

Improving the Performance of Reliable Transport Protocols in Mobile Computing Environments

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Introduction

- Context
 - Microcellular networks
 - Mobile computers
- Motivation
 - Current protocols tuned for wired networks
 - Packet losses assumed to signal congestion
 - Protocols slow transmissions in response to losses
 - But wireless networks exhibit other types of losses
- What happens to active connections when hosts move ?

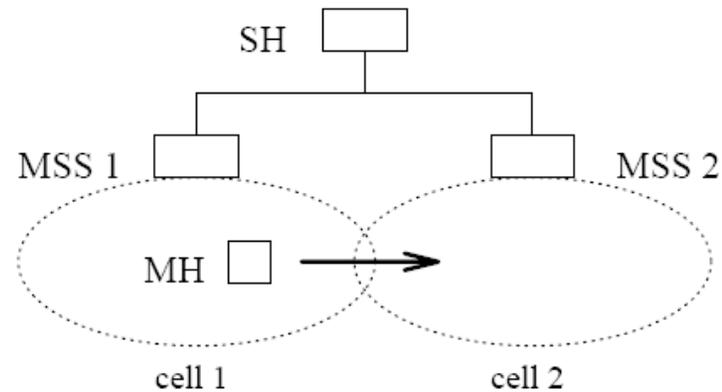
Summary

- Carried out a measurement study
 - TCP
 - Mobile IP
 - Wave LAN radios
- Found that motion degrades performance
 - Unacceptable interactive response
 - Significant drops in throughput
- Identified causes of performance degradation
 - Long waits for retransmission timeouts
 - Slow growth of transmission windows
- Devised an effective solution
 - Regains lost performance
 - Works over an internetwork

Outline

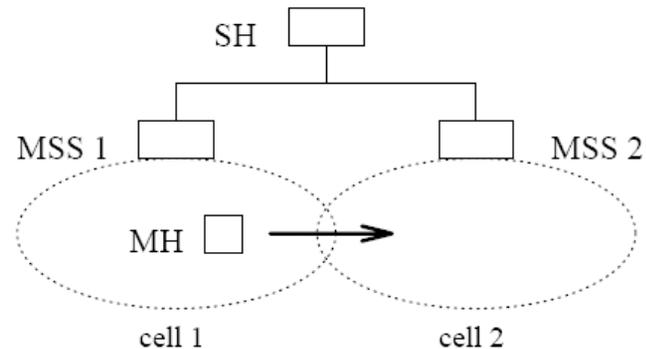
- Wireless networking test bed
 - Hardware and software components
 - Cellular handoff procedures
 - Experimental methodology
- Effects of motion
 - Loss of throughput
 - Pauses in communication
 - Packet losses
- Alleviating the effects of motion
 - Fast retransmissions
 - Improvements in latency
 - Improvements in throughput

Wireless Networking Testbed



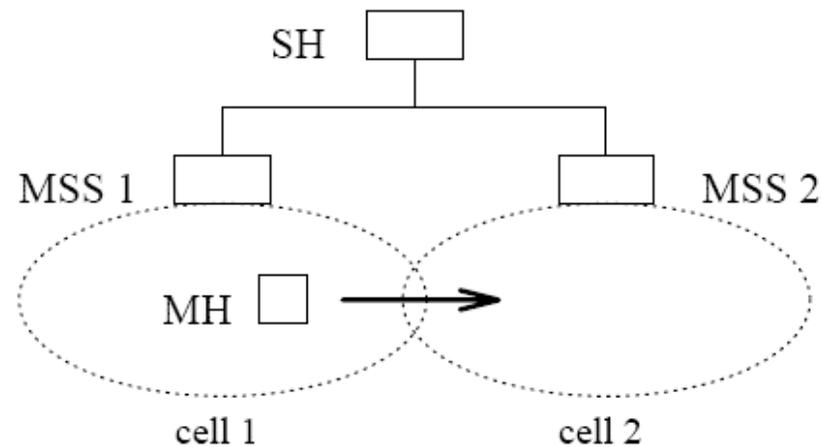
- Hardware
 - 2-Mbps WaveLAN radio network
 - 10-Mbps Ethernet
 - 50Mhz- 486 MHz PCs
- Software
 - Mach 3.0 kernel with Unix server
 - Columbia University's Mobile IP
 - 4.3-BSD Tahoe TCP

