Control-On-Demand

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Active Networking

- Placement of *user-controllable* computations *inside* a network
- Provision of an *uniform* interface to the network
- Current Approaches:

Project	Language	
C-o-D		AT&T
Smart Packets	Spanner/Sprocket	BBN
Netscript	Netscript	Columbia
CANEs		Georgia Tech.
ANTS/Capsules	Java	MIT
SwitchWare	PLAN	Univ. of Penn.

Control-On-Demand — Key Ideas

- Networks already support different *transport* needs

  C-o-D enables networks to support different *control* needs

- Flow *specific* control can be specified by the flow participants

  Each receiver in a multicast can specify different desired flow characteristic depending upon network conditions

- Explicit Flow labeling

  Use the IPv6 Flow label

  Flow Pinning

- Efficiency

  Staying in the fast path

Staying in the *fast* path

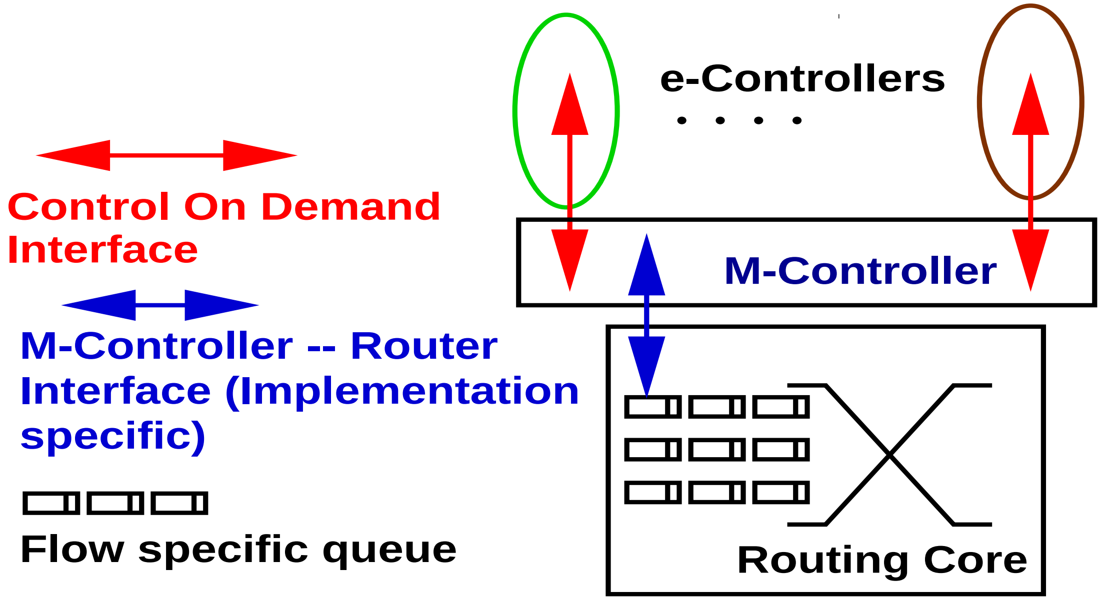
- Reducing on-line requirements
  - Enhancement control

    Flow semantics not modified by controller not being present
  - Best-effort control

    Controller does not have to process *every* packet
- Reducing bandwidth across the interface
  - Frame Peeking
- Lightweight Signaling (using extension headers)

Architecture

- Meta-Controller
  - Interface between routing core and flow specific controller
  - Responsible for installing and initiating flow specific controller



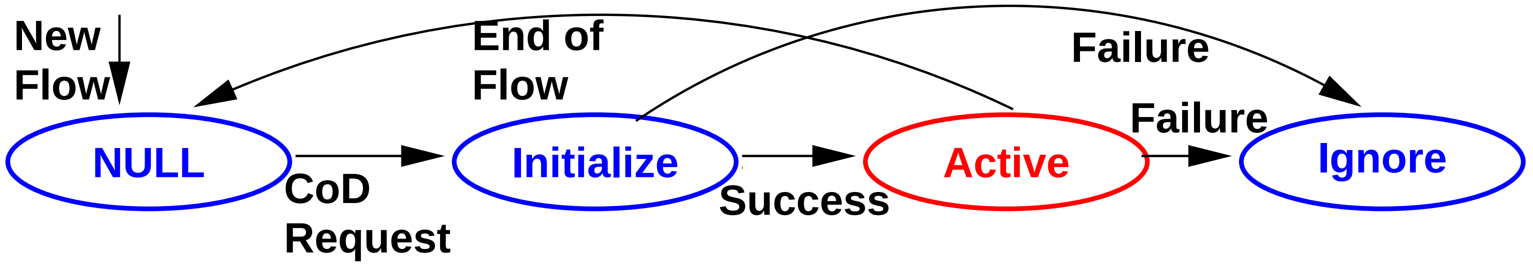
Flow-specific Controllers

- Dynamically installed by the M-Controller
- Uses the Control on demand interface to customize per-flow control
- Controller performance enhanced by:
  - Application level framing
  - Frame Peeking
- C-o-D interface is designed to minimize *coupling* and *synchronization* between the per-flow control and the routing core

