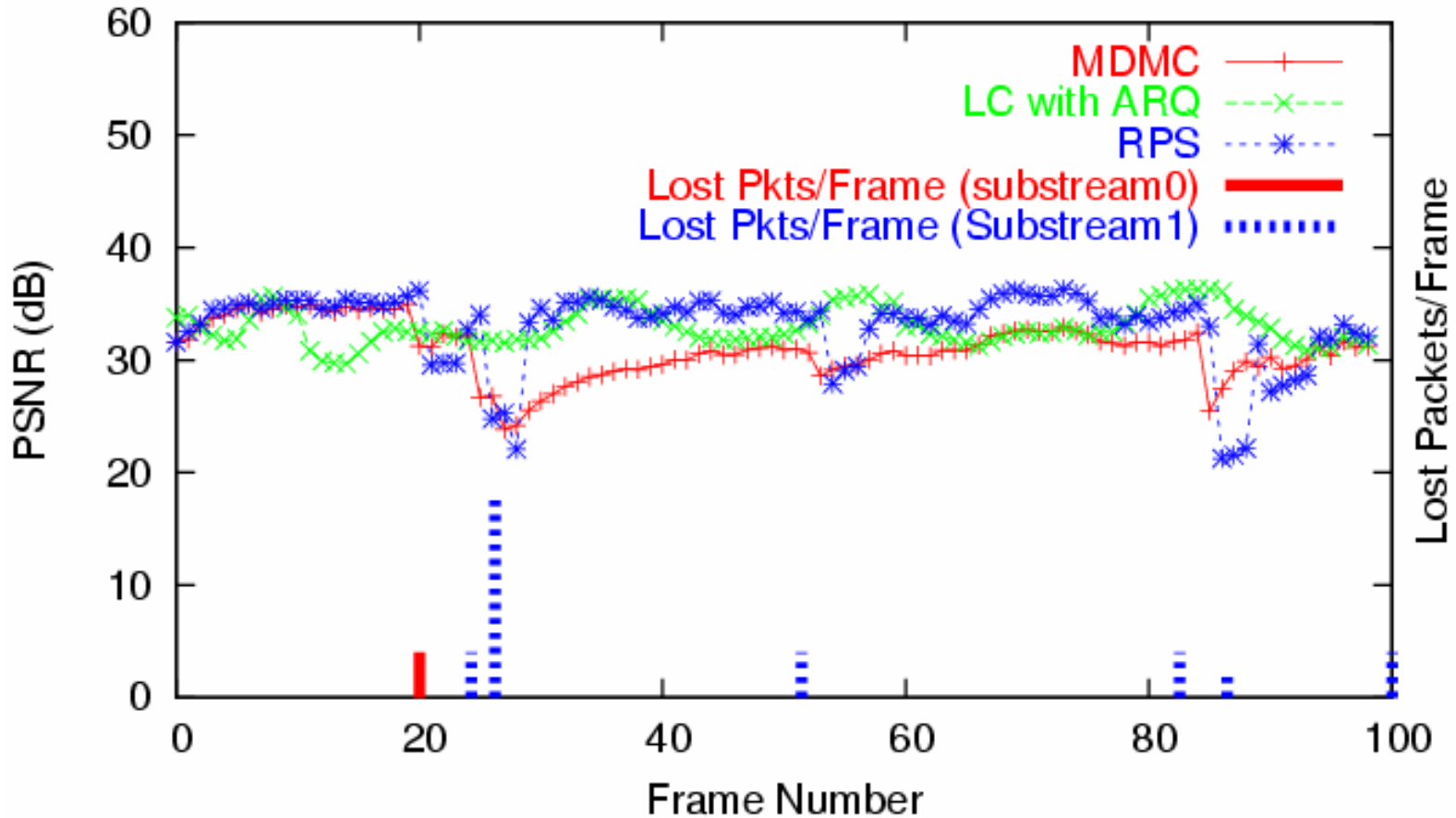
- Current version uses four nodes and static routing:



- The next version:
 - More nodes: ≈ 30 nodes
 - Dynamic routing: Implemented Multipath Routing DSR on the MS Windows platform.

Testbed: Results

- Four nodes, two 2-hop paths, in building and not line-of-sight





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Part II: Optimal Traffic Partitioning



