On Dynamics of Network Transport Protocols

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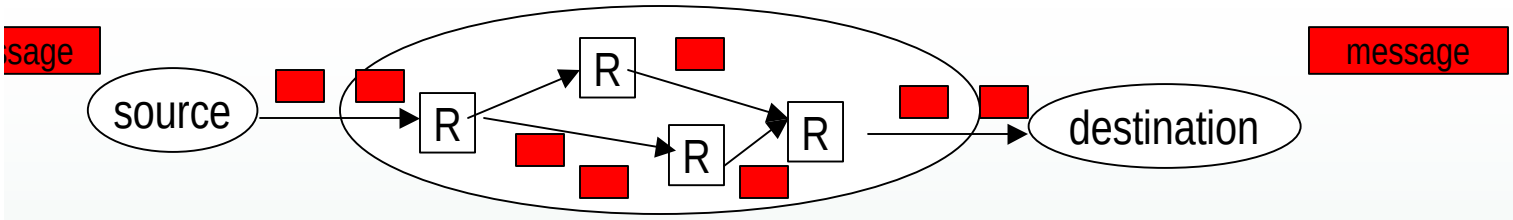
line of Presentation

- TCP Simplified Dynamics
- Composition Model
- Experimental Results

work Transport (Simplified View)

- Messages from source get broken into packets



- Packets are routed over the network
  - Routes are decided by routers and service providers in Internet
  - Source has very little control on paths traversed by packets
- Most network transport is controlled by two protocols
  - TCP: Transport Control Protocol
    - Ensures reliable delivery – retransmits delayed or lost packets
    - Vast majority of Internet traffic
  - UDP: User Datagram Protocol
    - Sender puts datagram on the network to be routed
    - No further action is taken –lost packets are lost forever

End-to-End Transport Dynamics are Important

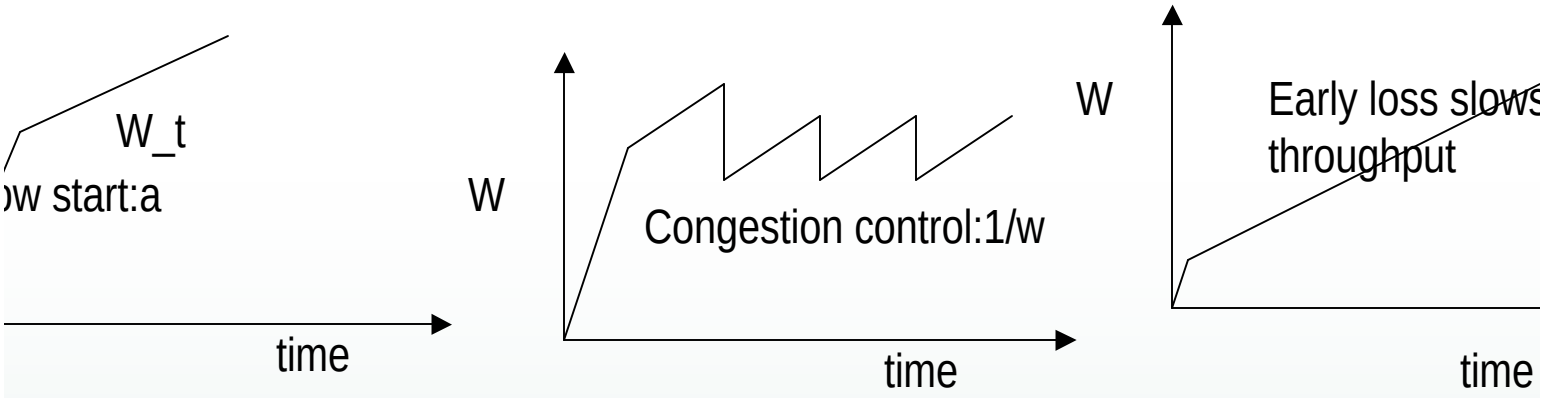
- TCP performance: High bandwidth for large data transfers
  - initial transients can force TCP into congestion control, achievable bandwi is very limited
- Control of end devices: Remote control of instruments
  - Jittery dynamics will destabilize the control loops
  - Will not be able to effectively execute interactive simulations

Very Limited insights about end-to-end dynamics

- Chaotic TCP window dynamics (Veres)

But observations are a give-away

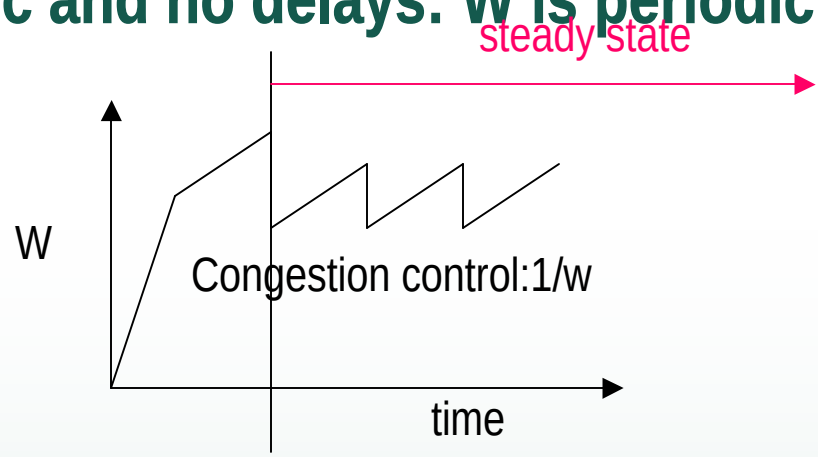
ditional View: Dynamics of TCP



ransport Control Protocol (TCP) Outline

- Uses window mechanism to send W bytes/sec
- Dynamically adjusts W to network and receiver state
  - Keeps increasing is no loses
  - Keeps shrinking if losses are detected
- Slow start phase:
  - W increase exponentially until W_t or loss
- Congestion Control:
  - linearly increase W with delivered packets
  - Multiplicatively decrease with loss