Cellular Handoff Procedures



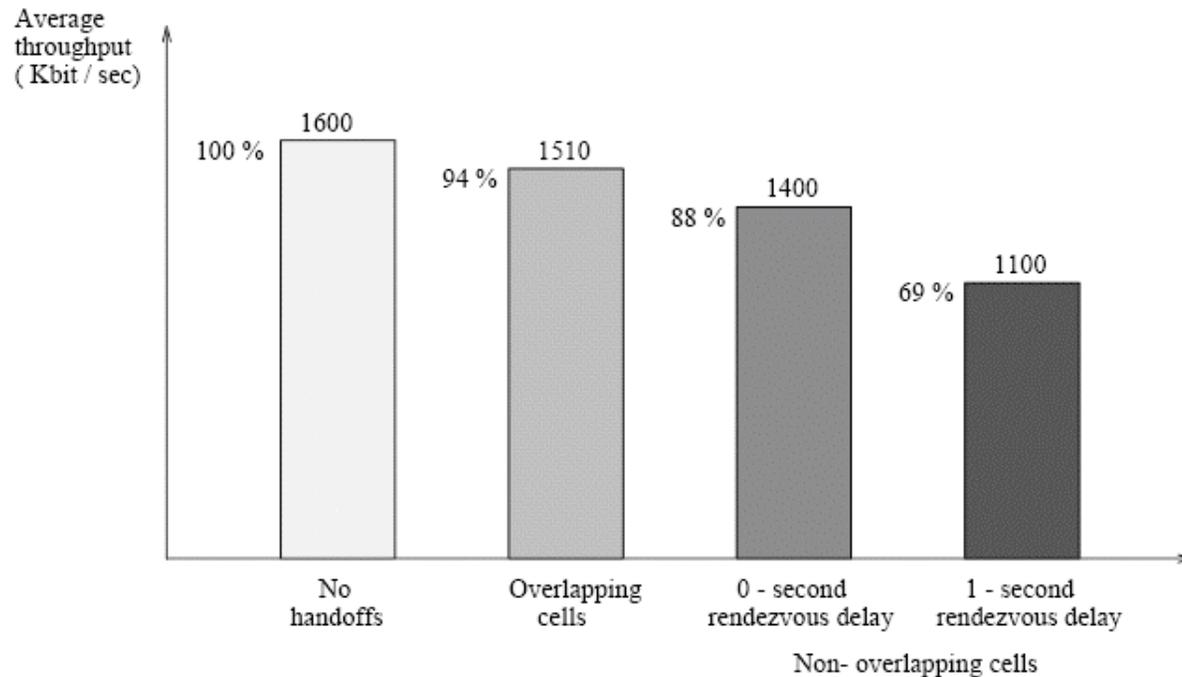
- Mobility Support Stations (MSSs) route packets to/from MHs
- MSSs broadcast periodic beacons
- MHs decide to switch based on signal strength / missing beacons
- Mobile IP handoff protocol
 - MH greets new MSS
 - MH changes its routing tables
 - New MSS changes its routing tables
 - MH informs new MSS of old MSS
 - New MSS notifies old MSS of handoff
 - Old MSS changes its routing tables
 - New MSS acknowledges handoff to MH

Experimental Setup



- Methodology
 - Establish TCP connection between SH and MH
 - Instruct MH to periodically change cells
 - Measure TCP performance
- Parameters
 - Overlapping vs non-overlapping cells
 - Rendezvous delay

Loss in Throughput...