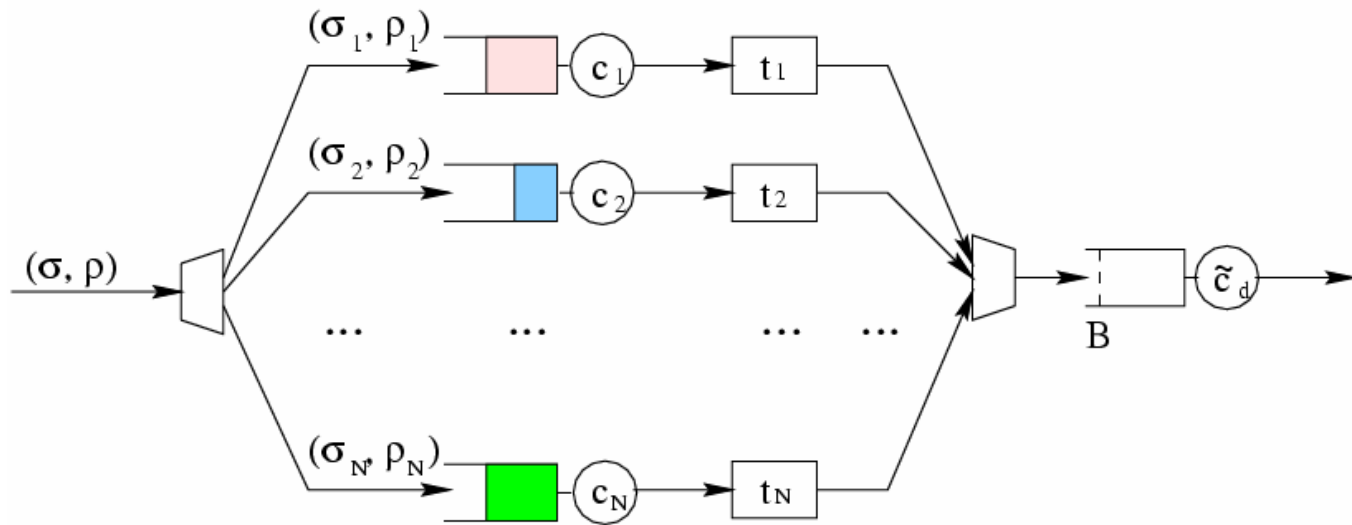
- The remaining two components:
 - Traffic allocator: assigns packets to the paths
 - Resequencing buffer: reorder the received packets
 - Given the realtime traffic flow and the path parameters, these two components jointly determine the end-to-end delay
- Suppose the traffic flow and the parameters of the paths are given, how much improvement in total end-to-end delay can be achieved by optimally partitioning the traffic
- Use deterministic network calculus: worst case bound



System Model

■ Model:

- The original flow is regulated by a (σ, ρ) leaky bucket
- There is a single bottleneck node on each path, which is modeled as a queue with a constant service rate
- All other delays, including delays at other intermediate nodes and the propagation delay, are represented by a fixed delay.
- Deterministic traffic splitting



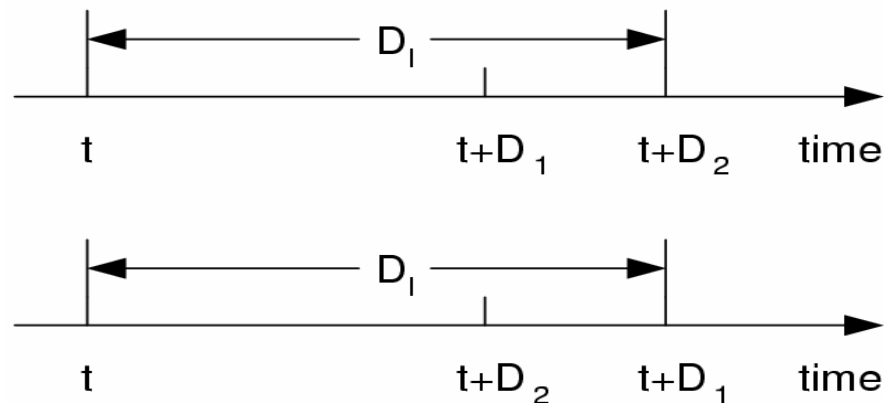
End-to-End Delay

- End-to-end delay: If no loss is allowed, the end-to-end delay, D_i , including the queueing delay at the bottleneck node, the fixed delay, and the resequencing delay, is:

$$\tilde{D}_i = \max \{ \tilde{D}_1, \tilde{D}_2, \dots, \tilde{D}_N \}$$

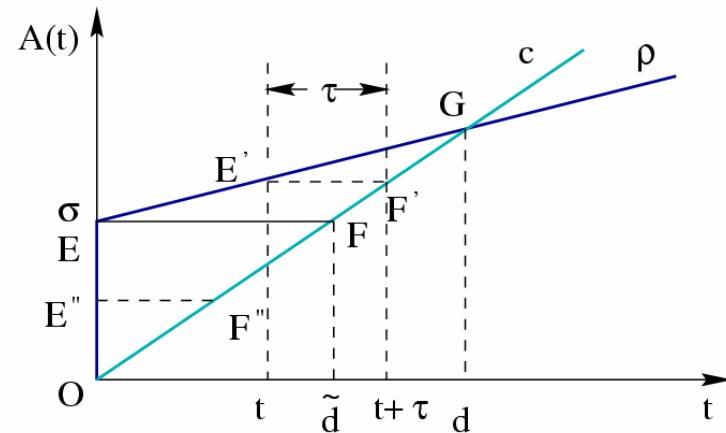
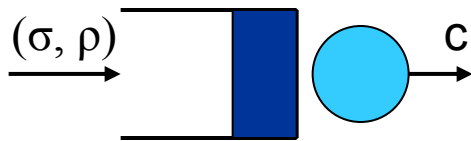
where D_i is the delay on path i .

