Network-Aware Application Adaptation for Mobile Hosts

Benjamin Atkin and Kenneth P. Birman

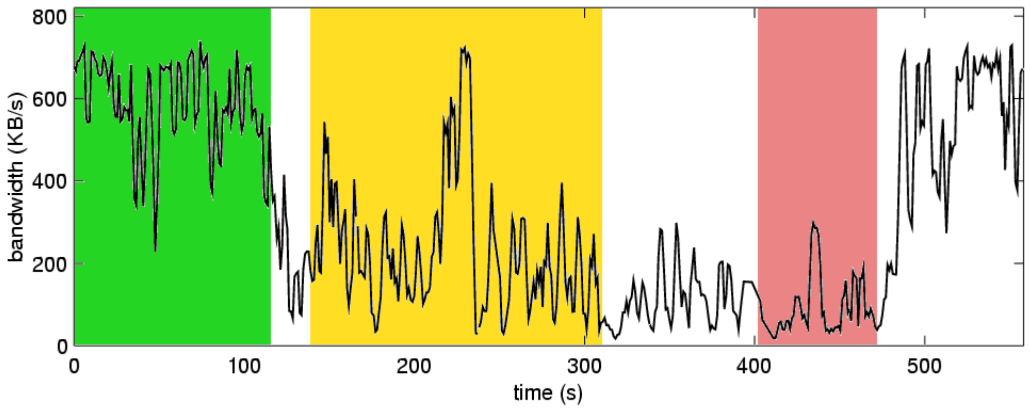
Department of Computer Science
Cornell University
Ithaca, NY

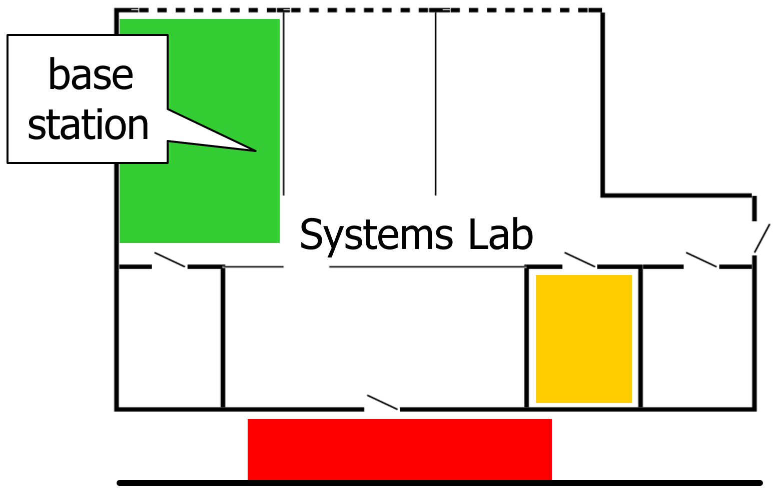
Network-aware adaptation

- Adapting to variable network behaviour
  - Availability of bandwidth
  - Amount and types of traffic
- Structure application communication
  - Rapid adjustment to changes
  - Efficient use of bandwidth
- Principal example: wireless networks

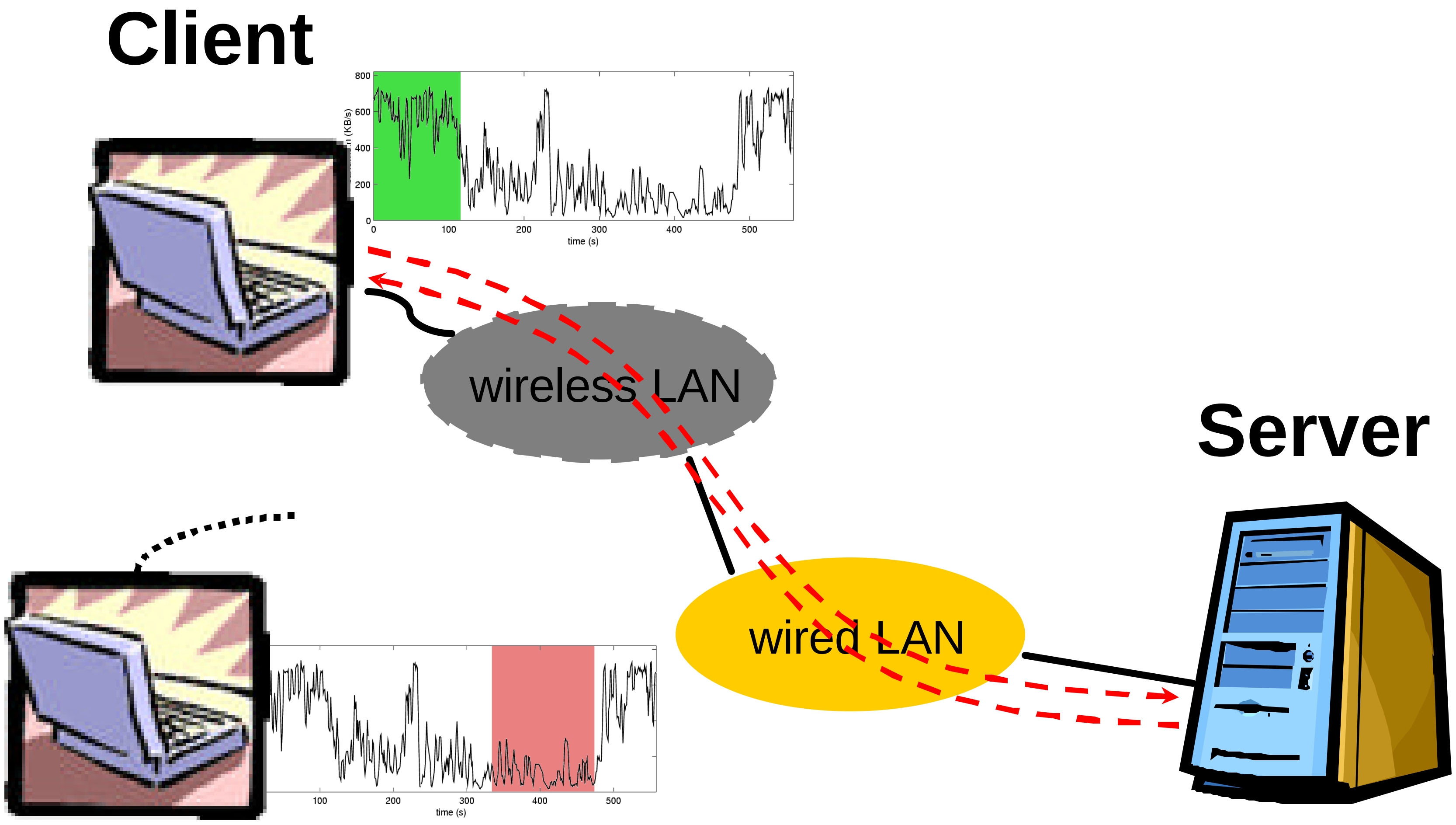
Wireless network characteristics

- Noisy medium leads to high error rates
  - 802.11b is "reliable", but throughput drops
- Mobile hosts experience rapid changes
  - Difficult to predict future bandwidth