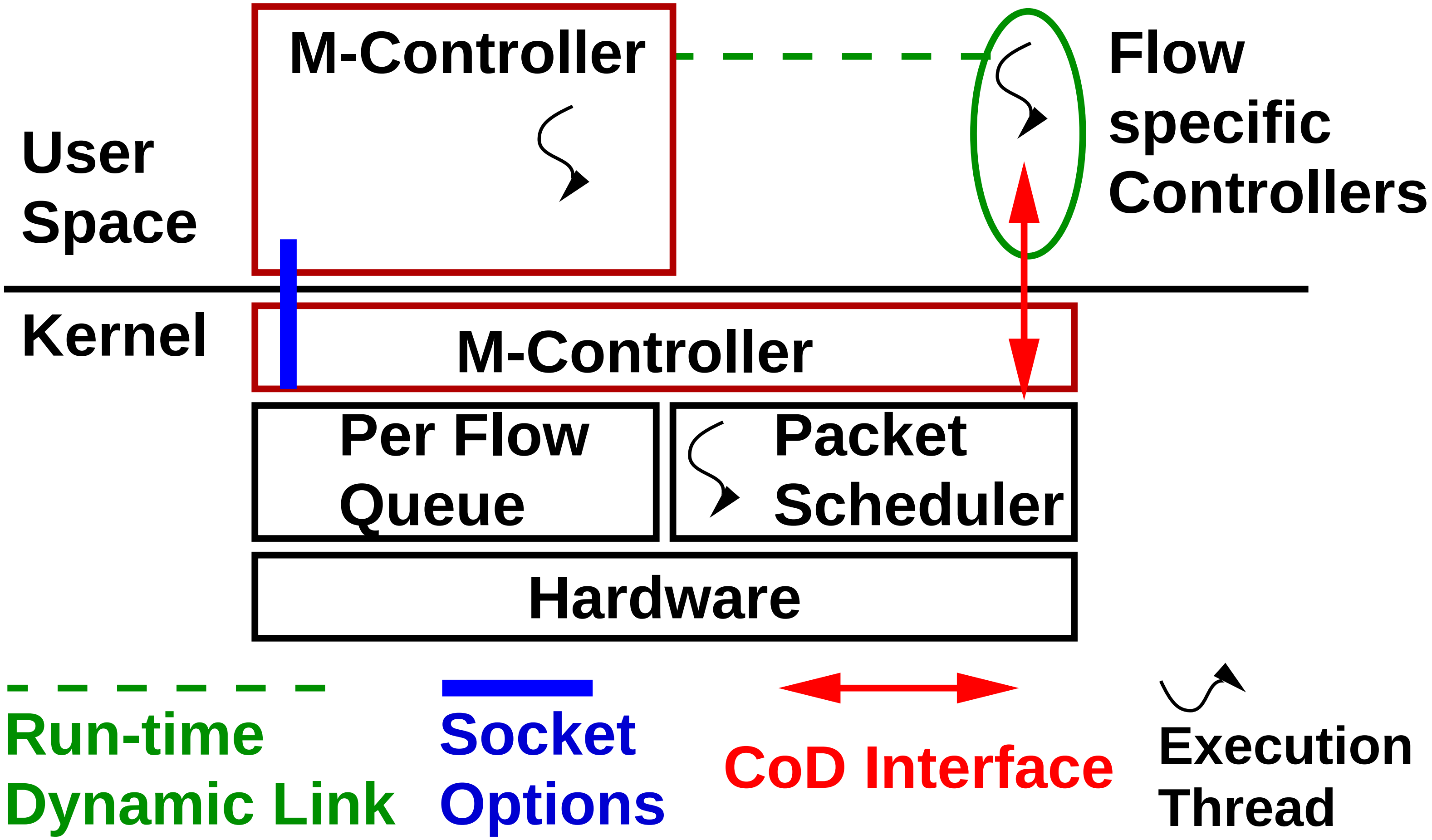
Flow Classification

O(1) flow classification based upon flow id. into 1 of 4 states:

`NULL`	if C-o-D header present
	copy packet to M-Controller
	set state to `Initializing`
	create FCB, cache output port, forward packet
`Initialize`	M-Controller knows about flow,
	FCB exists, keep statistics, forward packet
`Active`	Flow specific controller active, queue
`Ignore`	Error condition, forward packet