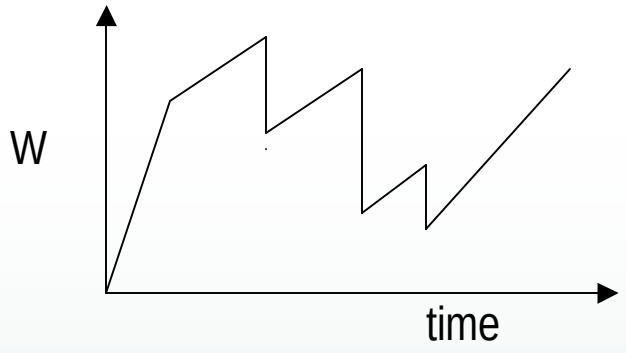
Competing Traffic and no delays: W is periodic



CP has a stable cycle under no network delays

- Prolonged Unstable regime:
  - W bytes increases with acknowledgments
- Instantaneous stabilization:
  - Bring W to a lower value with a loss as soon as bottleneck BW is exceeded

npeting traffic delays: W is not guaranteed to be periodic



vork delays:

otification of losses are delayed

Meanwhile packets are sent which will overflow – multiple losses

- W bytes increases with acknowledgments

all buffers at routers:

ackets exceeding the bandwidth are buffered

Network delays and competing traffic will generate complicated profiles of W

npeting traffic, Network Delay, Router Buffers

omplicated traffic can generate complicated TCP dynamics

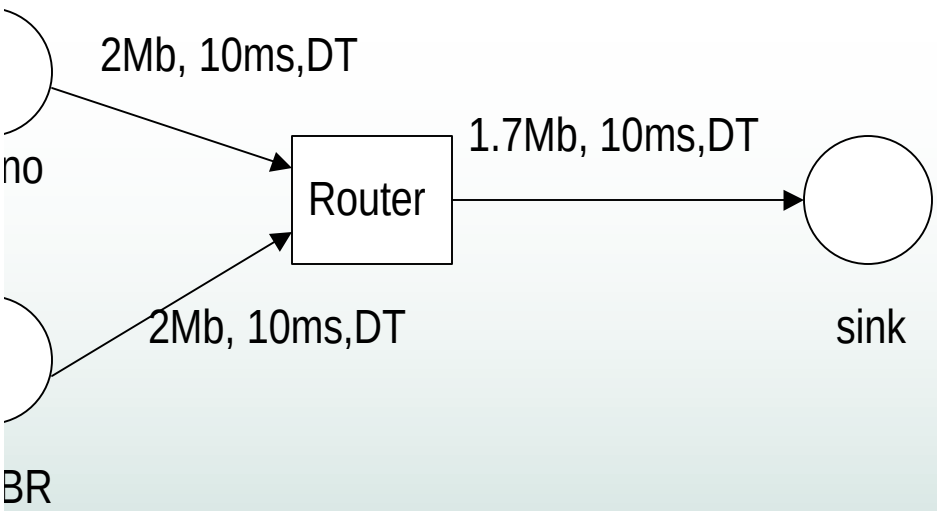
uestion: Can simple traffic generate complicated trajectories ?

Yes, under certain conditions

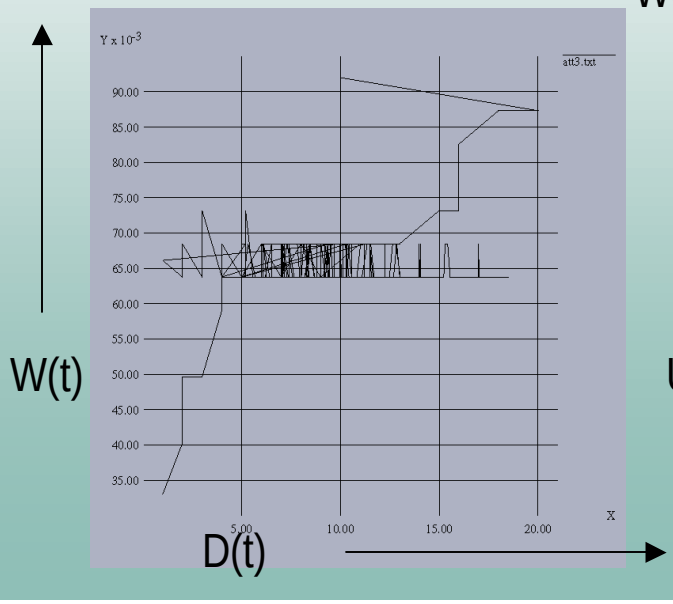
- Net-Effect: The stabilization part of the ideal case is prolonged, and is replaced by another unstable regime.
- To see this effect we introduce end-to-end packet delay

tate-Space of TCP:

P Competing with UDP
simulation)

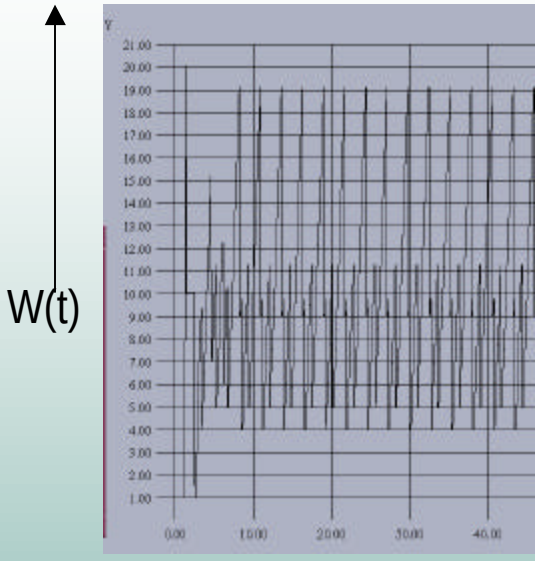


are phase plot:
w-size W(t) vs.
d-to-end delay D(t)



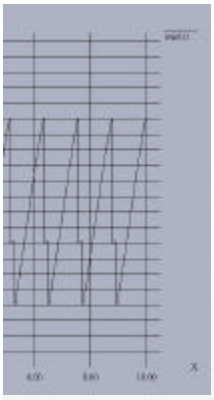
As CBR rate is varied

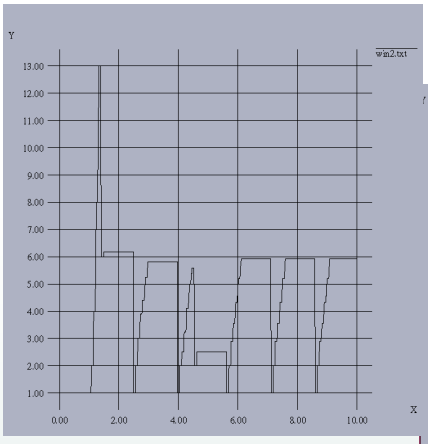
TCP competing with UDP/C
the router generates a v
of dynamics

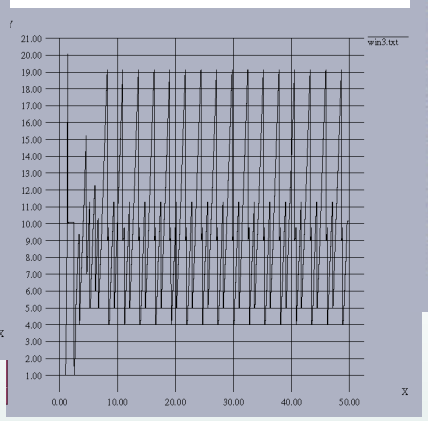


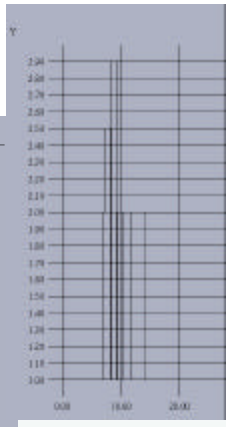
UDP/CBR=1Mbs

P Competing with UDP





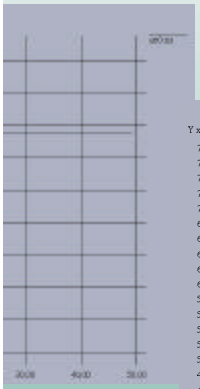




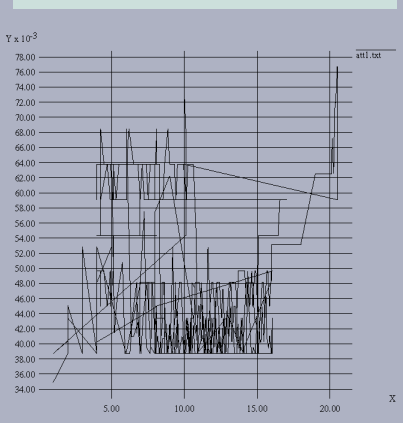
R: 0Mbs

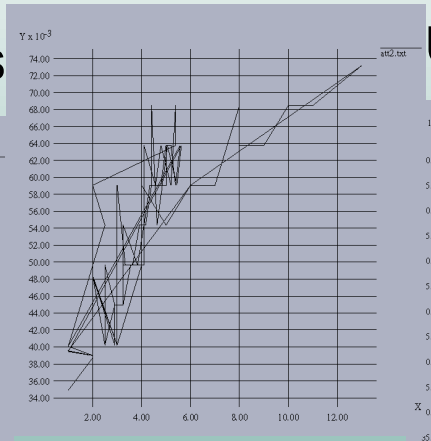
UDP/CBR: 1.0Mbs

UDP/CBR:

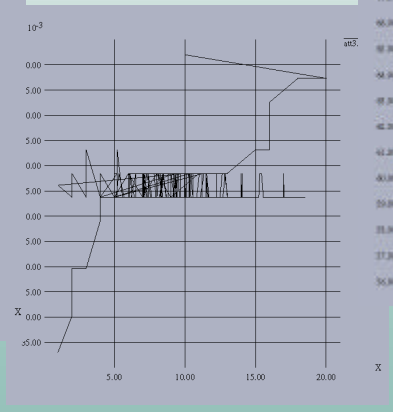


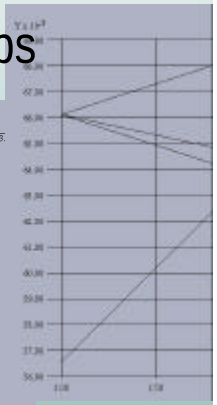
UDP/CBR: 0.5Mbs





UDP/CBR: 1.7Mbs

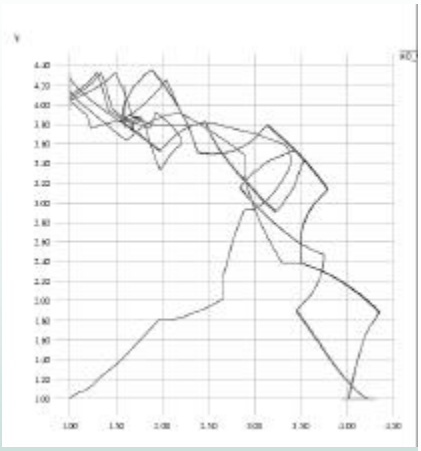




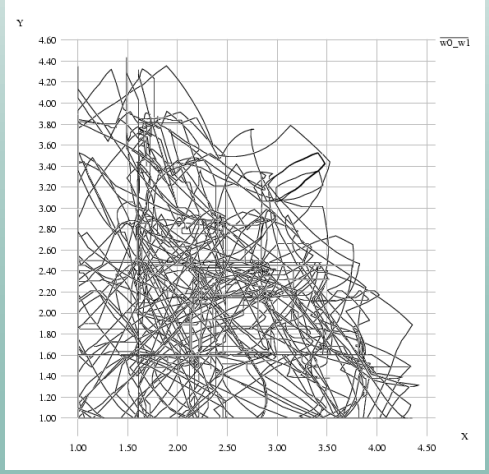
Chaotic Dynamics of TCP

Competing TCP streams: Window dynamics are chaotic

- Hard to predict – resemblance to random noise
- Hard to conclude from experiments – nearby orbits move faraway later
- Hard to characterize – chaotic attractor
  - Poincare map of two window sizes
    - Two-streams case
    - Four streams case



eres (2000) did not rigorously
stablish chaos in a formal sense
Attractor could have been
generated by periodic orbit with large period
/e are attempting to show
napback repellers in TCP equations
formal result

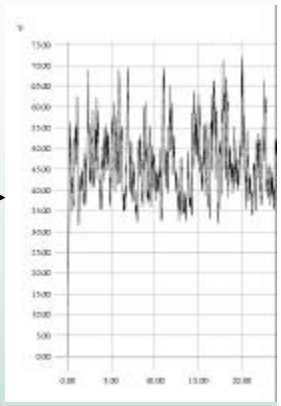


Noisy Nature of TCP
(simulation)

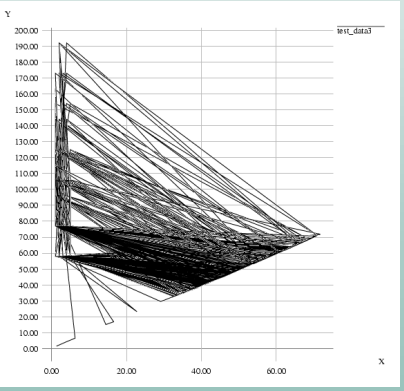
TCP source → Router: uniform random drops → destination

imple random traffic generates complicated attractors

- TCP reacts to network traffic randomness
  - Jittery end-to-end delays



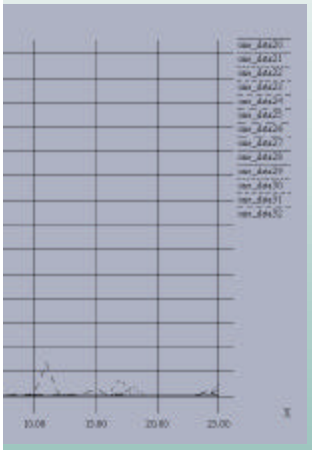
- Do not need chaos to generate complicated attractors
  - Poincare map of message delay vs. window size

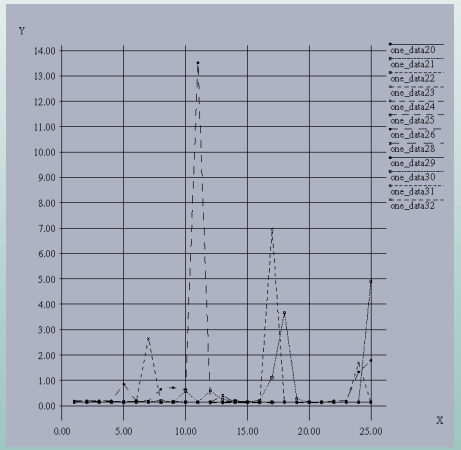


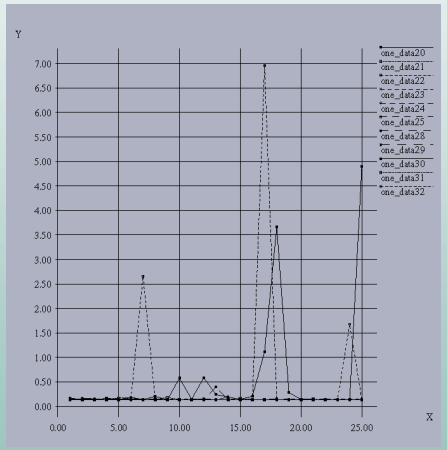
Jitter in End-to-End Delays
(wireless LAN - Internet measurements)