System setup



Application adaptation

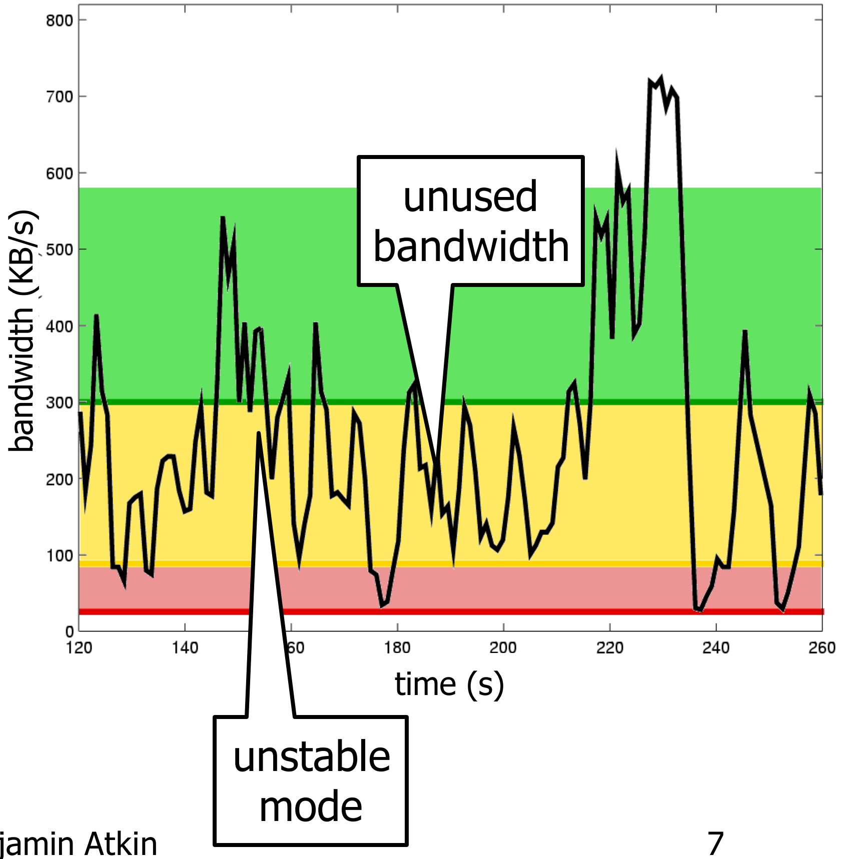
- Applications using network must adapt
  - Interactive tasks need good response time
  - e.g. Video, web browsing
- Multiple forms of network adaptation
  - Monitor network characteristics
  - Control bandwidth allocation
  - Poll status of ongoing operations
  - Prioritise concurrent data transmissions

Related work

- Network-level adaptation
  - wireless TCP enhancements: ELN [BPSK97], I-TCP [BB97], M-TCP [BS97]
  - congestion control/bandwidth allocation: Congestion Manager [ABCSB00], SCTP [RFC2960]
- Web browsing and video streaming
  - Transcoding through proxies: TACC [FGBA96], ...
  - Quality adaptation for streaming video [RHE99, ...]
- Application support
  - Odyssey [BN99]
  - Rover [ATK97]
  - HATS [LWZ02]
- Distributed file systems
  - Coda [KS92], Little Work [HH95]
  - Ficus [PGH+98,KP97]
  - Low-Bandwidth File System [MCM01]

Modal adaptation

- Small number of modes
  - each corresponds to data quality/fidelity
  - bandwidth determines mode
- Can waste bandwidth
- Changing modes could be expensive
- Not all applications have natural modes



Modeless adaptation

- Variable bandwidth or variable traffic
- Multiple classes of communication
  - e.g. HTML, images
  - not equal importance
- Fine-grained, bursty
  - make decisions on a per-message basis

Adaptation by autoconfiguration

- Modeless adaptation reconfigures communication automatically
  - communication "policy" changes with bandwidth
  - analogous to discovering modes
  - no need to assign thresholds

Adaptive applications

- Well-suited for RPC client-server applications
  - Distributed file system
  - E-mail client
  - Publish-subscribe
  - Web browsing
  - Web services with "differentiated service" to clients