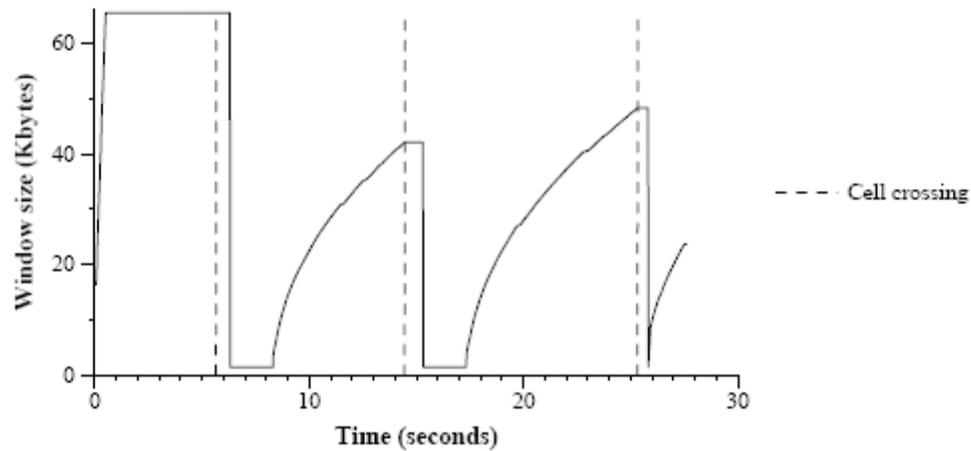
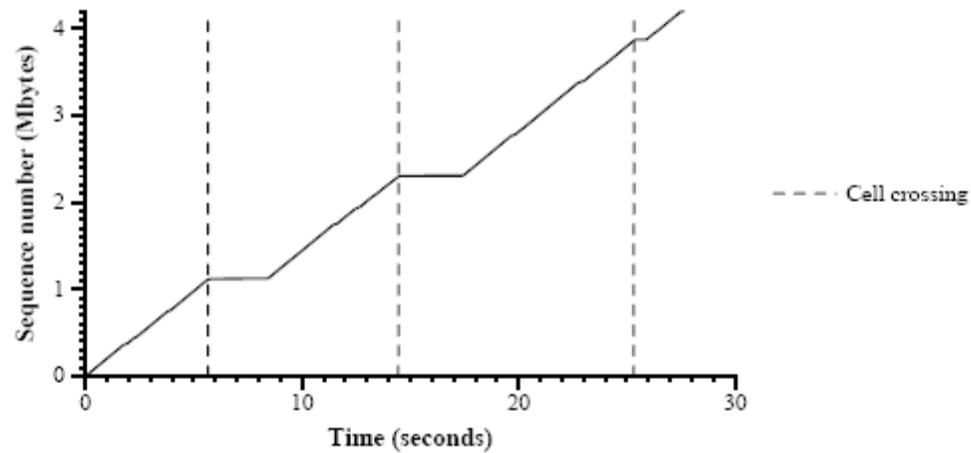


- Parameters
 - 4 Megabyte bulk data transfer
 - 1 second beaconing interval
 - Handoffs occur every 8 beacons (8s)