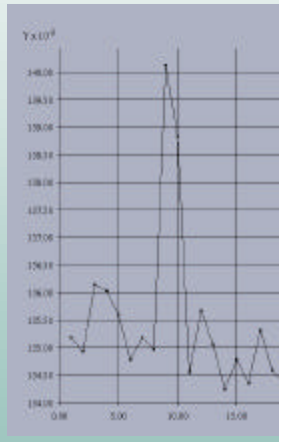
- Source: constant sized messages sent at regular intervals

ments from SC2001 booth to ORNL: Wireless network: 10K msgs - sent 25 times
n intervals - approximately every half hour – 13 measurements









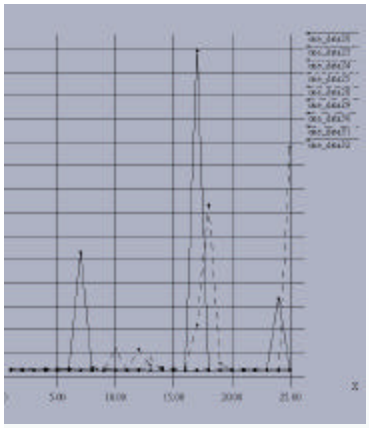
0-140 sec

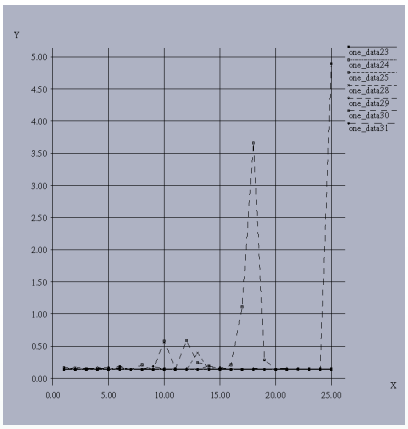
Scale: 0-14 sec

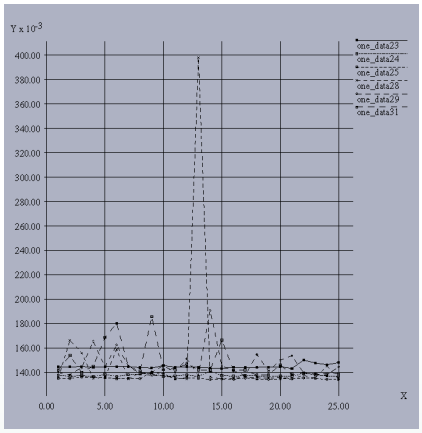
Scale: 0-7 sec

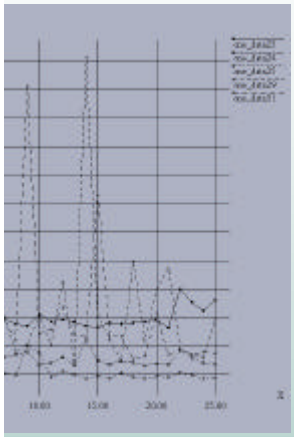
Scale: 0-150

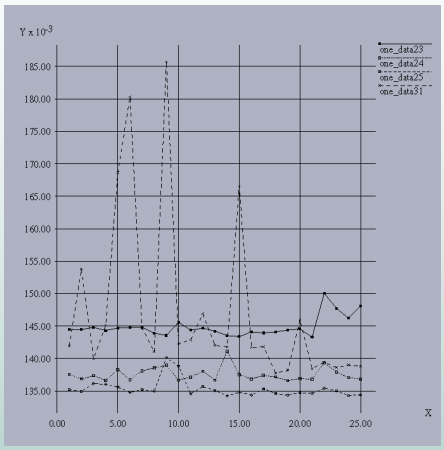
Measurements from SC2001 booth to ORNL: Wireless network