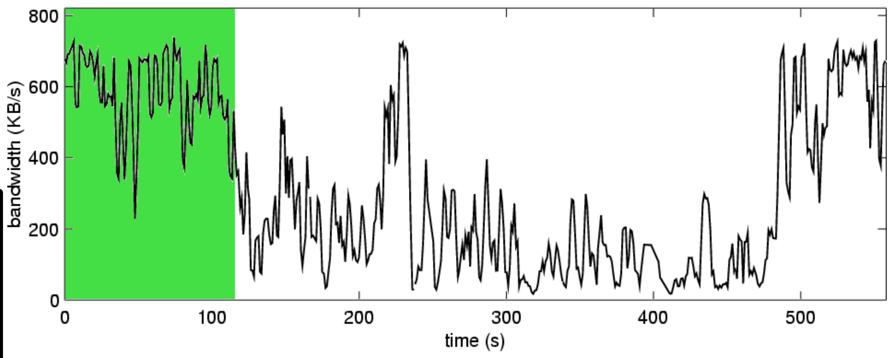
Applying modeless adaptation

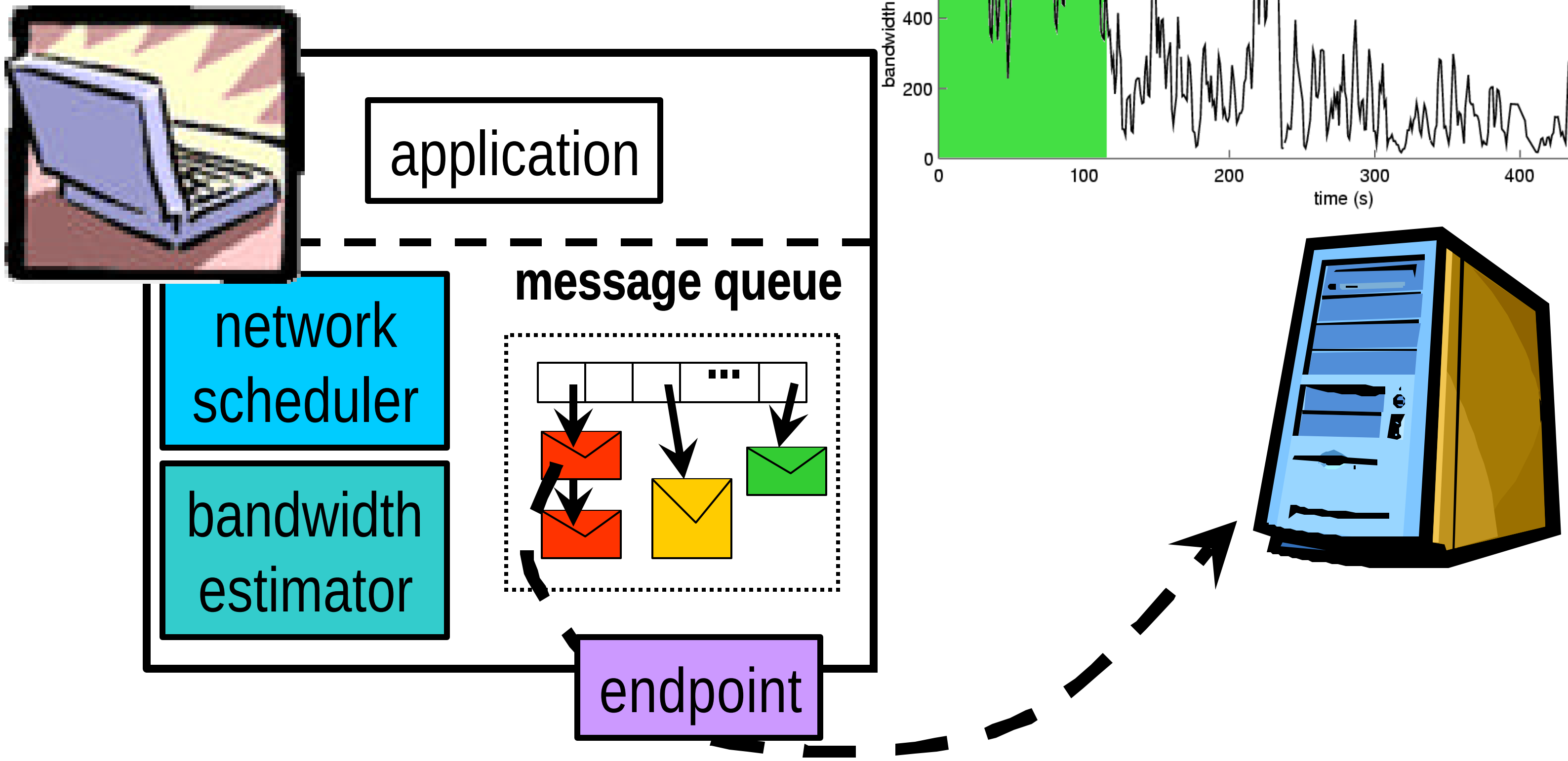
- Two levels of adaptation investigated:
  - ATP: adaptive transport protocol [Infocom 2003]
  - MFS: adaptive distributed file system

Adaptive Transport Protocol (ATP)

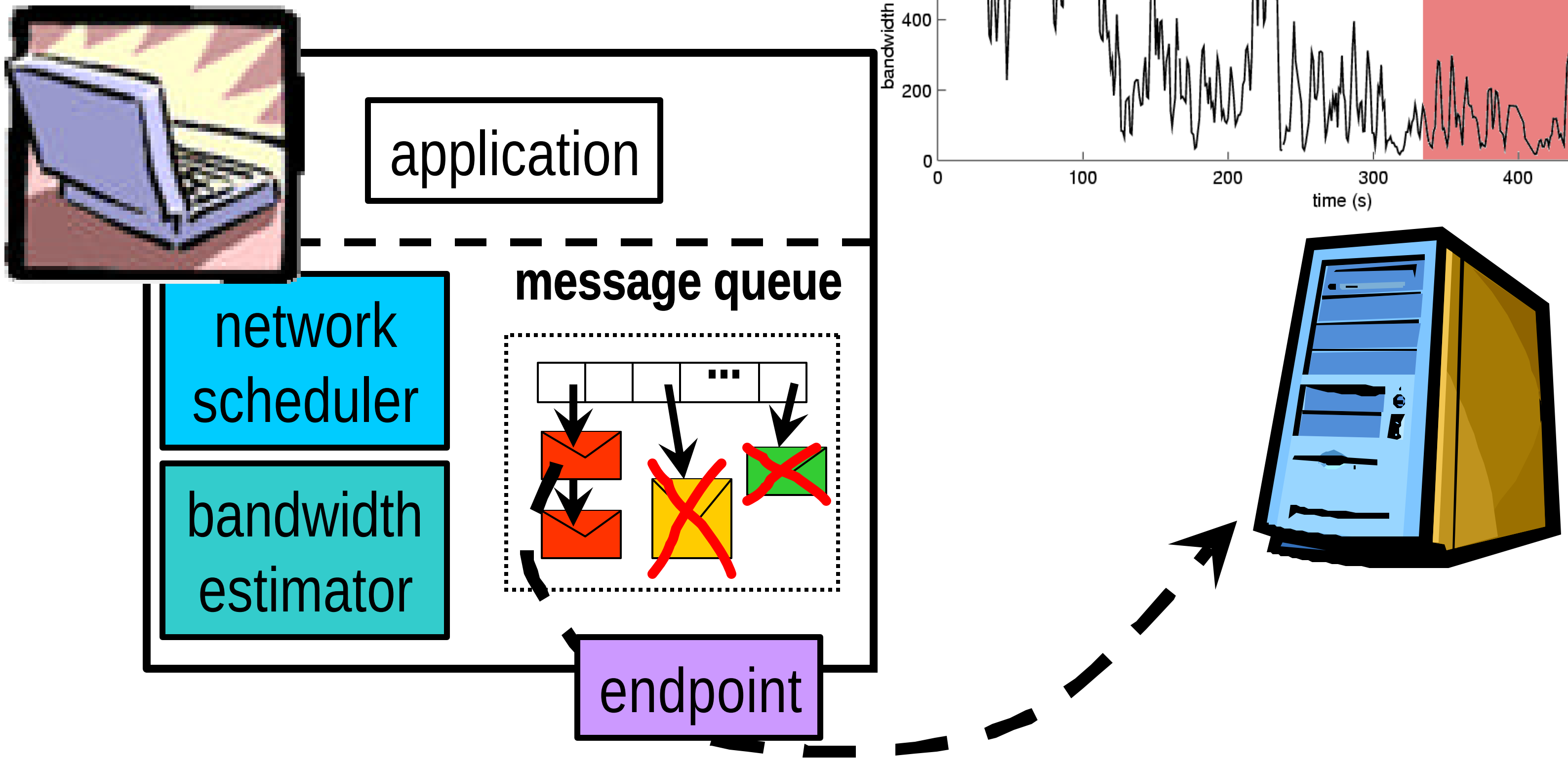
- Message-oriented
  - Reliable delivery
- Bandwidth notifications via upcalls
- Priorities to determine send order
- Allows speculative communication
  - High priority preempts low priority
  - Inessential activity can run "in background"
  - e.g. Prefetching files

