PAN: A High-Performance Active Network Node Supporting Multiple Mobile Code Systems

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`http://www.pdos.lcs.mit.edu/~nygren/pan/`

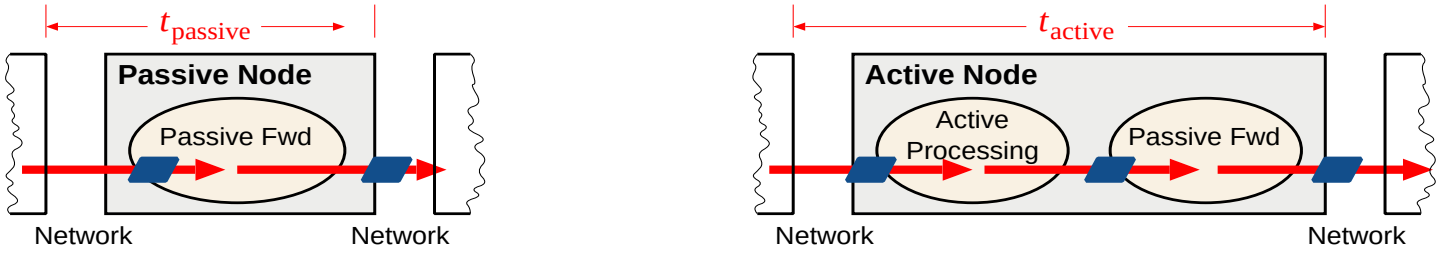
Active Networks

- Traditional *passive* networks forward packets based on packet headers
- *Active networks* process *capsules* containing both code and data
  - Code tells the node what to do with the capsule
  - Allow new network protocols to be dynamically deployed
  - Critical issues:
    performance, safety, security, resource management, interoperability
- *PAN* is a high-performance active network node
  - Inspired by Wetherall and Tennenhouse's *ANTS* system
  - Designed for performance and to allow experimentation
    with active network implementation issues

The Active Overhead

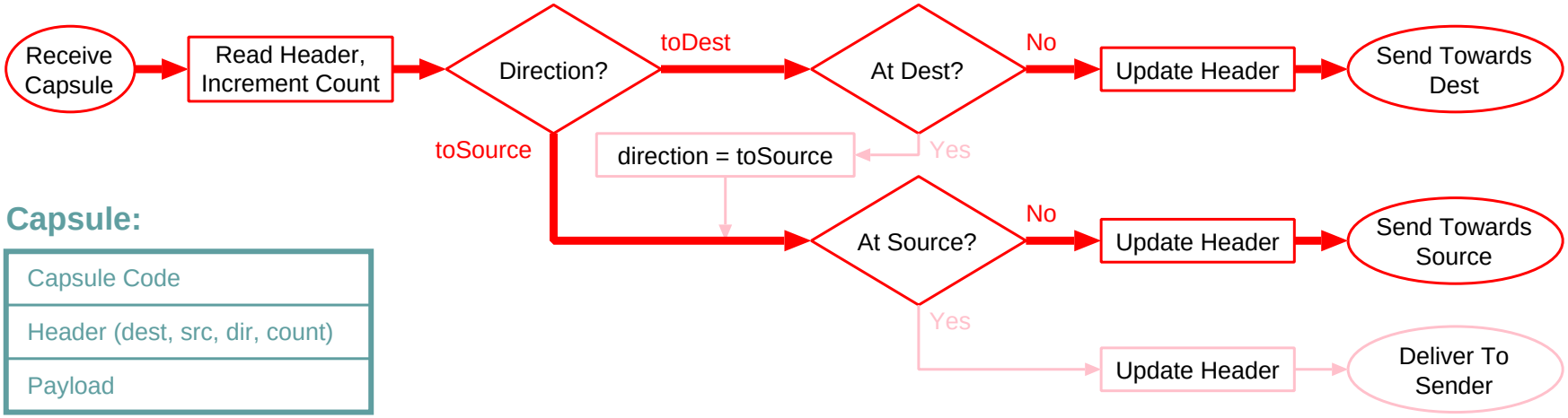
- Prototype active nodes written in Java and running in user-space tell little about potential performance
- Goal: demonstrate that an active node can obtain high performance with a low *active overhead*
- *Active overhead* is the percentage increase in processing time between passive and active forwarding:

$$\text{ActiveOverhead} = 100\% \cdot \left(\frac{t_{\text{active}} - t_{\text{passive}}}{t_{\text{passive}}}\right)$$



The Baseline Performance Hypothesis

- **Baseline Case:** a simple "ping" capsule which heads towards a destination then returns towards a source:



  - Functionality can be added incrementally to the baseline with an incremental performance cost

- **Performance Hypothesis:** In the baseline case, an active node can be made to process capsules with performance comparable to a traditional passive node while incurring only a small active overhead.