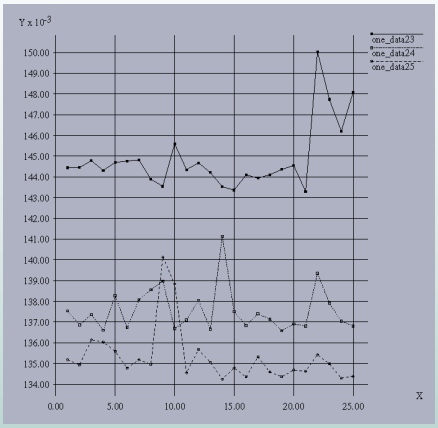


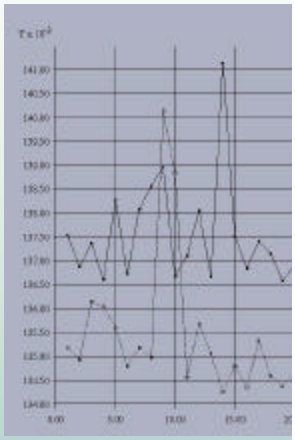


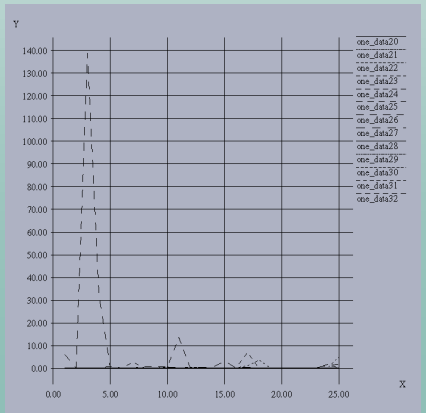


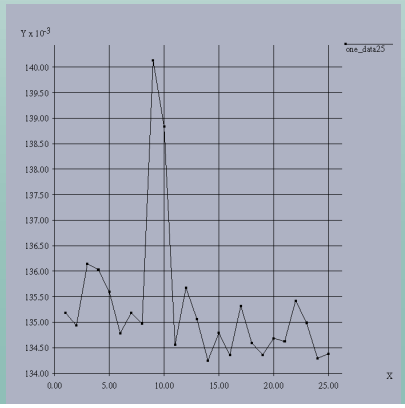












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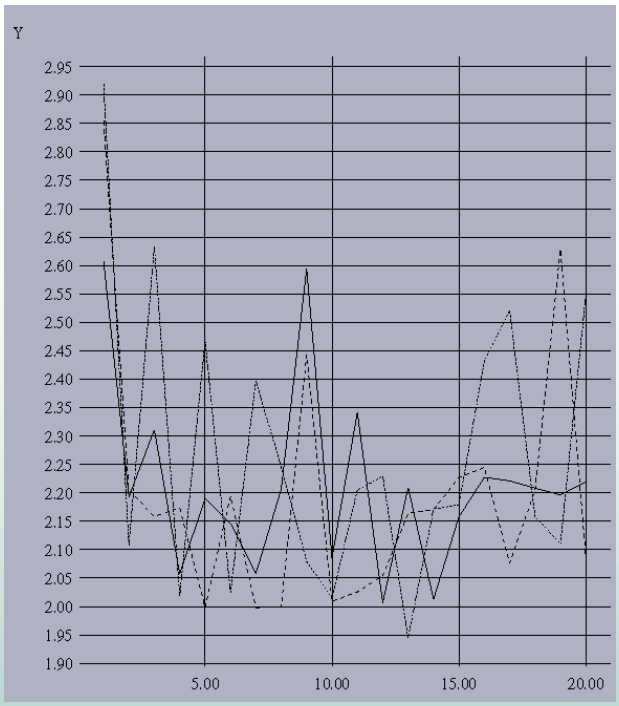
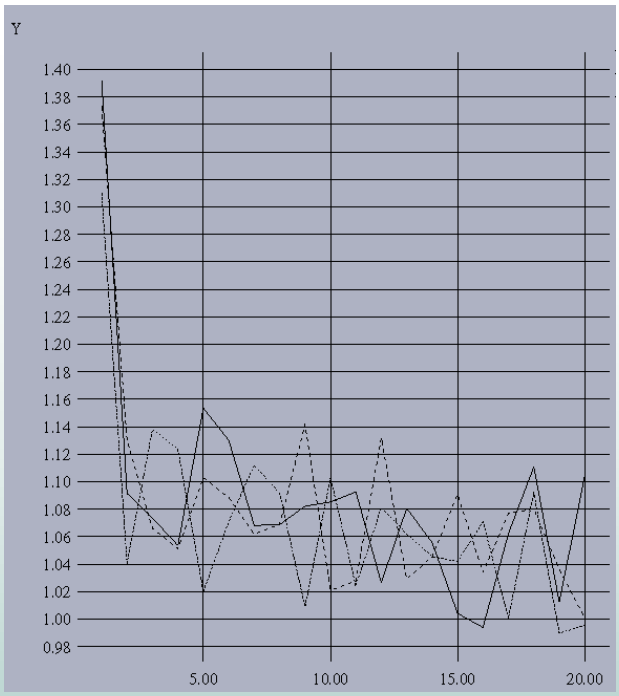
Internet Measurements from ORNL to OU (wired ~1000 mile Internet connection)