Congestion Avoidance and Control

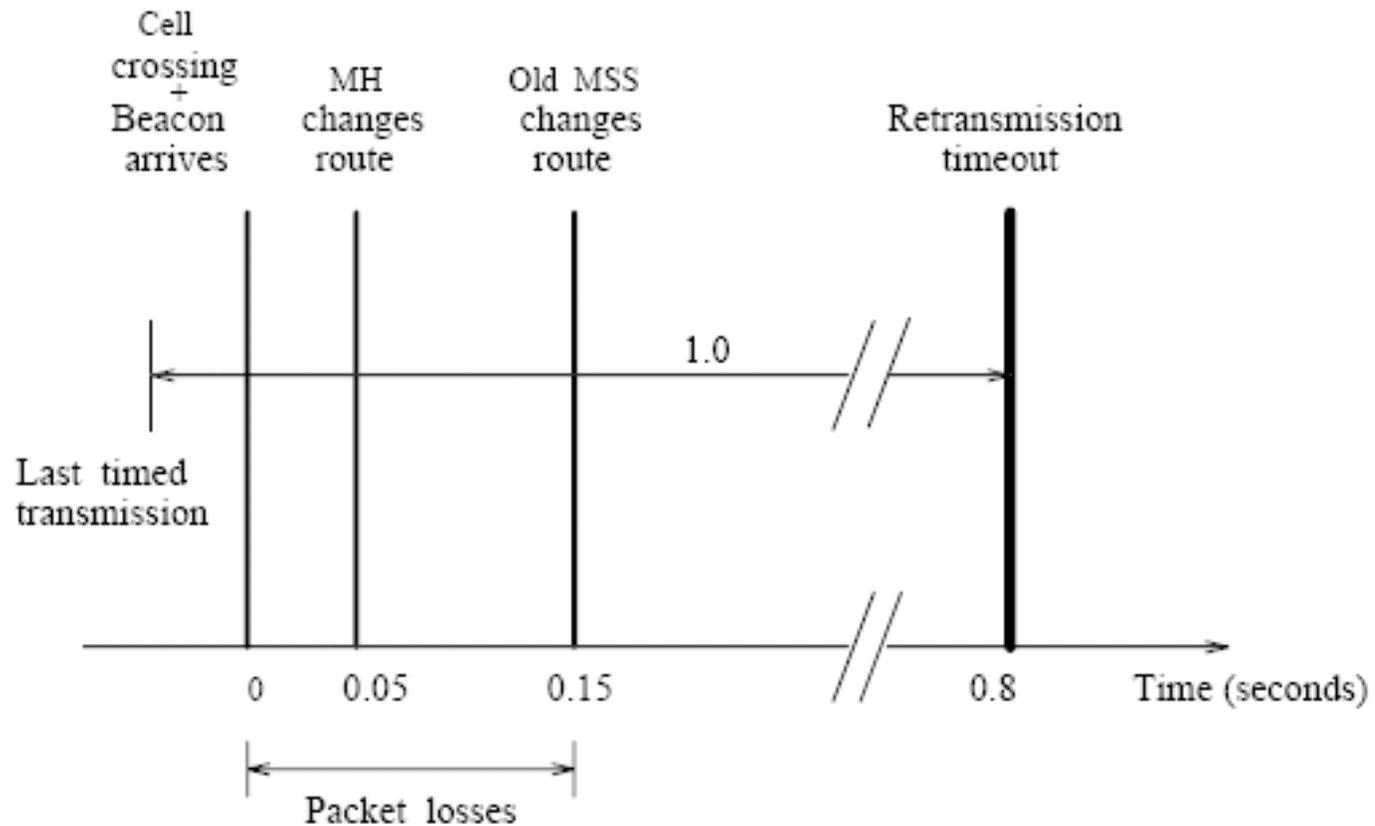
- Delay estimators
 - Maintain average of roundtrip delay = D_{avg}
 - Maintain average of variation in delay = V_{avg}
- Exponential retransmission backoffs
 - Set retransmission timer $T_{out} = D_{avg} + 2 * V_{avg}$
 - Assume timeout signals packet loss
 - Retransmit lost packet after timeout
 - Double timeout with every consecutive timeout
- Slowstart algorithm
 - Drop window size to 1 on every timeout
 - Double window with every ACK until threshold
 - Add 1 to window with every ACK after threshold
 - Set threshold to 1/2 of window size at time of loss

Pauses in Communication...



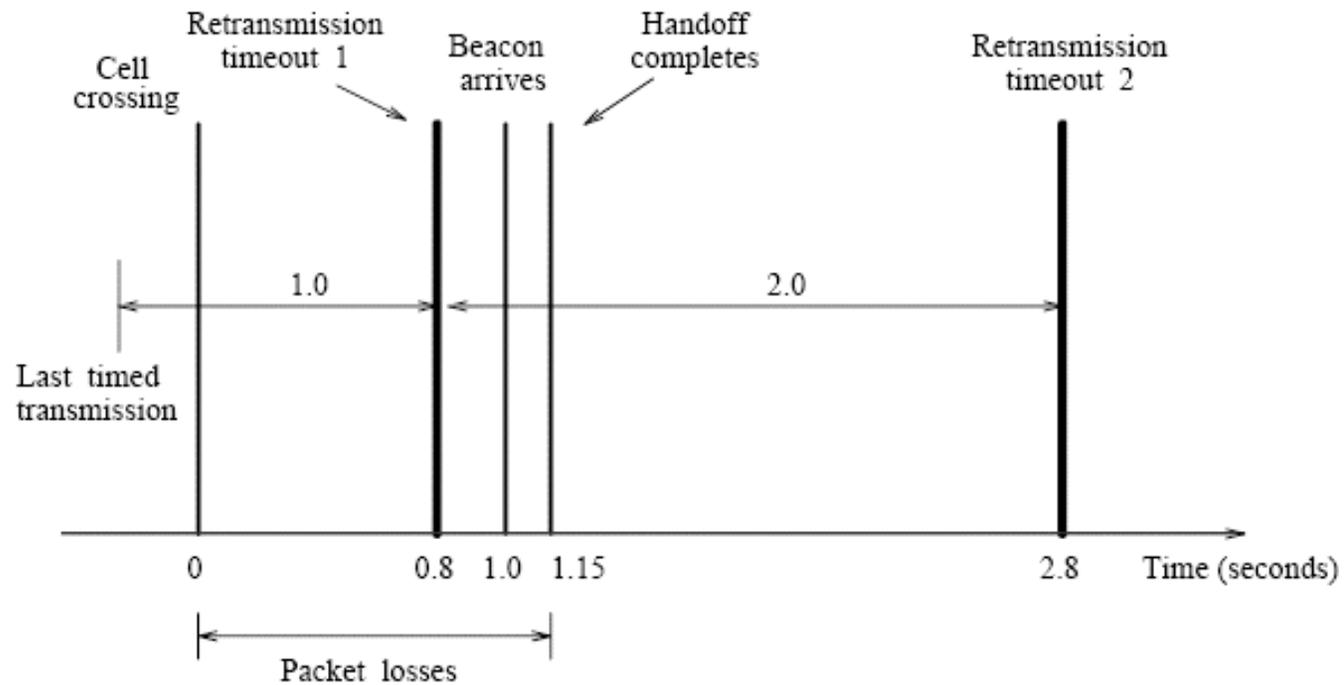
- Cell crossings with a 1 second rendezvous delay