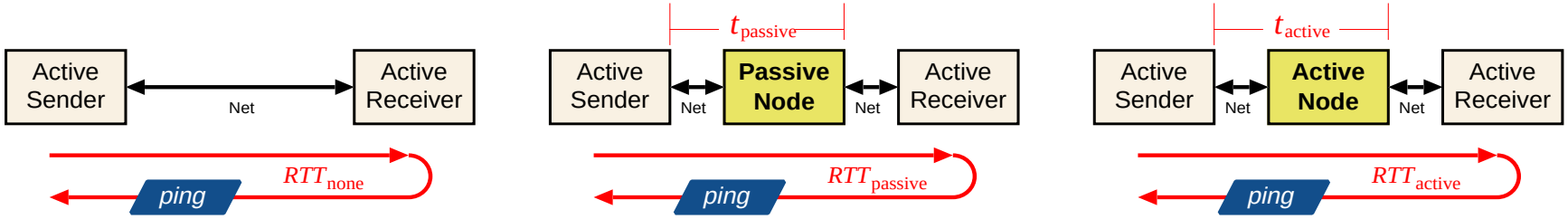
- Note: comparing against UNIX software router, not specialized hardware

Obtaining High Performance

- Approach:
  - Look at the active processing *critical path* in the baseline case
  - Eliminate potential sources of overhead
- Major sources of overhead:
  - Memory copies (bring capsule data into cache)
  - Code interpretation, loading, or translation in critical path
  - User / kernel boundary crossings
- These overheads can be eliminated through design choices
- Experiments:
  - Measure the cost of overhead sources
  - Show that overhead sources can be overcome
- **PAN points the way towards bridging the performance gap between a research prototype and a system with practical performance**

Measuring Performance

- Testbed: Three Intel PentiumPro 200's running Linux 2.0.32 with DEC Tulip-based 100 MBps Ethernet cards
- Network configurations:



$t_{\text{passive}} = \frac{1}{2} \cdot (RTT_{\text{passive}} - RTT_{\text{none}})$ For testbed, $t_{\text{passive}} = 157\mu s$

$t_{\text{active}} = \frac{1}{2} \cdot (RTT_{\text{active}} - RTT_{\text{none}})$

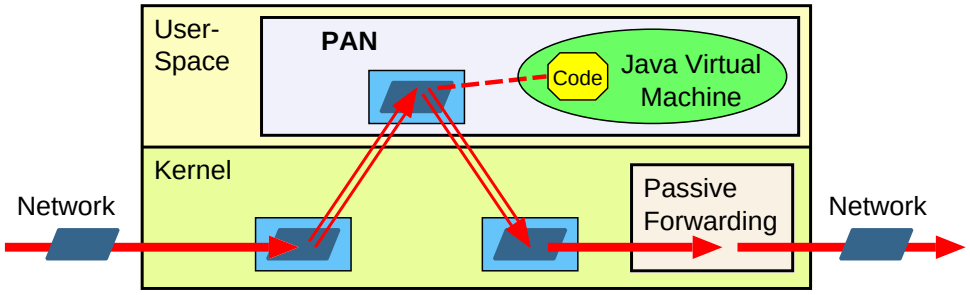
- Experiments:
  - Vary characteristics of *Active Node* and observe effect on ActiveOverhead
  - ActiveOverhead measured using 128 through 1500 byte packets

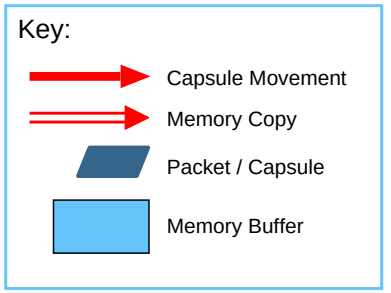
Bridging the Performance Gap

- ANTS: prototype designed without performance in mind
- PAN: can be configured with a wide range of performance characteristics

	ANTS	**PAN**
Written in...	Java	C
Mobile code	Java	Java *or* Intel native ix86 object code
Runs in...	user-space	user-space *or* kernel
Capsule data...	is copied	can be processed in-kernel without copies