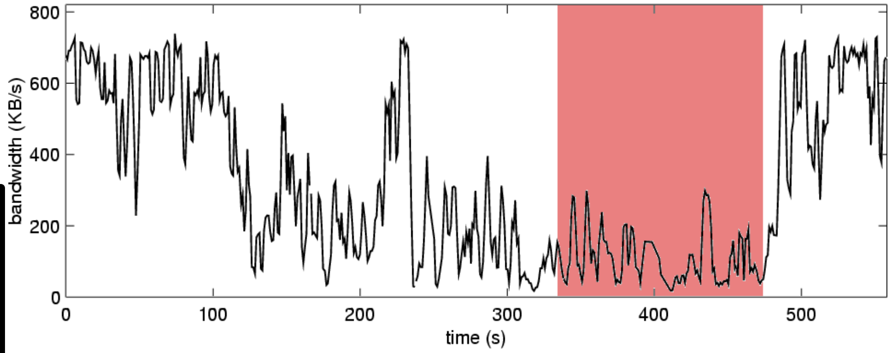
ATP implementation





ATP implementation





ATP adaptation

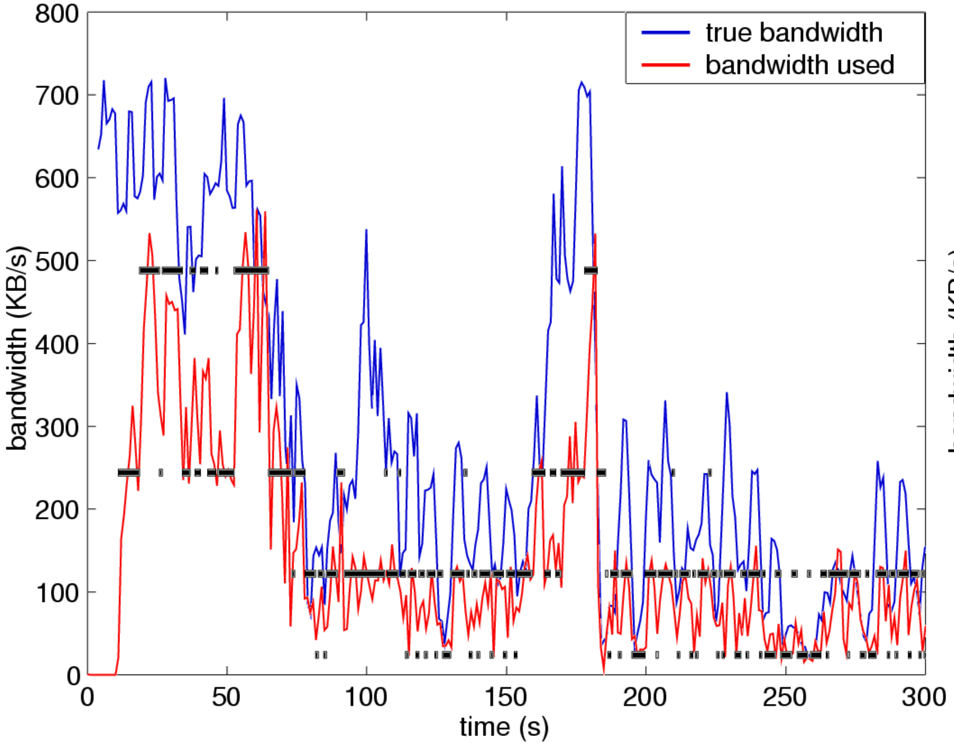
- Supports multiple adaptation styles
  - Modal using bandwidth notification
  - Modeless using send timeouts
  - Modeless using priorities

Modal versus modeless adaptation

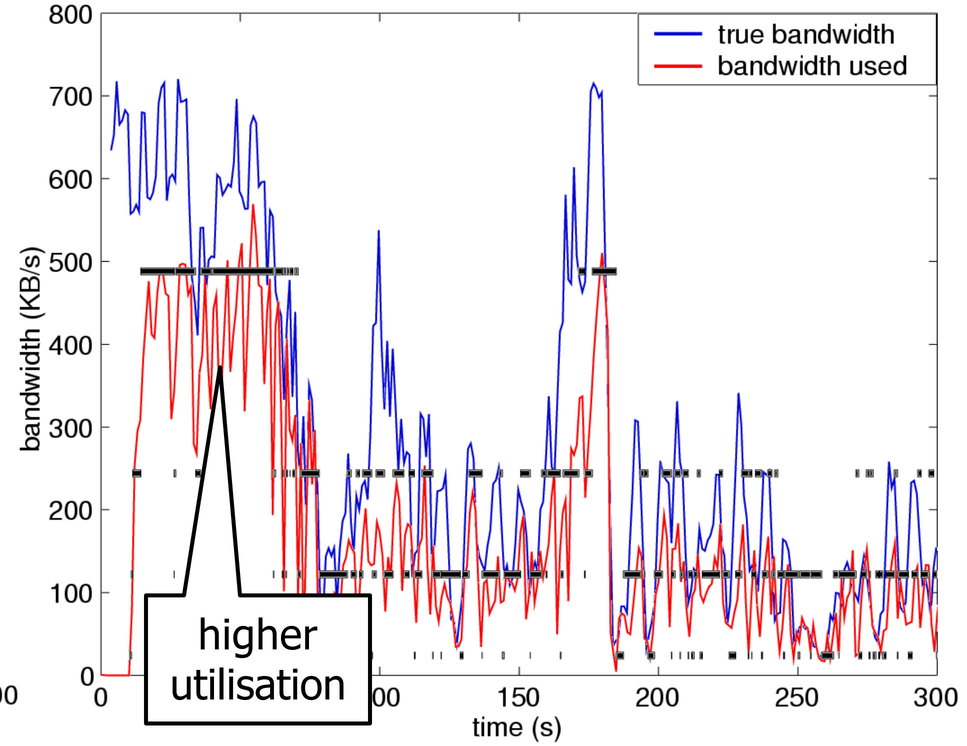
- Compared using a video-like workload
- Transfer data at 4 levels of quality
  - level 1 lowest, level 4 highest
- Modal: 4 modes, bandwidth estimates
- Modeless: differential encoding with priorities
  - transfer level 2 messages iff level-1 all delivered, etc