- Consider two tagged, back-to-back bits in a frame:



Delay Bound

- Consider a First Come First Serve (FCFS) queue with capacity c , fed by a (σ, ρ) source:



- Queueing delay is upper bounded by: $\tilde{d} = \frac{\sigma}{c}$

Formulation

- A constrained optimization problem:

$$\begin{aligned} \mathbf{Min:} \quad \tilde{D}_l &= \max\{\tilde{D}_1, \tilde{D}_2, \dots, \tilde{D}_N\} \\ &= \max\left\{\frac{\sigma_1}{c_1} + f_1, \frac{\sigma_2}{c_2} + f_2, \dots, \frac{\sigma_N}{c_N} + f_N\right\} \end{aligned} \quad (20)$$

subject to:

$$\begin{cases} \sigma_1 + \sigma_2 + \dots + \sigma_N = \sigma \\ \sigma_i \geq 0, \quad i = 1, 2, \dots, N \end{cases} \quad (21)$$

Solution

- Without loss of generality, suppose : $t_1 < t_2 < \dots < t_N$

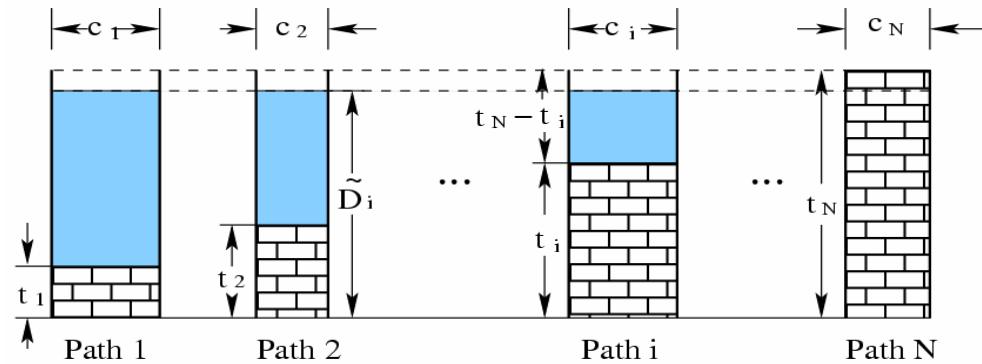
Theorem 3: Denote $\sigma_{th}^N = \sum_{i=1}^N c_i(f_N - f_i)$. The solution to the N -path optimization problem $\mathcal{P}(N, \sigma)$ is given as follows:

- (1) Case I: If $\sigma > \sigma_{th}^N$, the optimal partition that achieves the minimum end-to-end delay is: $\sigma_i^* = \frac{c_i}{c} [\sigma + \sum_{j=1}^N c_j(f_j - f_i)]$, $i = 1, 2, \dots, N$.
- (2) Case II: If $\sigma \leq \sigma_{th}^N$, the optimal assignment for path N is $\sigma_N^* = 0$. The optimal assignment for the remaining paths are determined by applying this theorem *recursively* on $\mathcal{P}(N - 1, \sigma)$, i.e., a reduced problem of (20) and (21) with the remaining $N - 1$ paths and a burst of size σ .

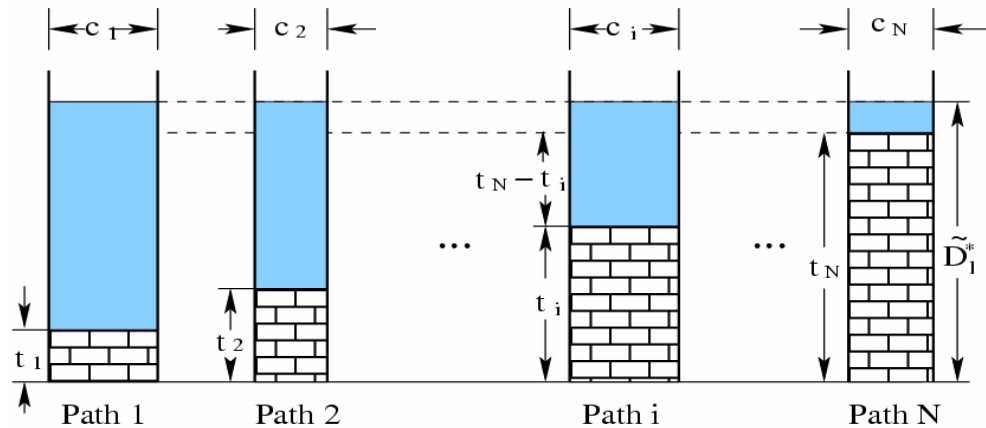
Proof

Water filling:

Case I:

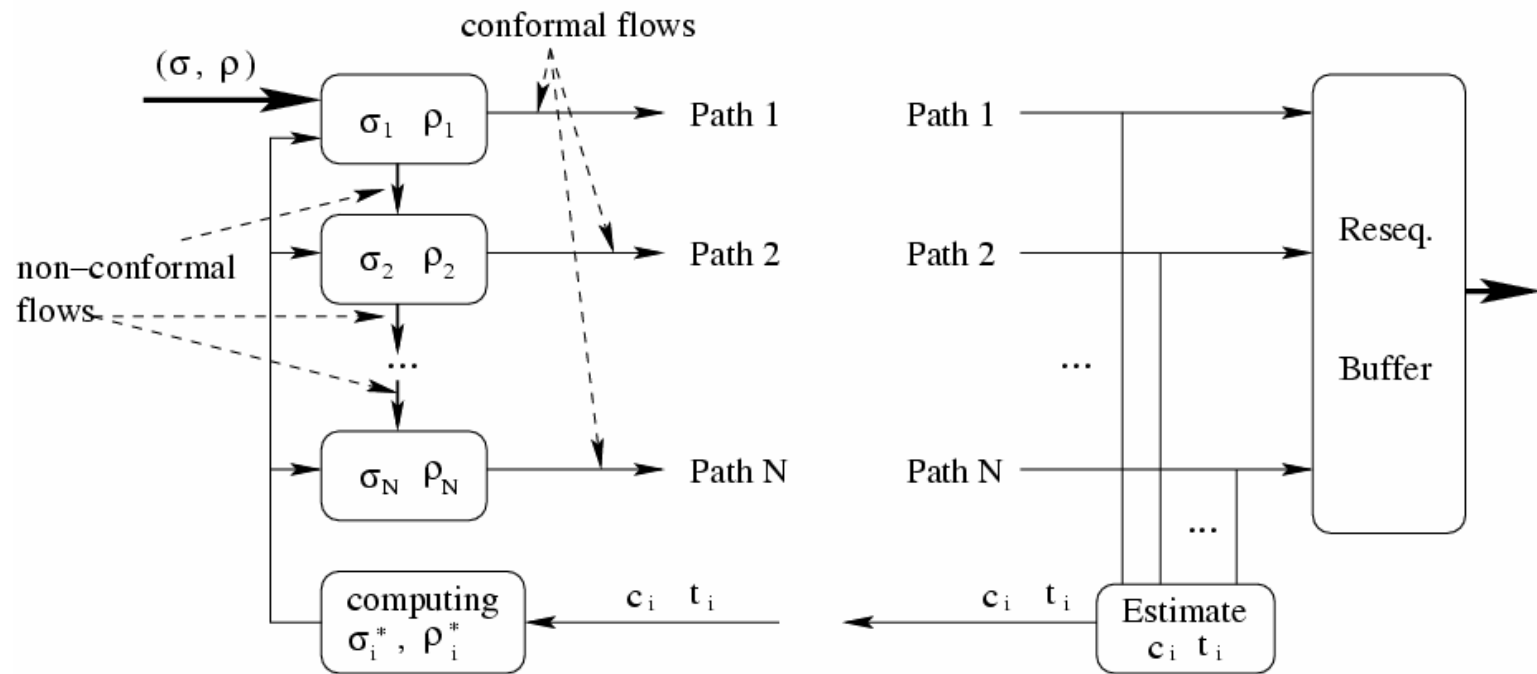


Case II:



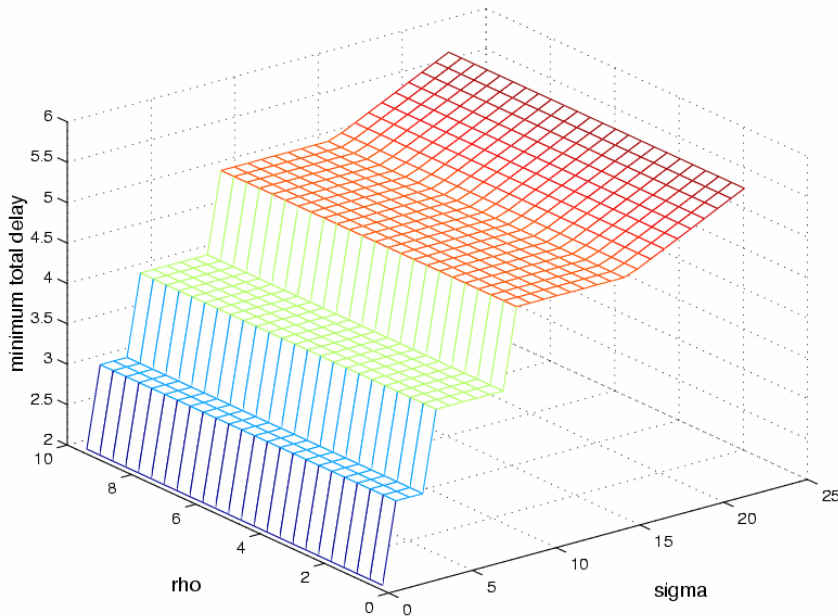
Implementation

- Use N leaky buckets, one for each path
- Non-conformal traffic are redirected to the next leaky bucket
- The receiver estimates c_i and t_i for each path, and the sender computes the optimal partition