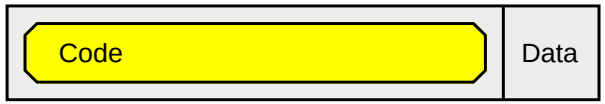
- Starting with low-performance PAN configuration:



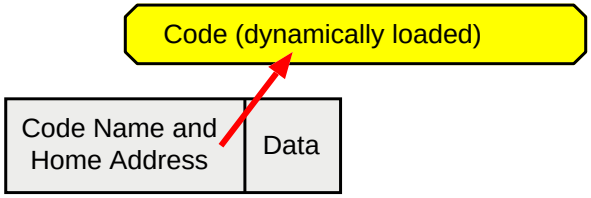


Step 1: Dynamic Code Loading and Code Naming

- Rather than having capsules *contain* code and data, capsules *name* code and contain data (done by ANTS and PAN):

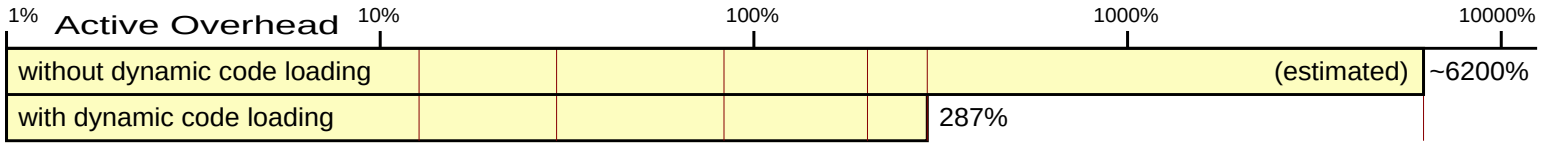


Capsule without dynamic loading



Capsule with dynamic loading

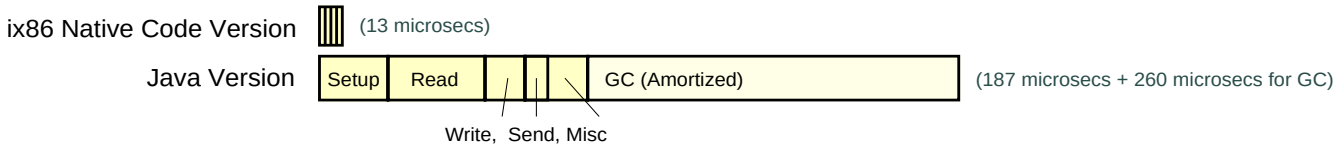
- Code is named by a crypto hash of the code, resulting in a unique name
- Code is dynamically loaded over network



(measurements using 1500 byte packets)

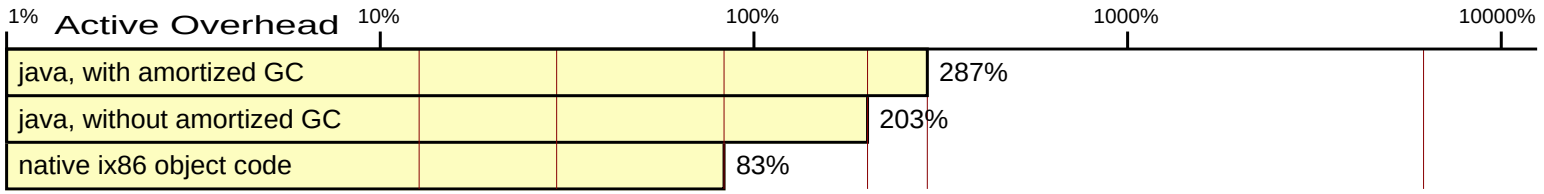
Step 2A: Importance of a Good Mobile Code System

- Current Java “Just-In-Time” (JIT) translators generate code that is much slower than comparable native code
  - Largest costs due to *garbage collection* and *object creation*
  - Some of this may be intrinsic to the design of the JavaVM
  - Comparison of baseline code run time between native ix86 code generated by gcc and Java code running in Kaffe OpenVM:



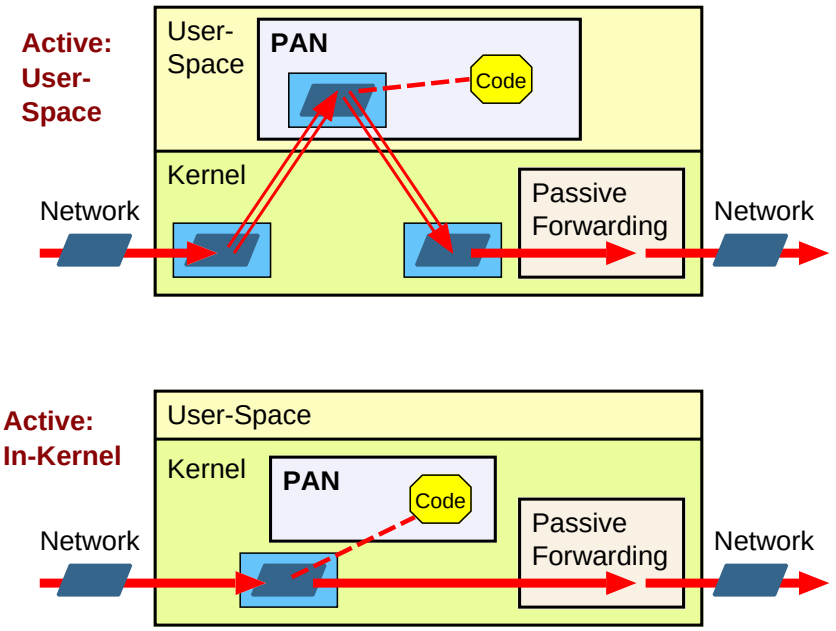
Step 2B: Using Native Code

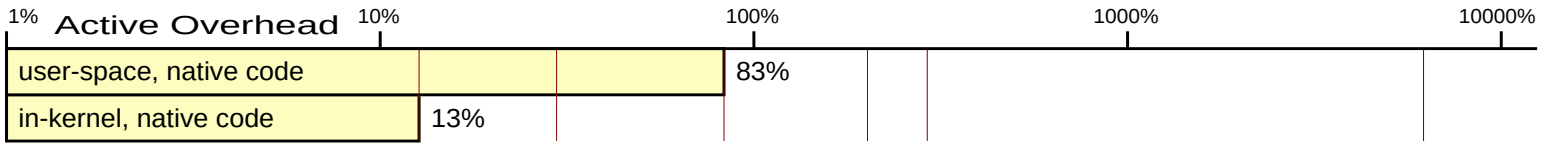
- Native code demonstrates performance that may be obtained as safe mobile code systems improve
- **Native object code doesn't provide safety, security, or interoperability!**



Step 3: Moving into the Kernel

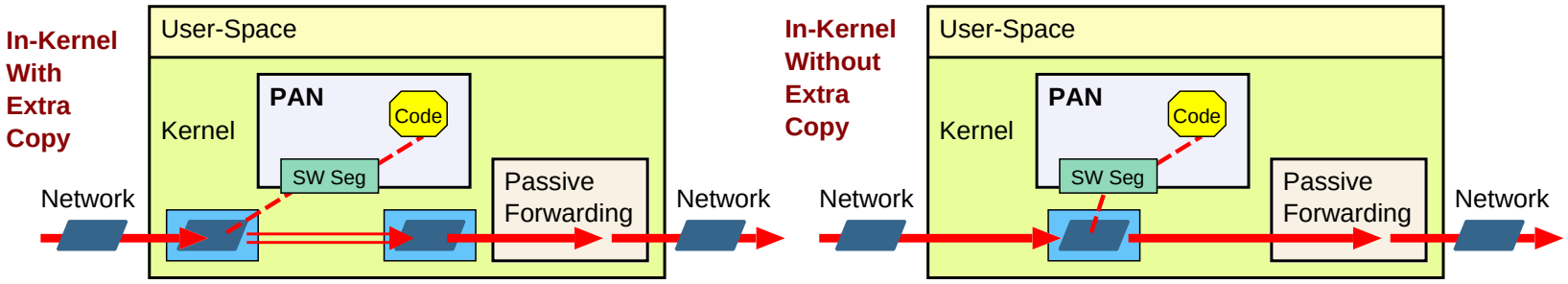
- Eliminates data copies and context switches to / from user-space