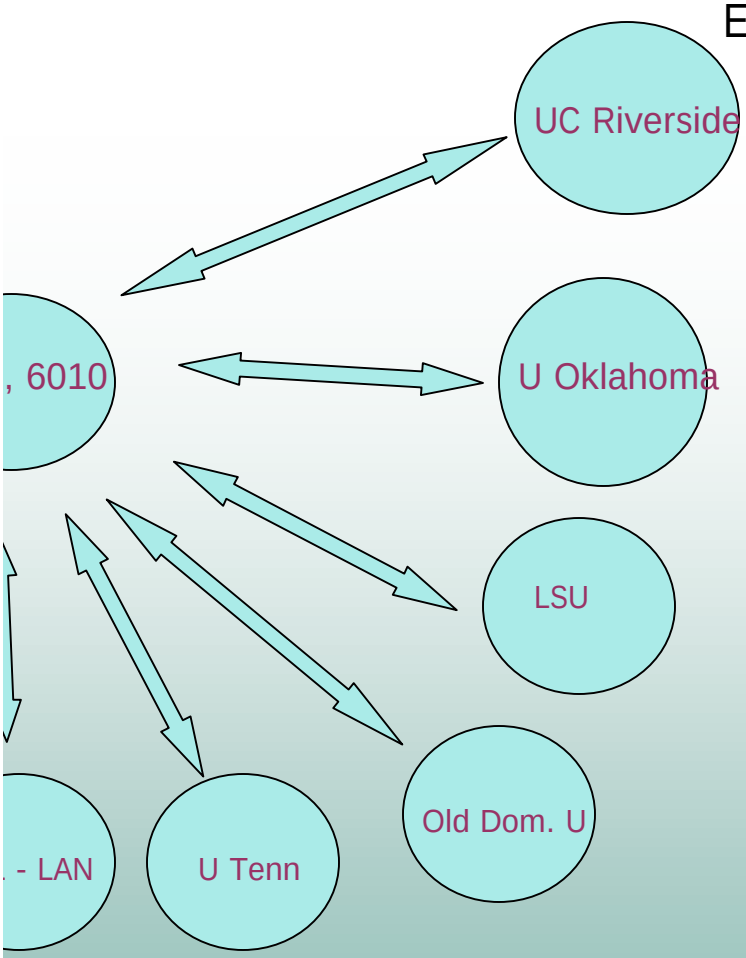
Time vs. end-to-end delay for fixed size messages sent regularly

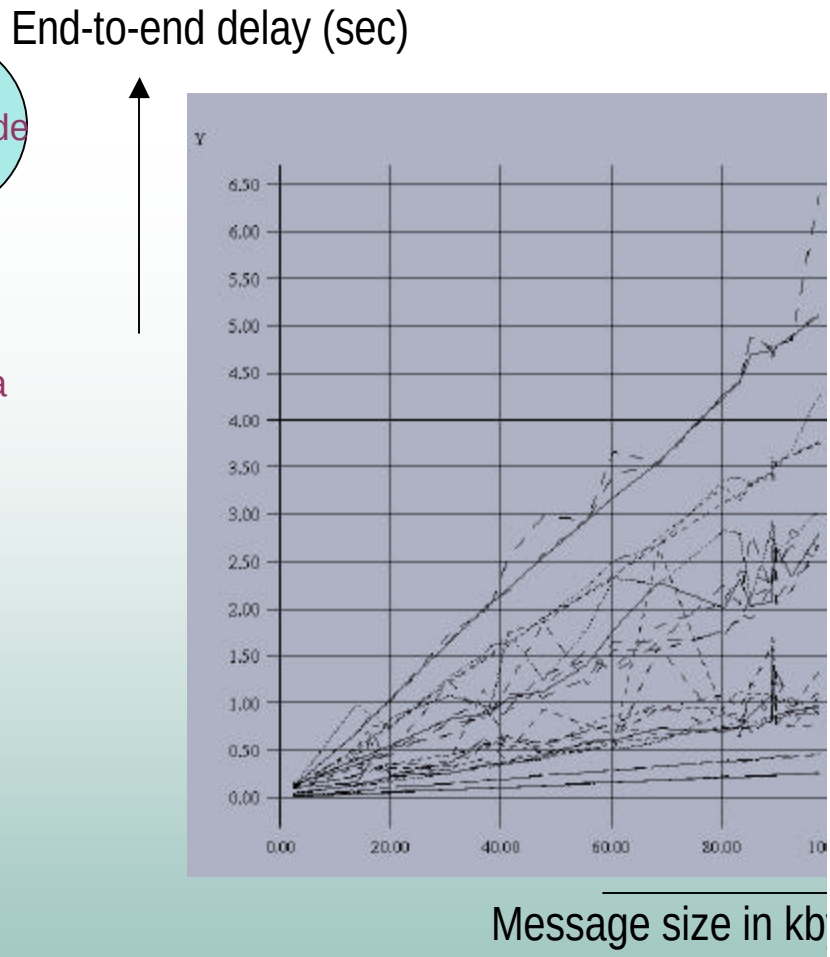




If messages are control signals to an end-instrument, the jitter can destabilize the control-loop

ork Measurements





TCP/IP end-to-end delivery times vs message size

End-to-End Delay Reduction

ernet Measurements:Four Daemons:

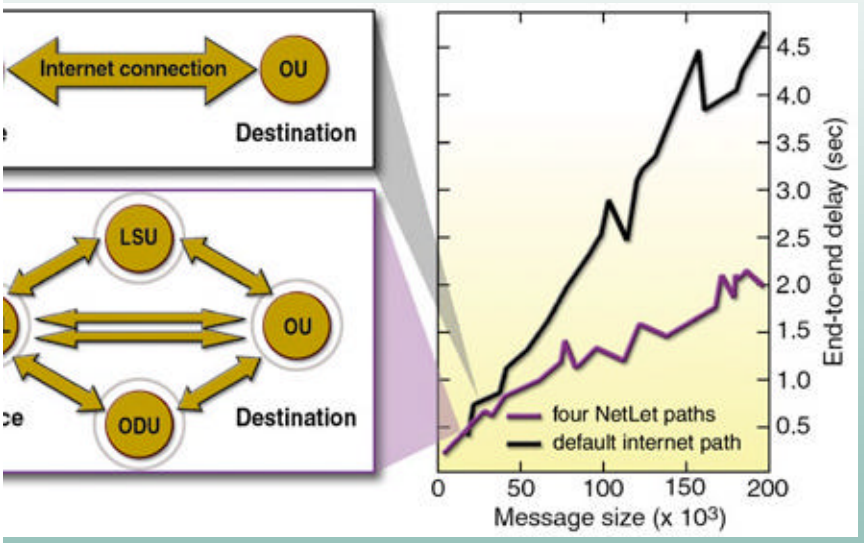
ır TCP streams: message optimally divided among