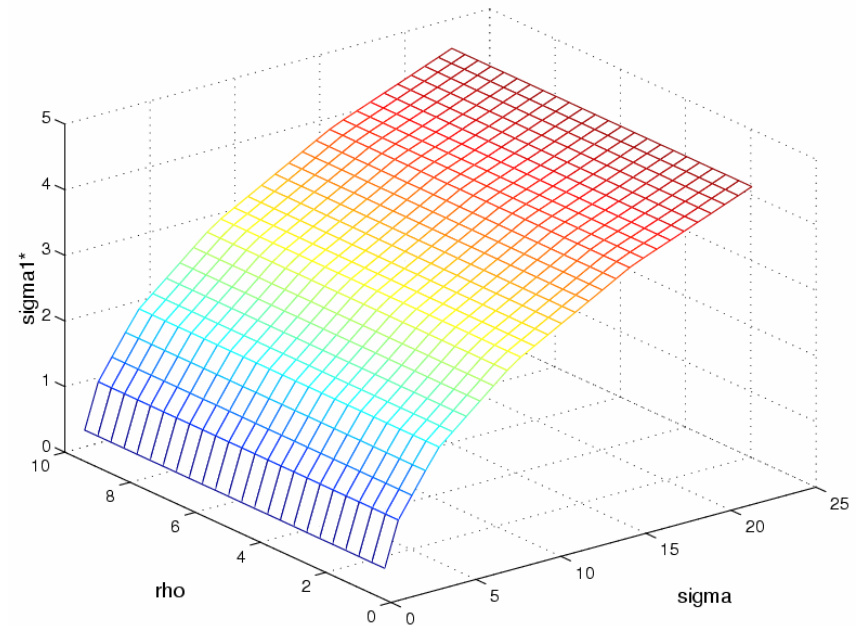


Numerical Results

- Five paths, $t=[1, 2, 3, 4, 5]$, $c=[1, 1.5, 2, 2.5, 3]$



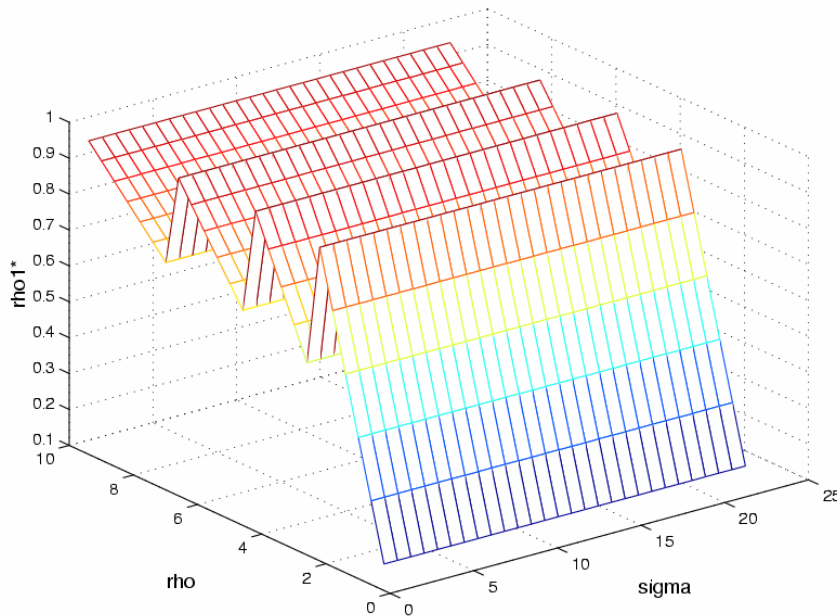
The minimum end-to-end delay



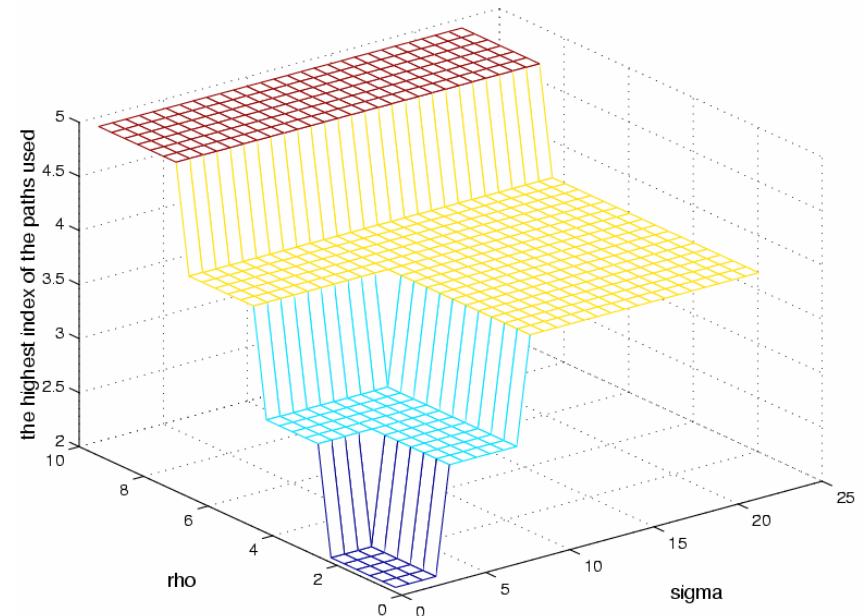
The optimal burst assignment for path 1

Numerical Results (ctd)