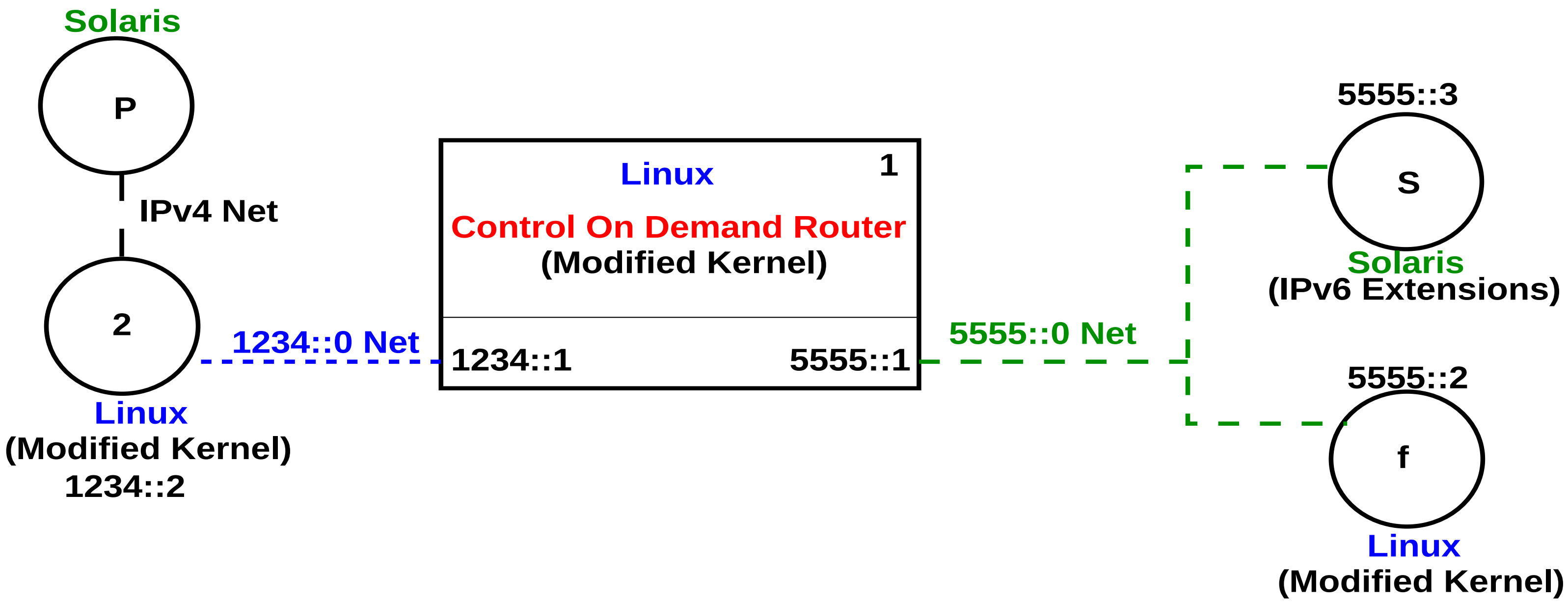
Implementation Architecture



Implementation Specifics

- Linux in-Kernel C-o-D implementation
- M-Controller–Routing-Core interface through socket options on an unconnected raw socket
- Flow specific controllers installed using run-time dynamic linking
- Additions to Linux IPv6 implementation :
  - Flow state caching and flow pinning
  - Per flow queuing
  - Per flow output queue scheduling

Implementation Topology



- Virtual Topology — 10 Mbps Ethernet implementation

C-o-D Controller Primitives

Command	Parameters	Effect
`CHANGE-FLOW-STATE`	{Flow, State}	Set flow state
`EXPOSE-QUEUE`	{Start Offset, Length, *Which*}	{Queue Info., # of matches, {matches}}
`SET-SCHEDULE`	$\{\{\text{Byte}_i, \text{Rate}_i\}\}$	After Byte_i bytes served, output rate set to Rate_i
`SET-PACKET-STATE`	$\{\{\text{Packet}_i, \text{State}_i\}\}$	Set packet state (e.g. `Discard`)

Applications

- Application-specific traffic shaping
  Video smoothing, Stream thinning
- Application-specific congestion control
- *Reliable Multicast*
- *Variegated Multicast trees*

Application-specific traffic shaping

- **Stream thinning :**
  Upon congestion, application specified headers are parsed to discard *least* important datagrams
  In case of MPEG video — I frames are preserved; B and P frames are discarded first.
  If entire frame cannot be fit into output buffer, all packets corresponding to frame is discarded

- **Video Smoothing :**
  Controller provided with client buffer size and frame sizes
  Provides proper rates such that buffers are not over/underflown