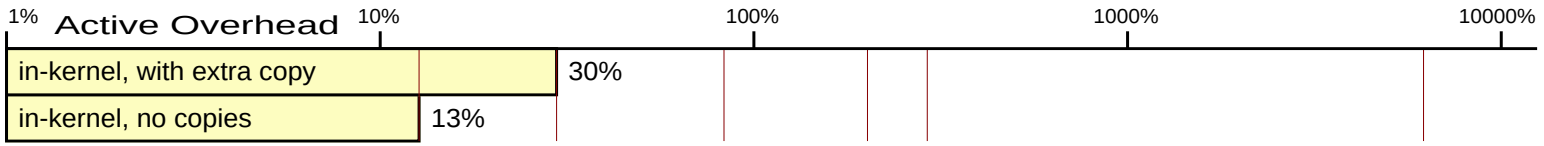




Step 4: Eliminating Data Copies With Software Segments

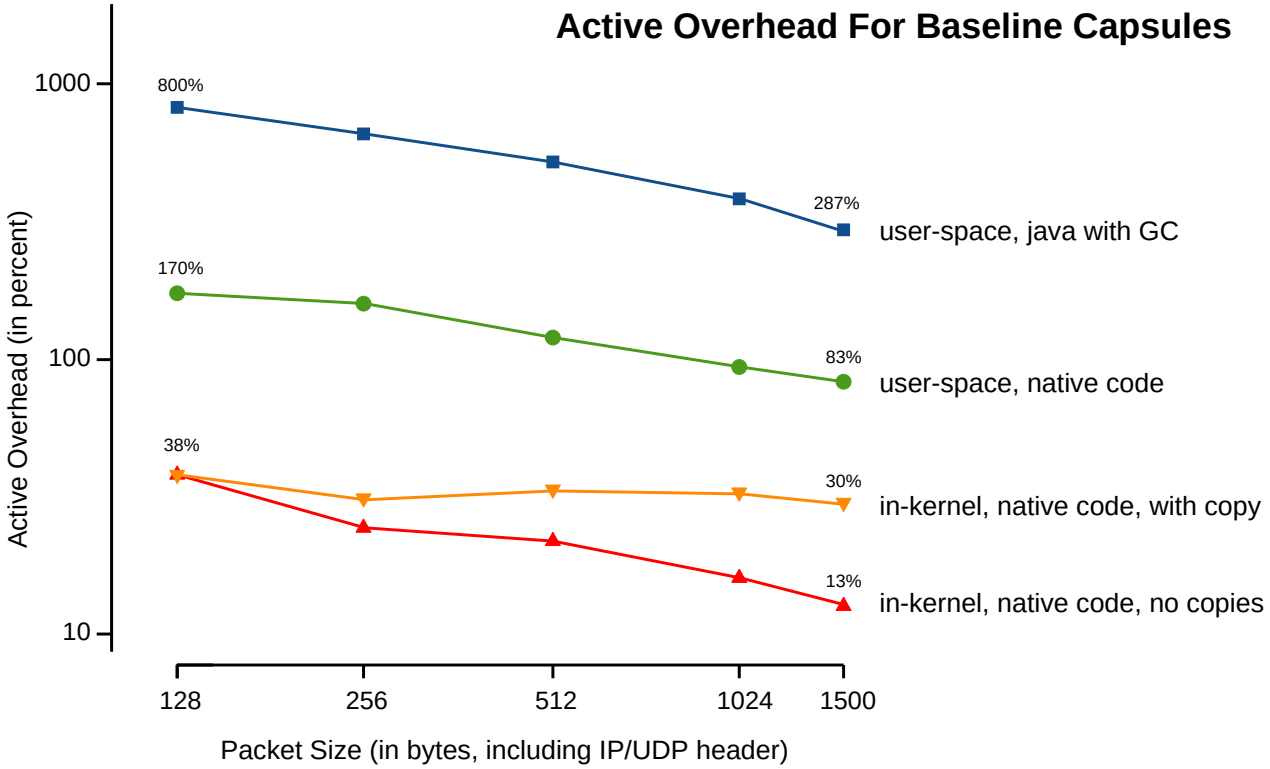
- Interoperability requires OS-independent memory format
- Naive approach: copy data into buffer for capsules to use
- *Software segment* abstraction wraps buffers
- Baseline can process capsules in-kernel without any copies!
  Results: $t_{\text{active}} - t_{\text{passive}} = 20\mu s$ regardless of capsule size
- Experiment:





Baseline Performance Hypothesis Verified

- Active overhead decreases with packet size:



Performance Explanation

- Low (13% to 38%) active overhead for in-kernel processing
- Very little on remaining critical path:
  - Capsule environment created and code looked up in code cache
  - PAN calls into capsule code
  - Capsule code looks at capsule header and calls API to forward capsule

Conclusions

- Contributions of this work:
  - Demonstrates that high performance is obtainable
  - Shows ways to get from a prototype to a high-performance active node
  - Experimental active network node for implementation research
- Future research:
  - Low active overheads with safety and security
  - By reducing overall bandwidth consumption, active protocols may generate overall gains in network performance