- Five paths, $t=[1, 2, 3, 4, 5]$, $c=[1, 1.5, 2, 2.5, 3]$



The optimal rate assignment for path 1



The highest index of the paths used

Contributions

- Major concerns in using Multipath Transport:
 - Resequencing delay
 - Path selection
 - How to use multiple paths
- Our analysis shows that:
 - The resequencing delay can be effectively minimized by optimal traffic partitioning
 - Path selection is made easy by translating multiple performance metrics into the end-to-end delay



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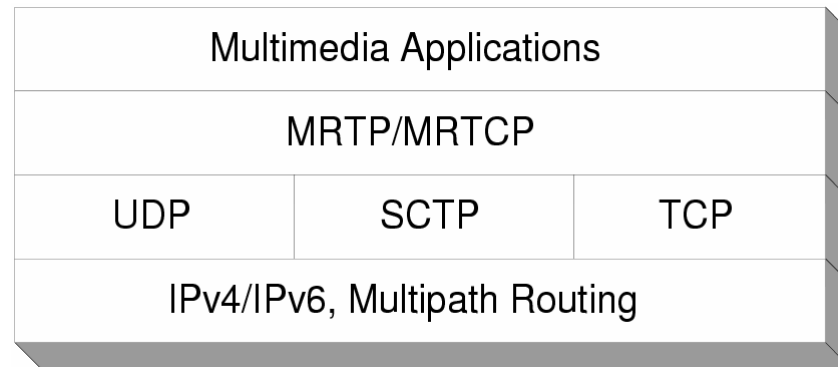
Part III: MRTP

- RTP/RTCP:
 - Does not support the use of multiple paths
 - Feedback is too coarse for the sender to react to congestion or link failures
- SCTP:
 - Built in system kernel. Inflexible in supporting various multimedia services
 - Lacks the essential functions needed by realtime services.
- The new protocol, MRTP/MRTCP, is:
 - An extension of RTP/RTCP to exploit path diversity
 - Complementary to SCTP in supporting realtime services



Overview of MRTP

- Protocol stack



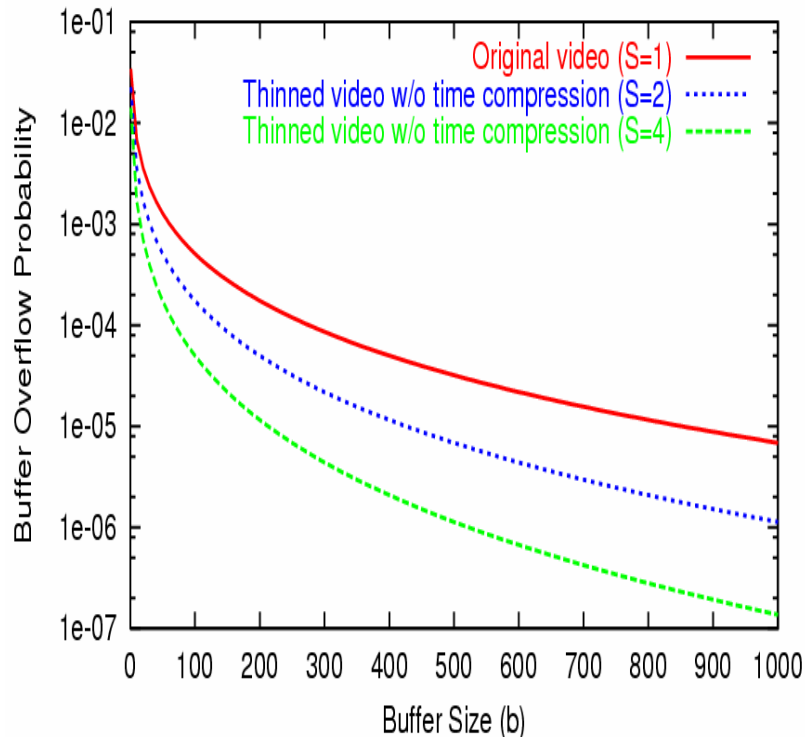
- MRTP: Transports multimedia data using UDP over multiple paths
- MRTCP: Flow/session control, QoS feedback, etc.
- The flow/session control can also be built on the Session Initiation Protocol (SIP) over TCP
- SCTP sockets can be used to set up multiple paths