Modal versus modeless adaptation: example

Modal adaptation

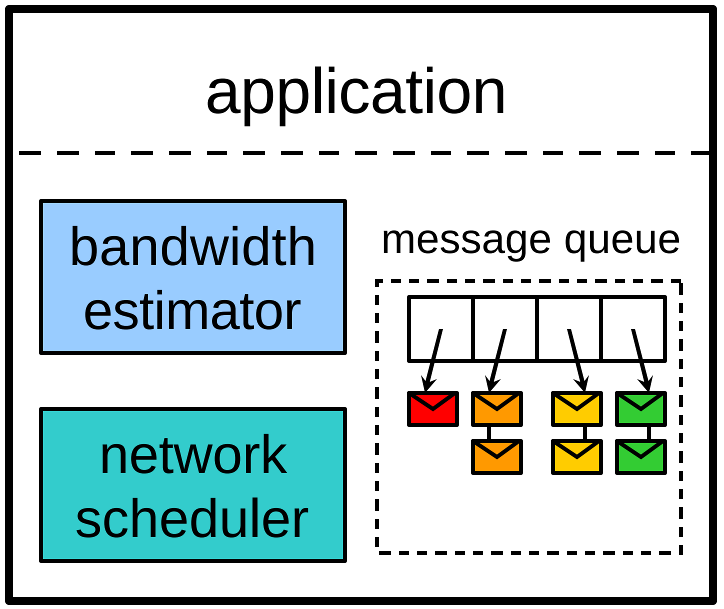


Modeless adaptation

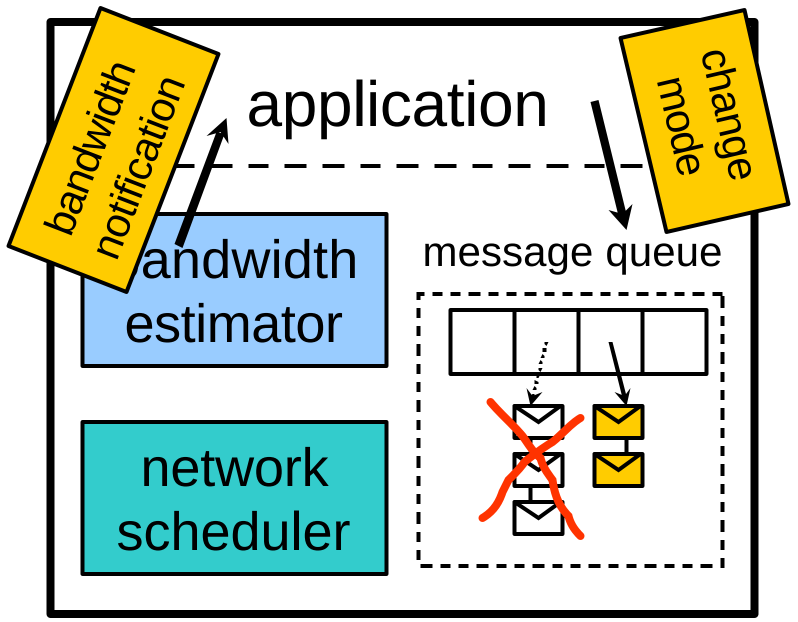


Modal versus modeless adaptation: explanation

Modeless adaptation



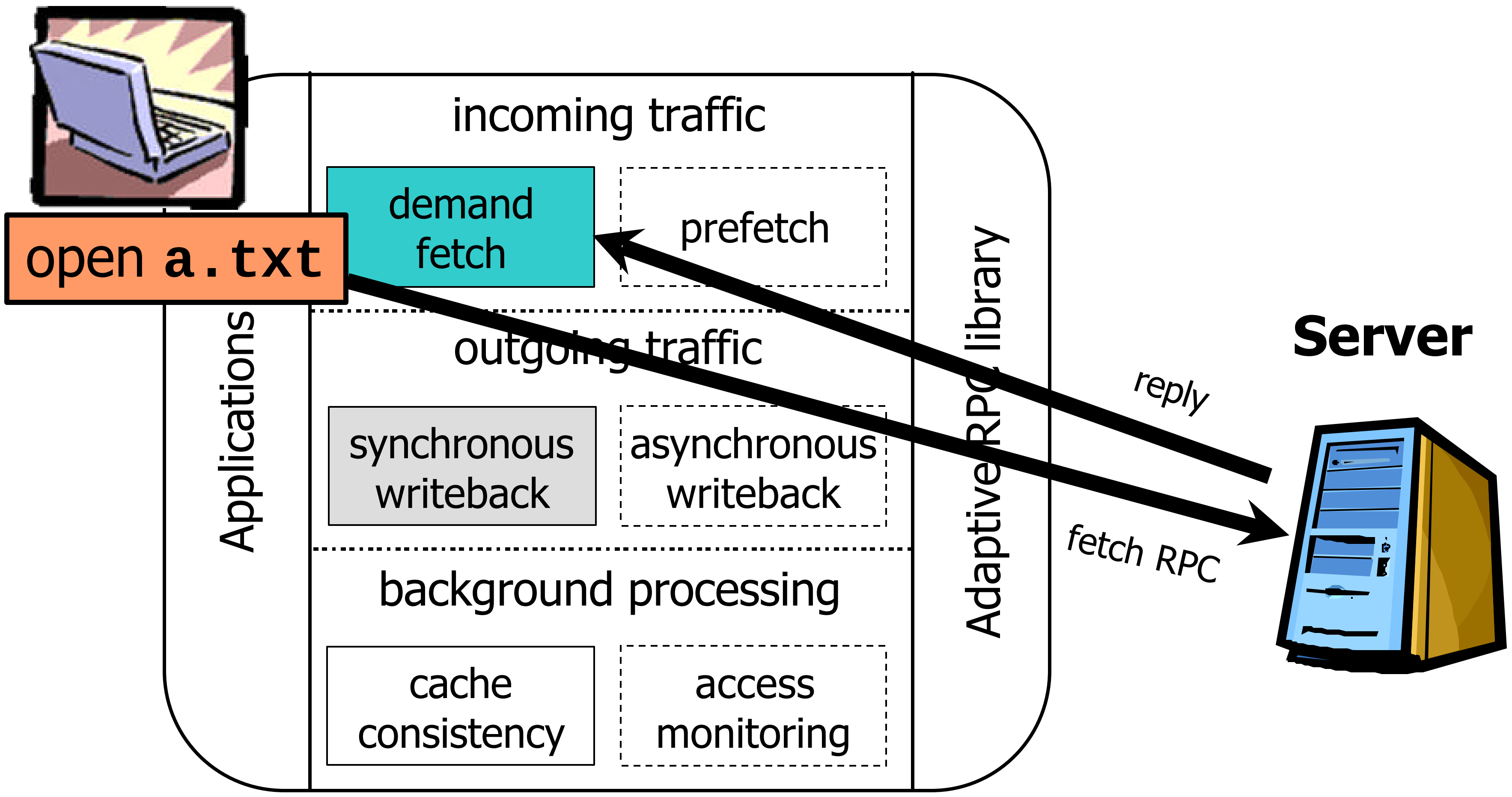
Modal adaptation



Mobile File System (MFS)

- AFS-style client-server design
  - Whole-file client-side caching
  - Stateful file server
  - Writeback-on-close semantics
- Modeless adaptation via ATP
- Filesystem-specific adaptation mechanisms to improve performance

MFS cache manager