Application of the CoD Interface

Stream Thinning

; **EXPOSE-QUEUE{***offset***,** *length***,** *which***}**

EXPOSE-QUEUE{0, sizeof(app-level-header), NEW-PACKETS}

if {Qinfo.Bytes-Queued $>$ (0.8 QSize)}

  for ($i = 0$; i $<$ # matches ; i=i+1)

    f $\leftarrow$ (app-level-header) matches[i]

    if ({f.type != I-FR} **and** {Qinfo.Bytes-Queued $>$ 0.3 QSize })

      Pinfo[Pinfo.valid].id $\leftarrow$ matches[i].id;

      Pinfo[Pinfo.valid].state $\leftarrow$ PACKET-DISCARD;

      Qinfo.Bytes-Queued $-=$ f.len;

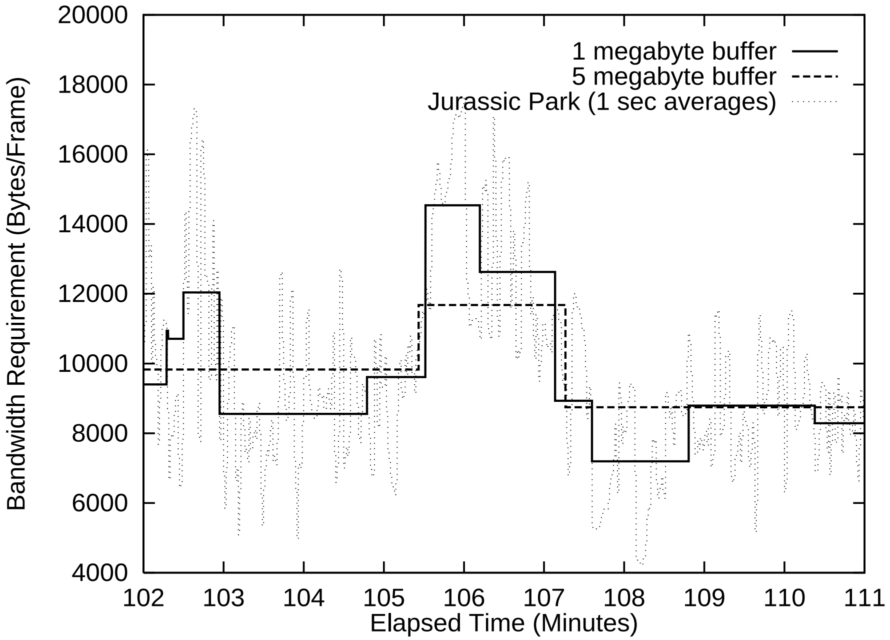
      Pinfo.valid=Pinfo.valid+1;

if {Pinfo.valid $>$ 0}

  SET-PACKET-STATE{Pinfo}

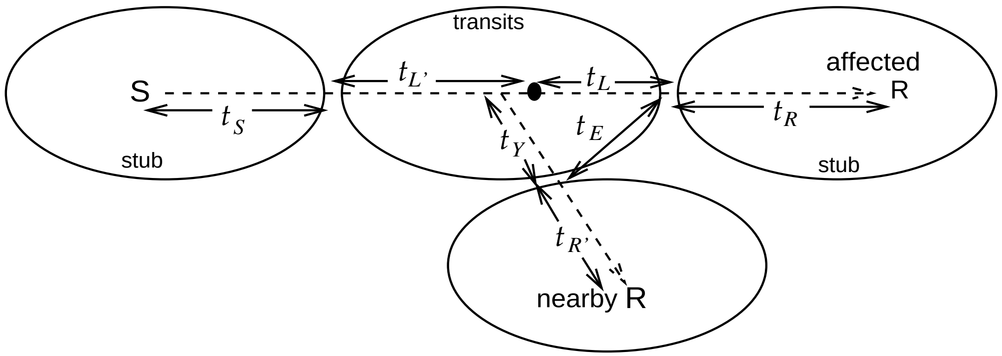
Video Smoothing

- Controller schedules frames to prevent client buffer over/underflow
- Given frame sizes, client buffer size — controller can compute transmission rates over time intervals



Applications in development

- Association between packets within a stream (stream thinning using a Multi-Description Coder (with Vinay Vaishampayan))
  - Video coded into two sub-streams of *equal* importance
  - Controller provides *at least one sub-stream*
- Reliable Multicast
  - Caching at intermediate nodes — *best possible* retransmission scheme



Future Work

- Implementation of other polices — field test of C-o-D interface
  - Reliable multicast
  - Variegated multicast trees
- Analysis of contention at output queues
- Inter-controller communication — *Composition of policies*
- Simulation of Control on demand systems (AN-Sim)
  - Wide-area dynamics of C-o-D
  - Behavior of C-o-D flows in heterogeneous networks