Basic Components

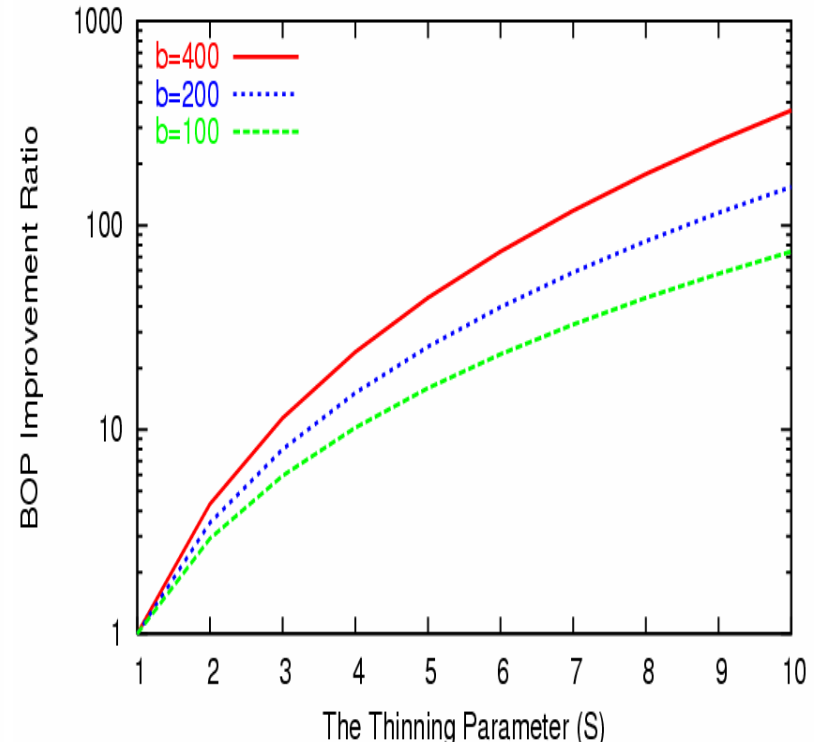
- Session and flow management:
 - Flow and session IDs
 - Dynamic updates: removing stale flows, adding new flows
- Traffic partitioning:
 - A simple *round-robin* algorithm is provided
 - Can be overridden by applications
- Timestamping and sequence numbering:
 - Similar as RTP
 - Also used in reassembly at the receiver
- QoS reports:
 - Timely QoS reports enables the sender to quickly react to congestion or link failures
- Reassembly at the receiver

Performance Studies (1)

- Analytical results using the Buhadur-Rao asymptotic
- 100 flows, $H=0.88$, $\sigma^2=1$, $c=1$, and $\mu=0.9$



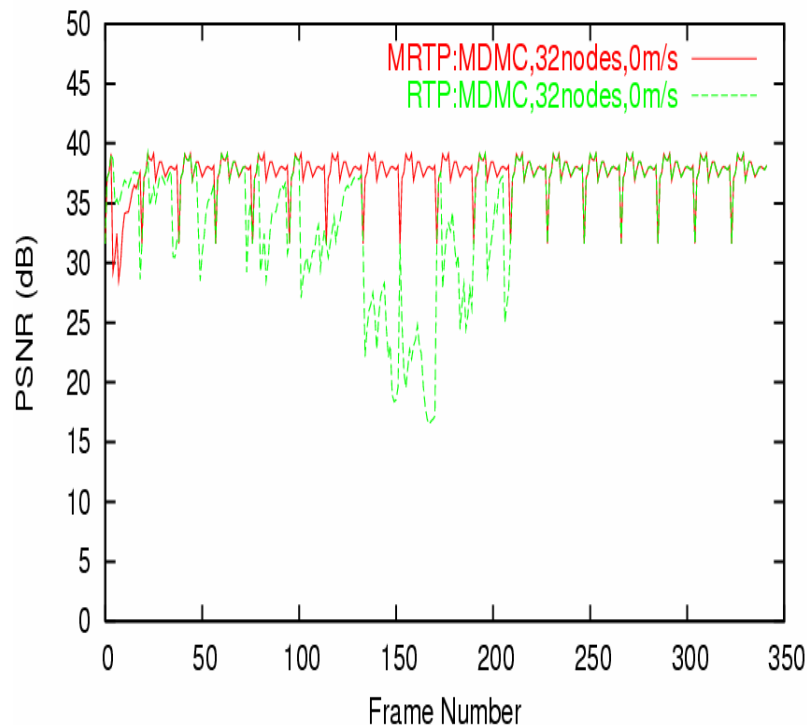
Buffer overflow probability vs. number of paths used