Packet loss during handoff



- Cell crossing with 0 rendezvous delay

Packet loss during handoff



- Cell crossing with 1 rendezvous delay

Problems caused by motion/mobility

- Packet losses
 - Hosts leave cells without warning (?)
 - Beaconing period limits how soon handoff begins
 - Two packet exchanges necessary to change routes
 - Routing inconsistencies cause futile transmissions
 - Up to a full window of data and ACKs are lost
- Transport level reacts badly to motion
 - Backoffs freeze TCP for ≥ 0.8 seconds
 - Slow-start throttles TCP for another ≥ 1 second
- How do we fix these problems
 - Hide motion from transport level ?
 - Adapt transport level to react better to motion ?

Hide Motion?

- Should strive for smooth handoffs
 - Make before break handoff protocols
 - More frequent or continuous beacons
 - Use signal strength to anticipate cell crossings
 - Buffer data in MSS while handoff completes
- But microcellular networks make it difficult
 - Many small cells
 - Little or no overlap between cells
- Microcellular networks are desirable for three reasons
 - Efficient reuse of electromagnetic spectrum
 - Low power consumption by mobile transceivers
 - Accurate location information

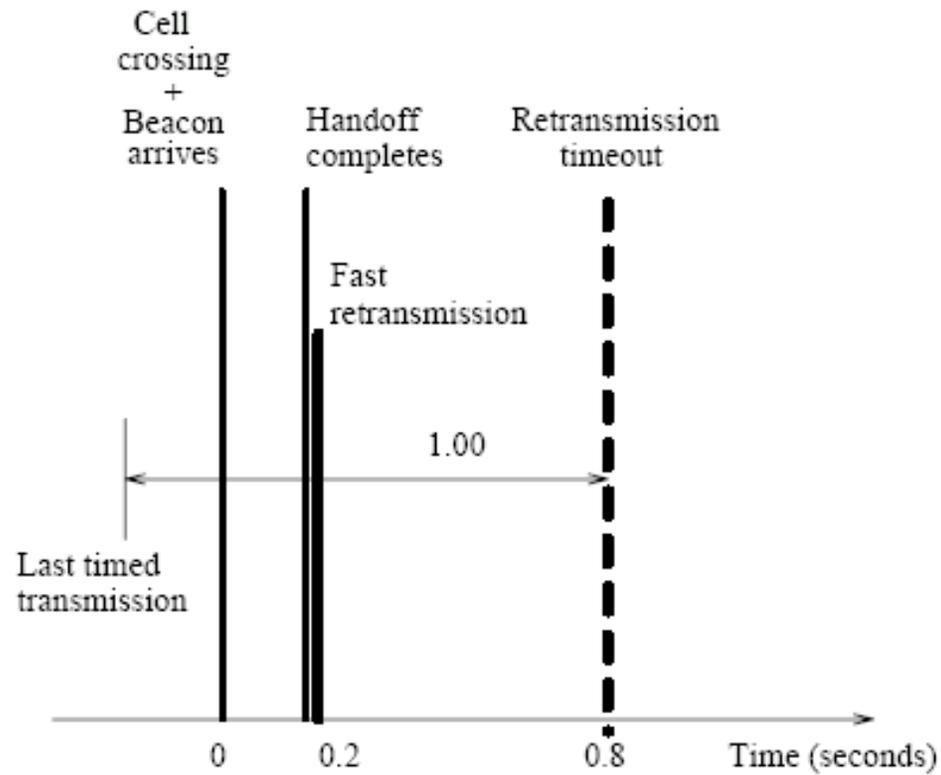
Fix Re-transmission Timers ?