Coda-style modal adaptation

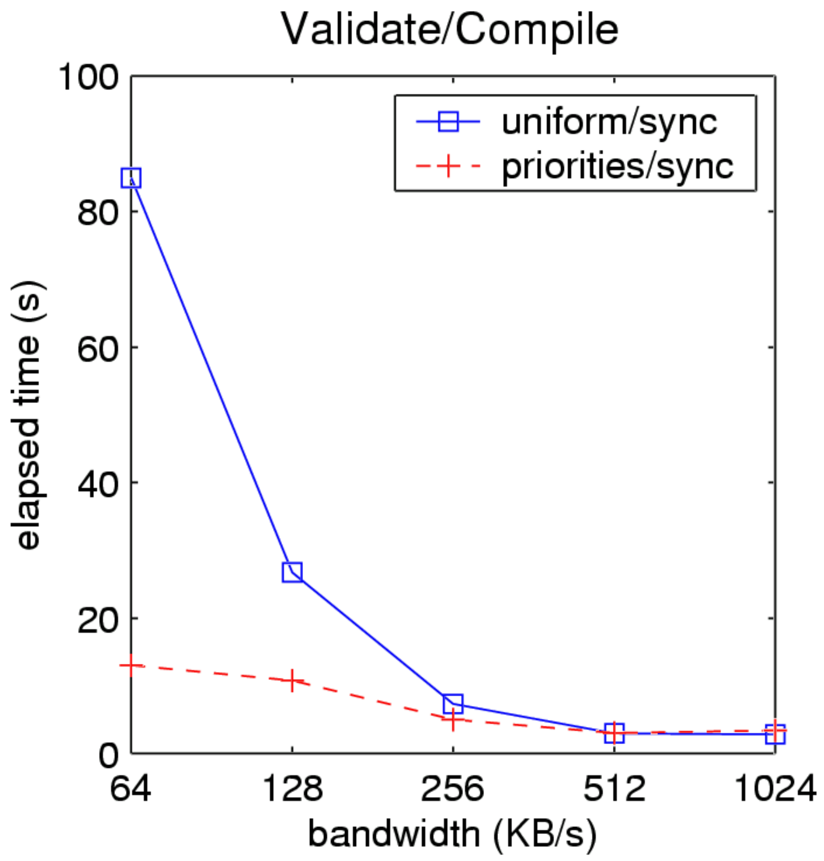
- Strongly-, weakly-connected or disconnected
- Weakly-connected mode
  - Log writebacks at low bandwidth
  - Periodic log flushes reduce traffic
- "Unpredictable" changes in semantics

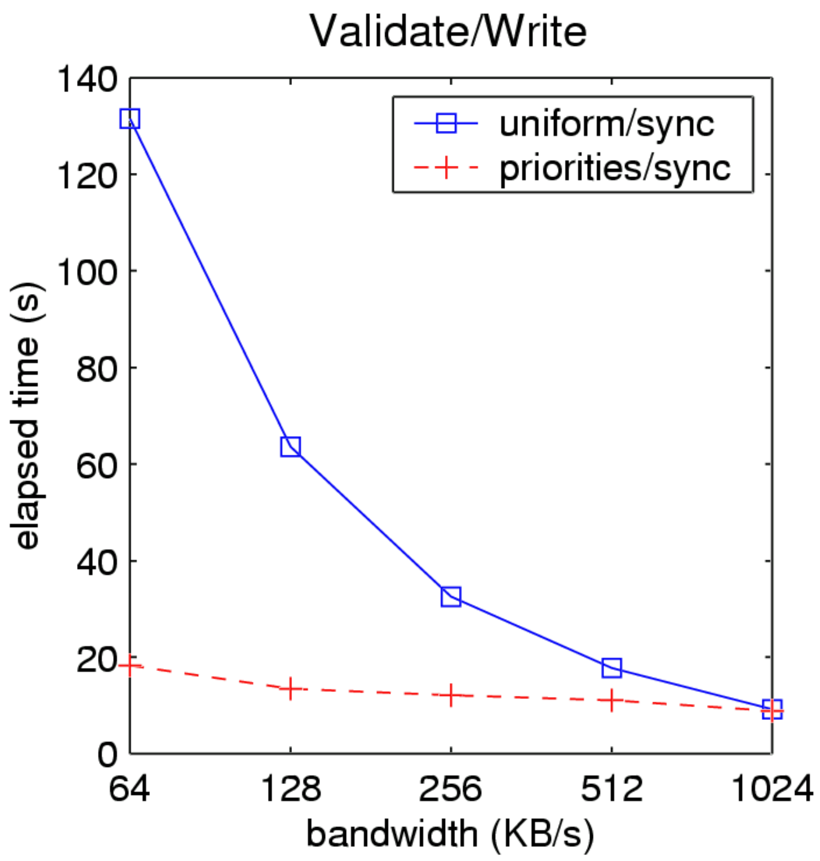
MFS adaptation to bandwidth variation

- Each RPC type has a priority
  - "Background operations" => low priority
  - "Interactive operations" => high priority
- ATP favours high-priority RPCs
- Background asynchronous writeback at all bandwidth levels