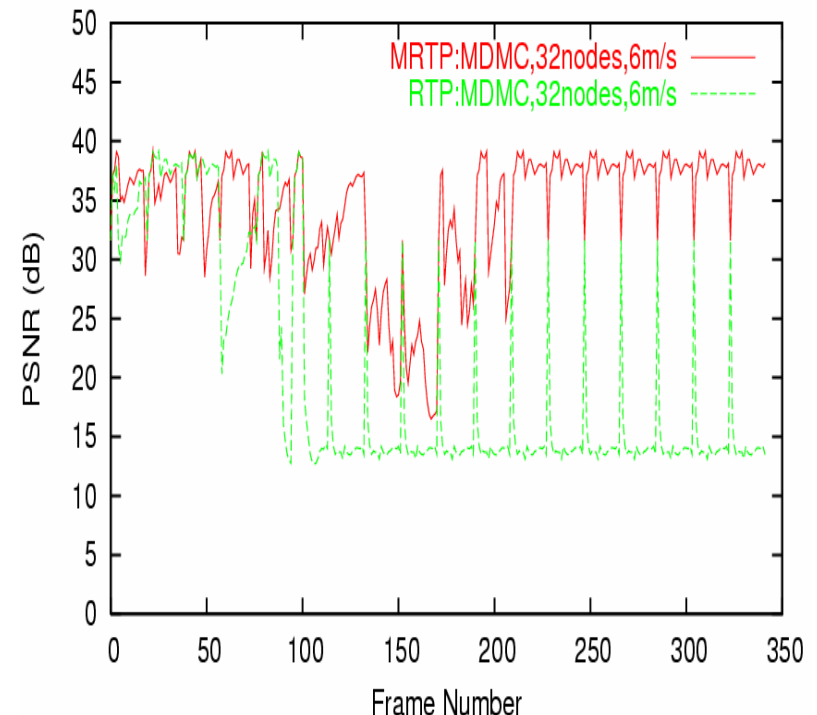
The improvement in buffer overflow probability

Performance Studies (2)

- OPNET simulations: comparison of MRTP and RTP
- 32 nodes, other parameters are the same as the previous slides



PSNRs from simulations
Where nodes are static



PSNRs from simulations where
Nodes moved at 6 m/s



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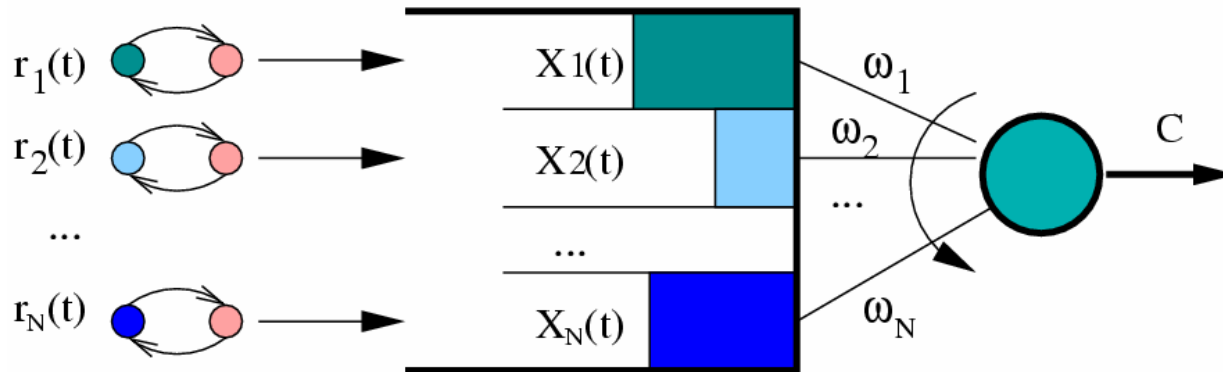


Part IV: GPS Analysis

- The network architecture capable of QoS provisioning should contain at least the following key components:
 - ❑ Traffic specification: Specifies the source traffic characteristics and the desired QoS
 - ❑ QoS routing: Finds routes with sufficient resource to support the desired QoS
 - ❑ Resource reservation: Reserves resource along the route
 - ❑ Admission control: Prevents the network from being overly congested
 - ❑ Packet scheduling: Schedules packets to be forwarded from a switch or router's incoming port to the outgoing ports, and meets its QoS requirements

Model

- The Generalized Processor Sharing system model:
 - N classes, each is modeled as a Markov Modulated Fluid Process (MMFP)
 - N logical queues
 - A set of GPS weights, $\{\omega_i\}$
 - A backlogged class is guaranteed with a minimum service rate $g_i = \omega_i C$, residual service are distributed among backlogged classes in proportion to their weights





Summary of Results

- Based on previous work, we derived the Effective Bandwidth of a MMFP class in the GPS system, and designed an admission control test using this result.
- We derived a GPS service bound which is tighter than previous work, resulting in a more accurate analysis of the tail distributions and a higher resource utilization.
- We extended the previous work on Matrix Analytic Method for stochastic fluid flows to the GPS analysis, and investigated the Caudal Characteristics of the MMFP classes.



Conclusions

- Realtime multimedia transport is a challenging problem, especially in wireless mobile ad hoc networks
- We propose to use multipath transport to combat frequent congestions and link failures
 - Three algorithms combining multistream coding with multipath transport for video over ad hoc networks
 - An analytical framework for optimal traffic partitioning and resequencing buffer design
 - A protocol supporting multipath realtime multimedia transport
 - An analysis of the GPS queueing system: network QoS support
- Future work