- Long pauses are due partly to long timeout values
 - TCP implementations use coarse timer
 - Minimum timeout values are 0.6 to 1 seconds
- Actual roundtrip times are much smaller
- But more accurate timers may not help
 - Multiple timeouts during handoffs
 - Multiple retransmissions before routes are consistent
 - Retransmission backoff grows exponentially causing more delay
 - Slow-start threshold decays exponentially
 - Other spurious retransmissions

An end-to-end Approach

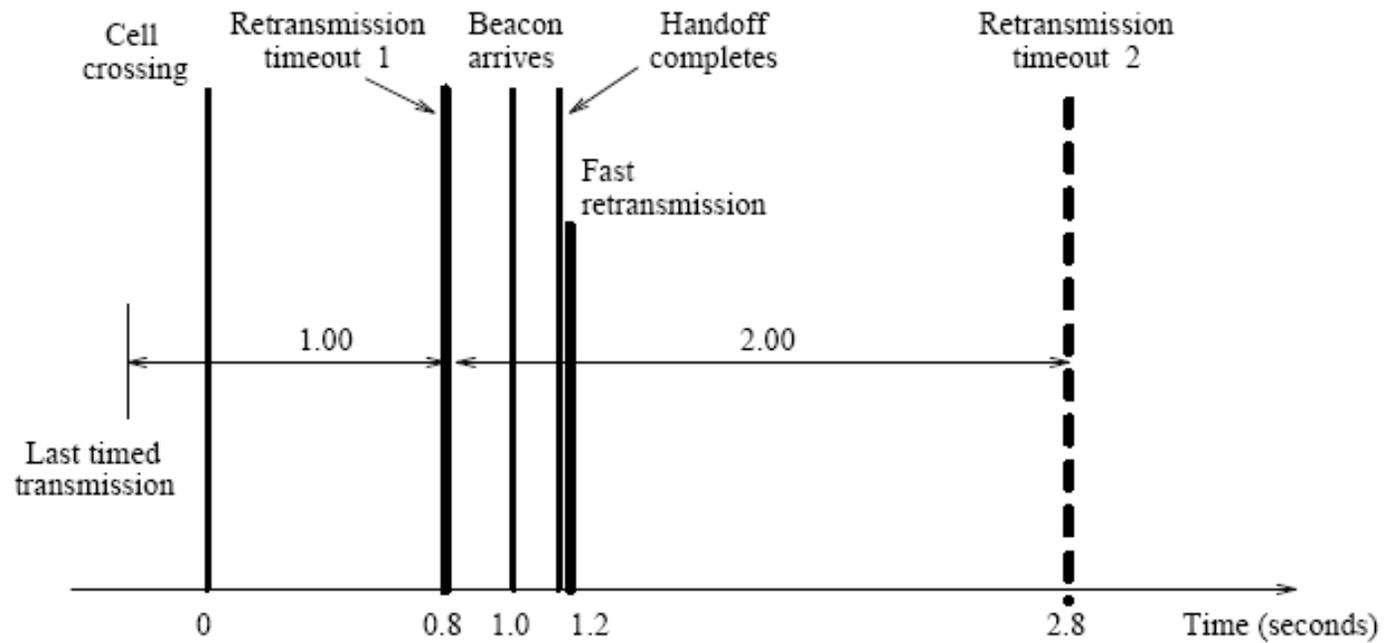
- Resume transport-level communication after handoffs
 - Signal transport level when routes settle
 - Invoke fast retransmission procedure
- Fast retransmission procedure
 - Retransmit earliest unacknowledged packet
 - Drop transmission window
 - Initiate slow start
- Advantages
 - Avoids waiting for retransmission timeout
 - Avoids congesting the new cell
 - Requires minimal changes to end systems
 - Requires no special support from network
 - Preserves end-to-end semantics