VALIDATE (high)
FETCH DATA
METADATA
STORE DATA
PREFETCH (low)

Validate workload



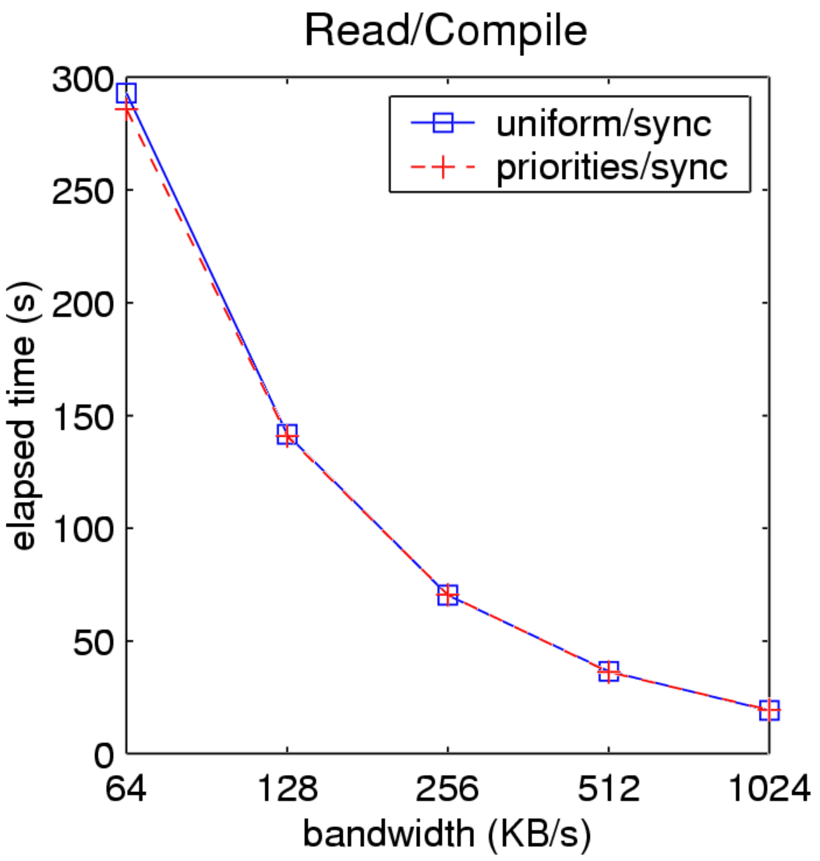


foreground: small RPCs
background: large RPCs, CPU-bound

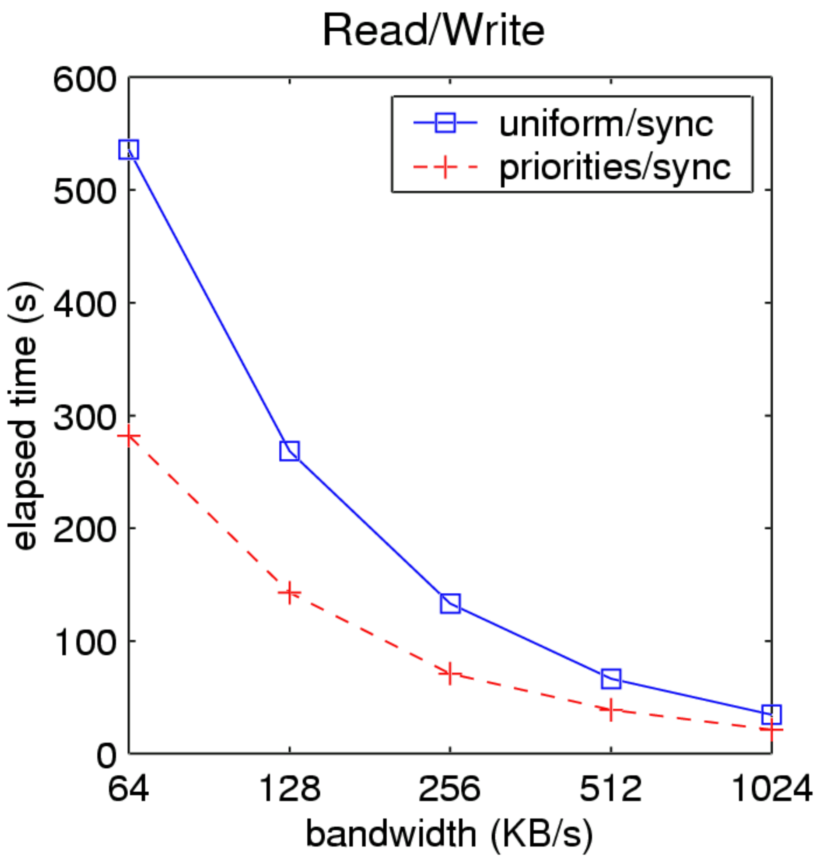
foreground: small RPCs
background: large RPCs, I/O-bound