- Two parallel TCP streams
- Two streams via daemon routers

sults:

ırly readings in a week:

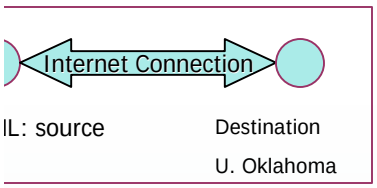
- Average 40% reduction in end-to-end delay
- Require no support from the network routers or service providers
- Daemons are user-level programs – can be executed using simple user accounts or on free telnet sites

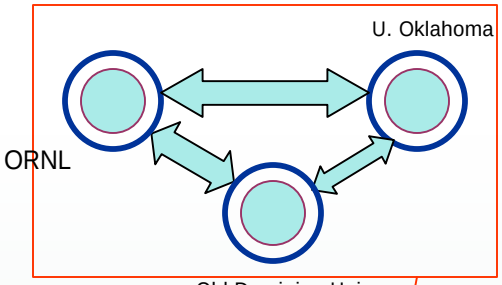


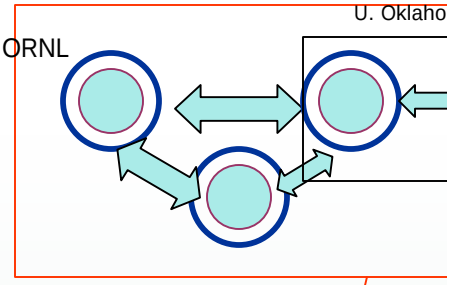
Ongoing Work:

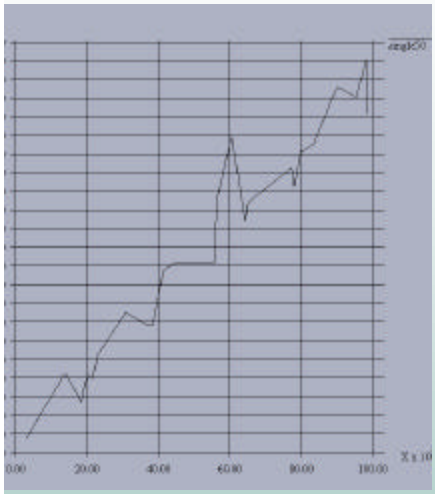
- Optimization of network measure
  - Statistical design of experiment
    - reduce measurement nodes a

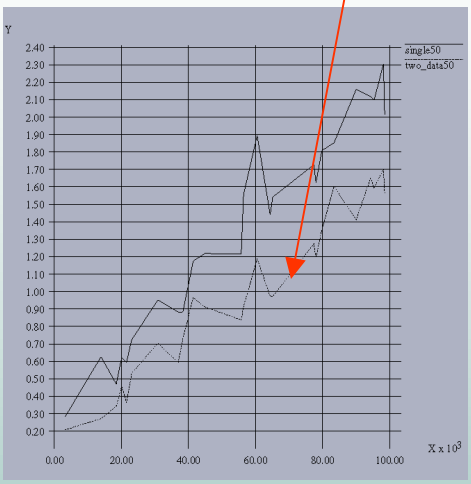
ernet Measurements: End-to-End Delay Dynamics Control

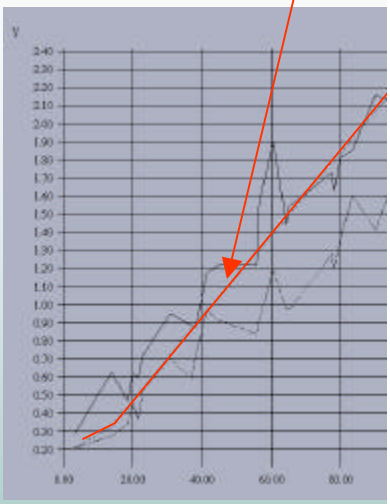












X-axis: message sizes (bytes)

Y-axis: end-to-end delay (sec)

mooth end-to-end delay

end-to-end delay using two-paths via daemons:
U, ORNL-ODU_OU
e output at destination

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DOE High-performance n/w program

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nclusions

- Networking Aspects
  - Study of end-to-end dynamics of transport mechanisms
    - Multiple paths, parallel TCP, TCP tuning and adaptation
    - Complex and chaotic regimes of transport methods
  - Develop method for controlling dynamics
    - End-filters, multiple throttles, adaptive performance tuning
- High-Performance Cooperative Computing Environments
  - Have Acute network performance needs
    - Not met by current operational networks – infrastructure and middleware
    - Will need targeted efforts; Will not be incidentally solved by other efforts
  - Provide supportive environments
    - Customized instruments can be installed to support
      - Avoid Congested parts
      - Aggregated bandwidths
      - Controlled dynamics