Fast Retransmission Approach



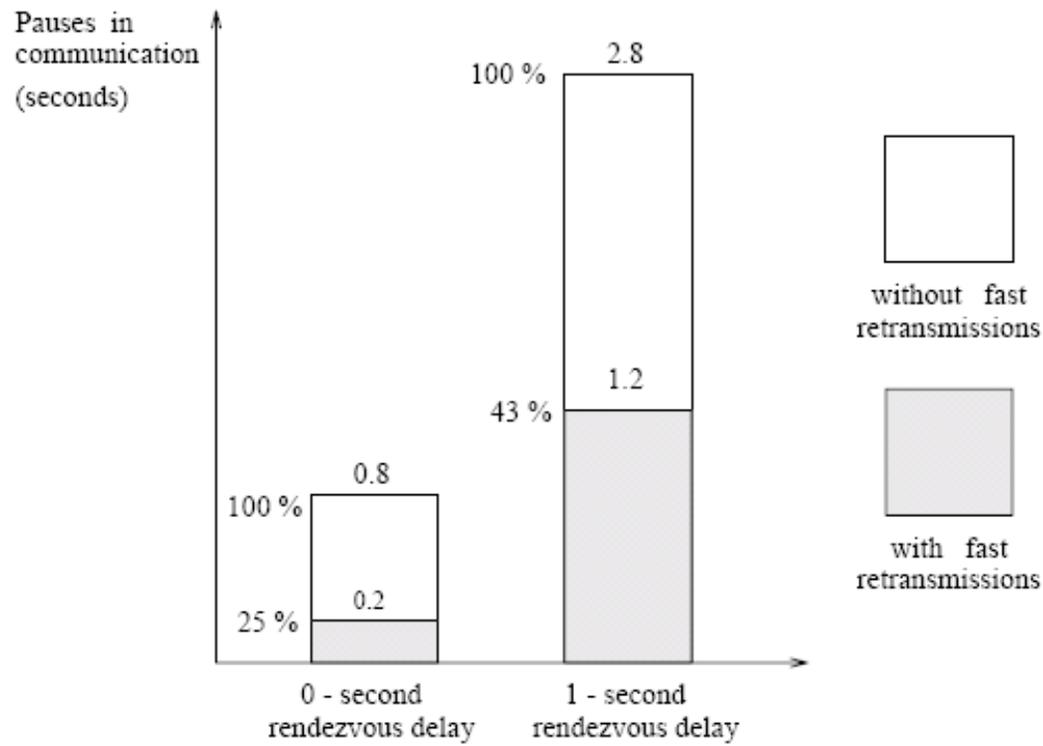
Cell crossing with a 0-second rendezvous delay

Fast Retransmission Approach (cont)