MFS priorities improve completion time of small RPCs

Read workload



foreground: large RPCs
background: large RPCs, CPU-bound



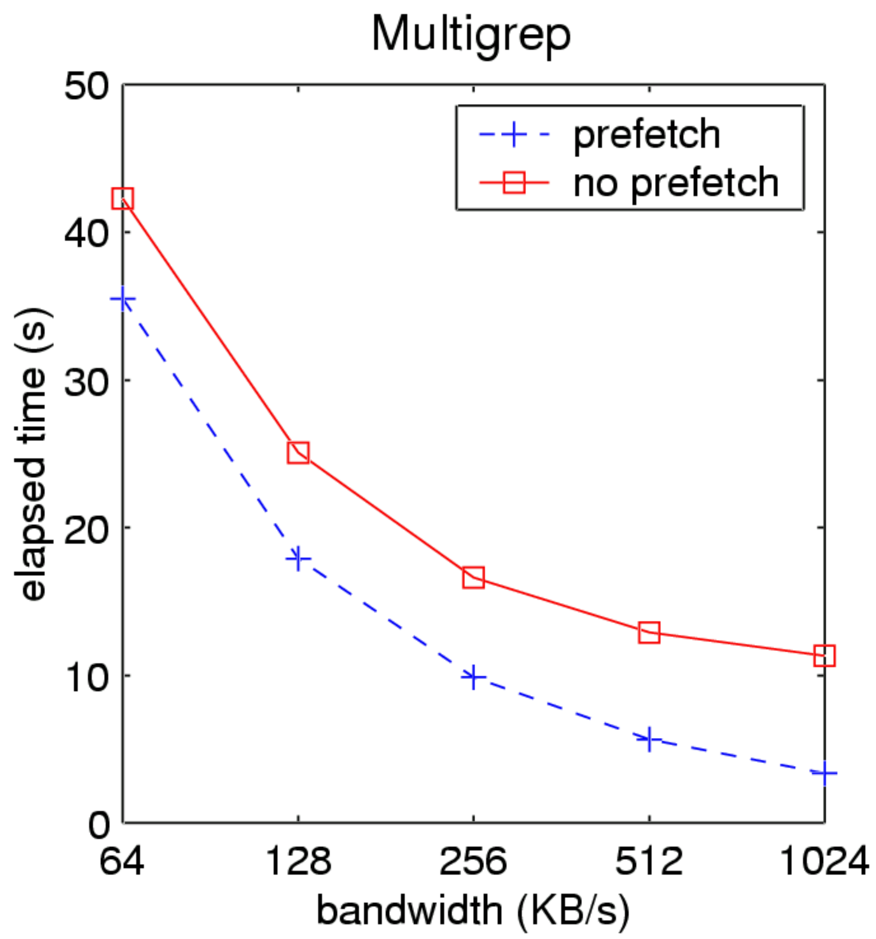
foreground: large RPCs
background: large RPCs, I/O-bound

MFS priorities improve completion time of large RPCs

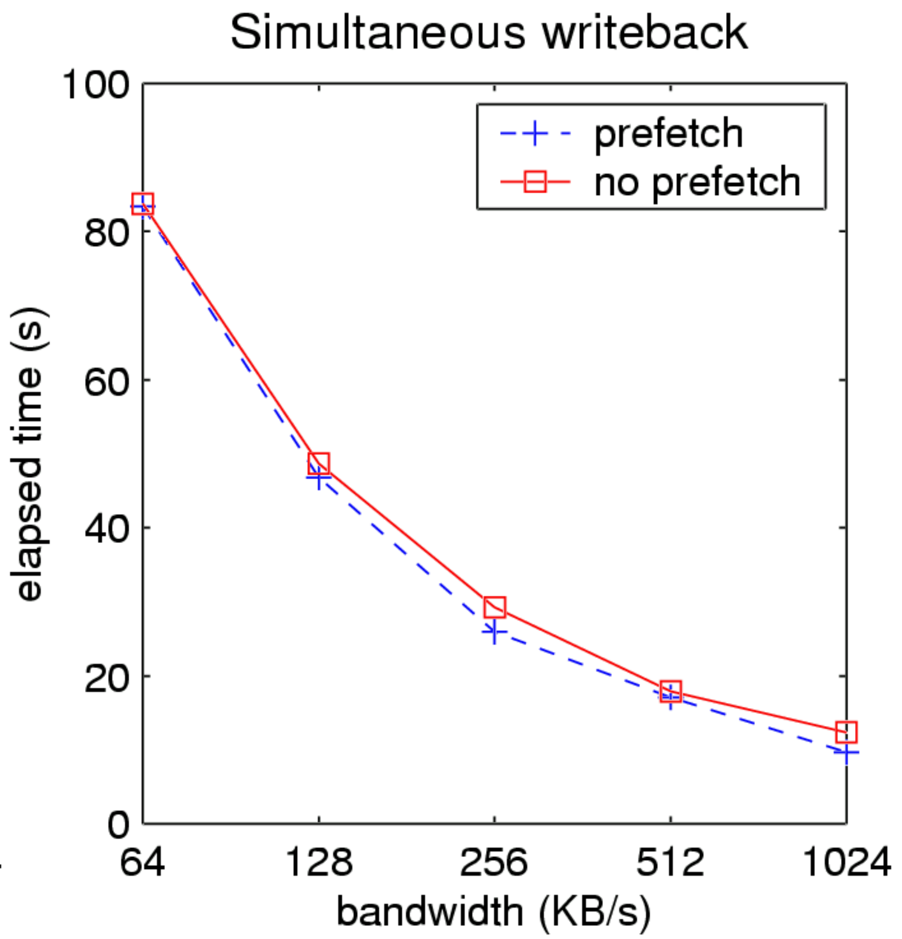
Background prefetching

- Extension from local file systems
  - Use surplus bandwidth speculatively
- Relies on prefetching hints
  - e.g. Application dependencies
- Automatically-generated file groups
  - Accessing a member triggers prefetching
  - Implemented as a special file type

Examples of prefetching



large "think time", surplus bandwidth



background write contention

Prefetching can be highly beneficial, rarely a liability

Prefetching statistics

test	elapsed time	traffic	good prefetches	bad prefetches
multigrep	28%	1.9 MB	1.9 MB	0.0 MB
pause	40%	8.0 MB	5.9 MB	0.0 MB
sim. demand	73%	8.0 MB	3.9 MB	0.1 MB
sim. writeback	69%	8.0 MB	3.8 MB	0.1 MB

Large think time increases the possibilities for prefetch-computation overlap

Prefetching statistics

test	elapsed time	traffic	good prefetches	bad prefetches
forward order	88%	8.0 MB	7.8 MB	0.0 MB
reverse order	76%	8.0 MB	3.6 MB	0.0 MB
bad groups	132%	4.0 MB	0.0 MB	18.1 MB

"Fast-linear-scan" can reduce benefit

Poor prefetching hints can decrease peformance (rare case)

MFS: future work

- Reconciling asynchronous writeback with strong cache consistency
- Consistent access to stale files
- Automatic derivation of caching policies from file usage patterns
- Performance under actual use

Summary

- Modeless adaptation provided by ATP
  - Improves bandwidth utilisation
  - Allows fine-grained adaptation at RPC level
- MFS: modeless adaptation in a file system
  - Priorities for RPC types using ATP
  - Speculative communication mechanisms to improving performance (e.g. prefetching)