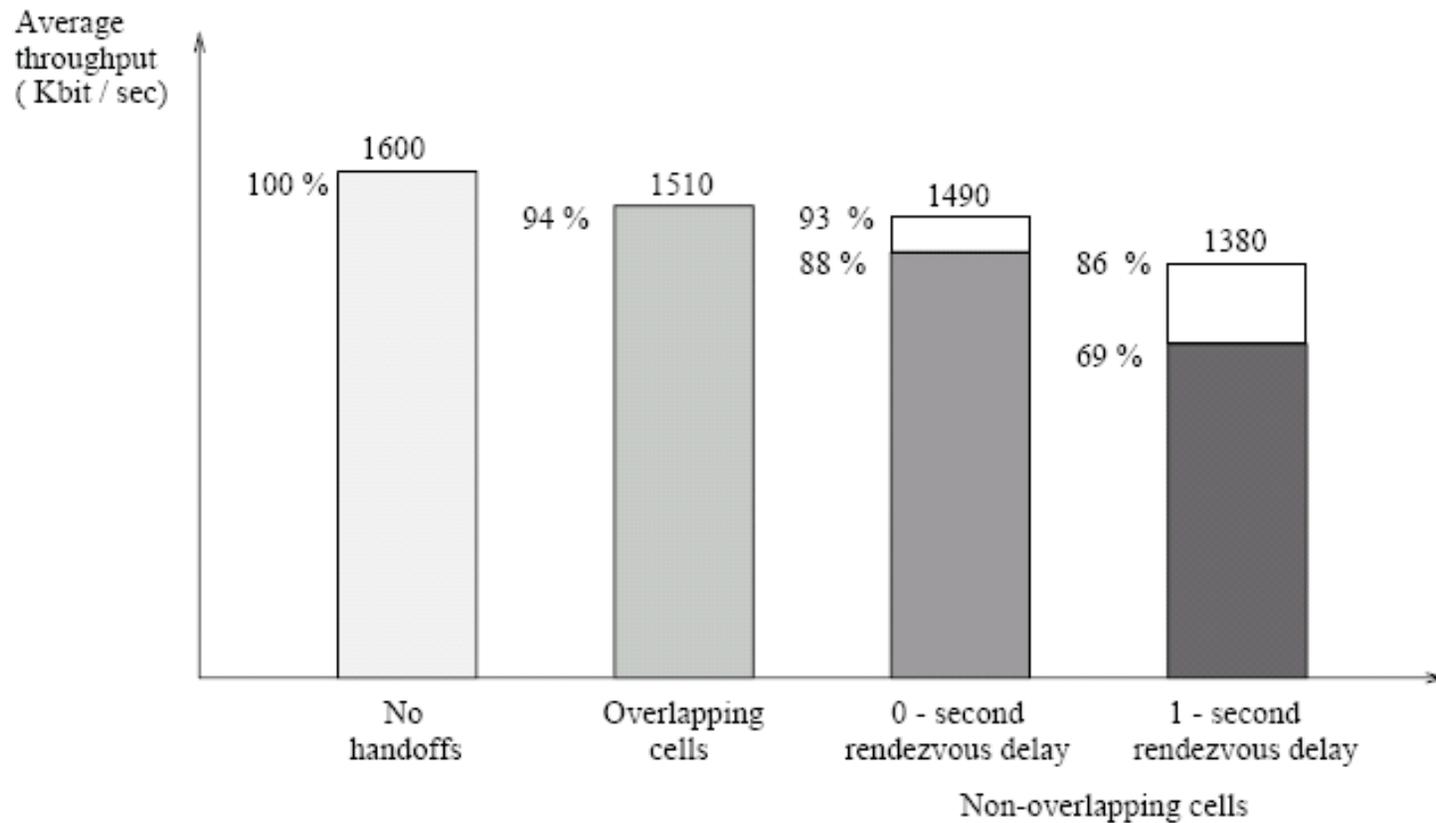
Cell crossing with a 1-second rendezvous delay

Improvements in Latency



Transmitter on the MH

Improvements in Throughput



Transmitter on the MH

Conclusion

- Measured the effects of motion
 - Unacceptable interactive response
 - Significant throughput degradation
- Identified the underlying causes
 - Cell crossings cause packet losses
 - Backoffs freeze communication for ≥ 0.8 seconds
- Proposed an effective end-to-end solution
 - Uses existing fast retransmissions
 - Reduces latency to acceptable levels (200ms – 300ms)
 - Significantly improves throughput
 - Preserves end-to-end semantics
 - Avoids network congestion
 - Works over the Internet

Discussion...

- “Micro-Cellular” networks as motivation (one handoff every 8s)...
- Are the long delays a function of poor implementation ?
 - Sec C. MH leaves cell without warning ?
 - Sec C. “The MH doesn’t know it has moved, thus does not update routes until new beacon arrives” ?
 - Sec D. “Mobile-IP is user level code” ?
- Beacons – 1s beacon interval pretty high (100ms for 802.11)
 - Would have been good to see intermediate results for other periods
- Would the performance be better if link-layer retransmits are used ?
 - 802.11 uses link-layer re-transmits (upto 8?)
 - Not really, as link-level retransmits are not effective for mobility losses
- 802.11 improvements to have better handoff
 - Proactive/passive scanning for APs, 100ms beacon intervals
 - Link-layer ACKs, Inter Access Point Protocol (IAPP)
 - Explicit Re-association packets on performing handoff, gratuitous ARPs

Wireless Transmission errors

- Wireless links exhibit high bit error rates
 - Ambient noise multipath interference
 - 10^{-6} for radio/infrared vs 10^{-12} for optical ber
- These errors also cause transport level problems
- But link-level retransmissions may not help
 - Competing retransmission timers
 - Transport level may time out first
- Other possible solutions
 - Selective retransmissions
 - Forward error correction