A Scalable High-Performance Active Network Node

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Motivation

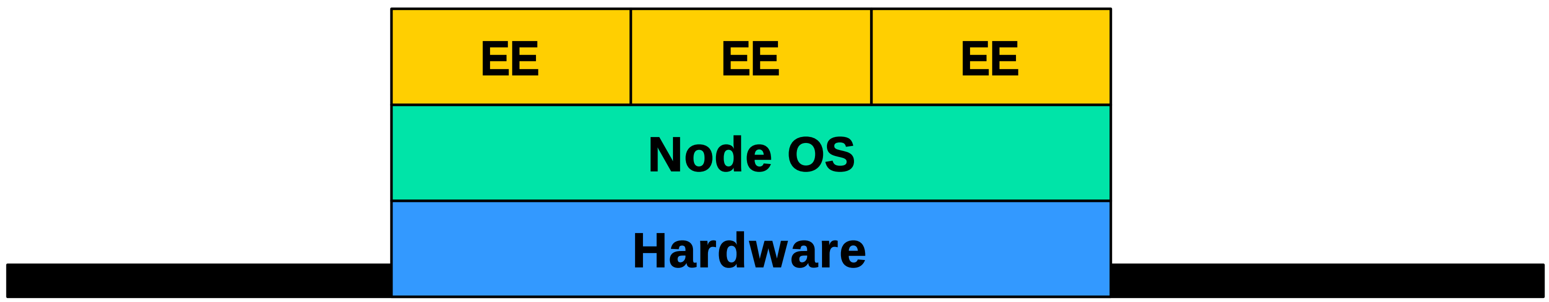
- Apply Active Network over gigabits links is a big challenge.
- Memory bandwidth and processing power of a microprocessor is the bottleneck for an active node in Active Network.
- No microprocessors can singled-handedly solve the problem, and thus an active node requires to be scalable on both hardware and software.

Related Work

- MIT
  - Capsules – Small fragments of code
  - ANTS toolkit – Packets carry pointers
- BBN
  - Smart Packets – Extend diagnostic functionality in the network
- Georgia Tech
  - Shows self organizing network caching extends network's capability
- U Penn
  - Switchware (switchlet) and uses field programmable gate arrays
- U Arizona
  - Scout - fast but not fast suit for high-volume high-bandwidth traffic
- Columbia U
  - Netscript – middleware for intermediate network nodes

Proposing a New Architecture

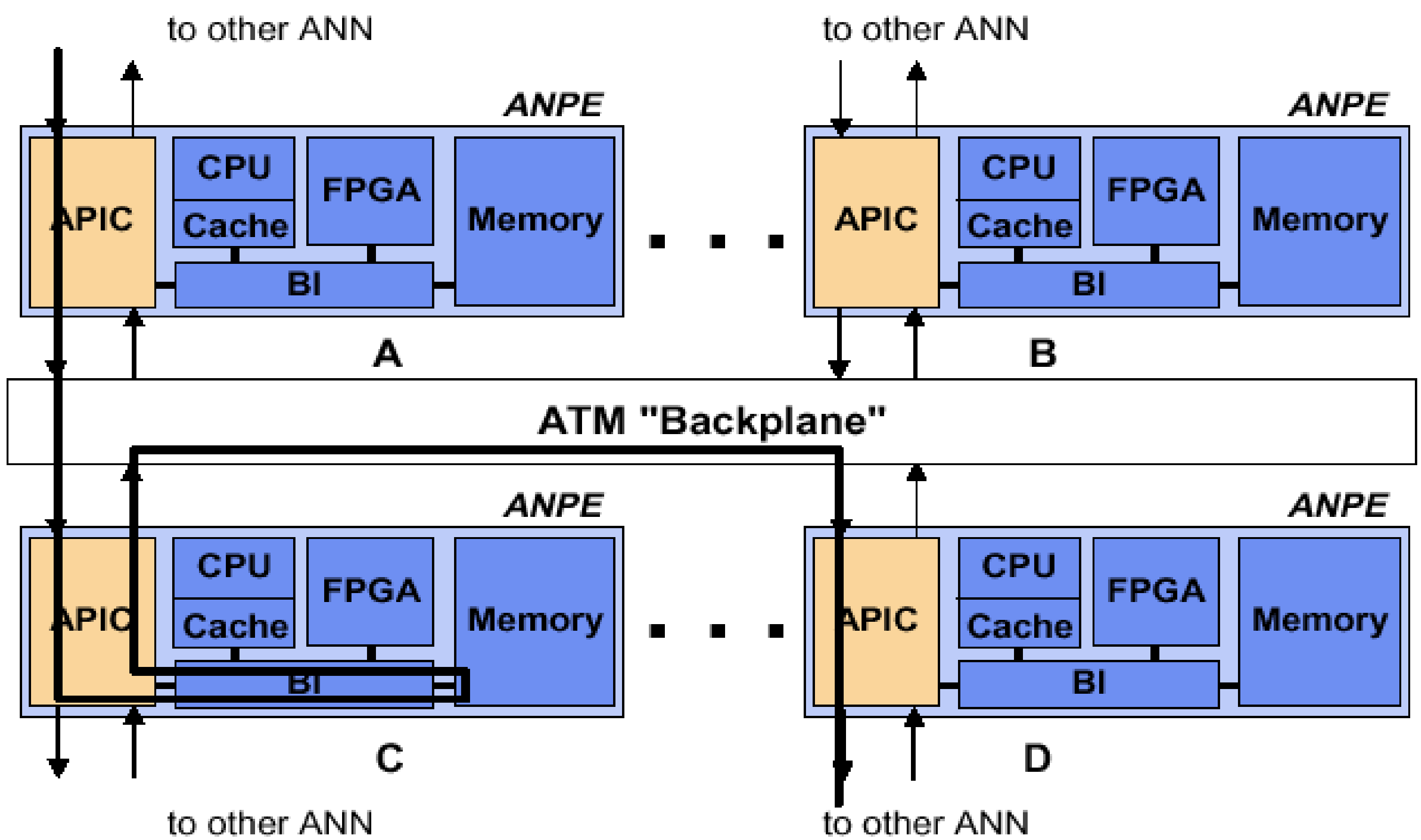
- 3 key components of the architecture
  - Hardware of an Active Network Node (ANN)
  - NodeOS of ANN
  - Execution Environment of ANN



Hardware Requirement

- High number of processing elements per router ports
  - General purpose CPU and a Field Programmable Gate Arrays on every port on backplane
  - CPU does majority active functions, while FPGA takes care performance-critical functions
- Tight coupling between engine and network
  - Network traffic is flow-oriented and burst of packets share common forwarding properties
  - Majority of non-active packets allow cut-through with CPU intervention
- Scalability
  - Evenly distribute computation over processing unit (CPU + FPGA)

Hardware for ANN Overview



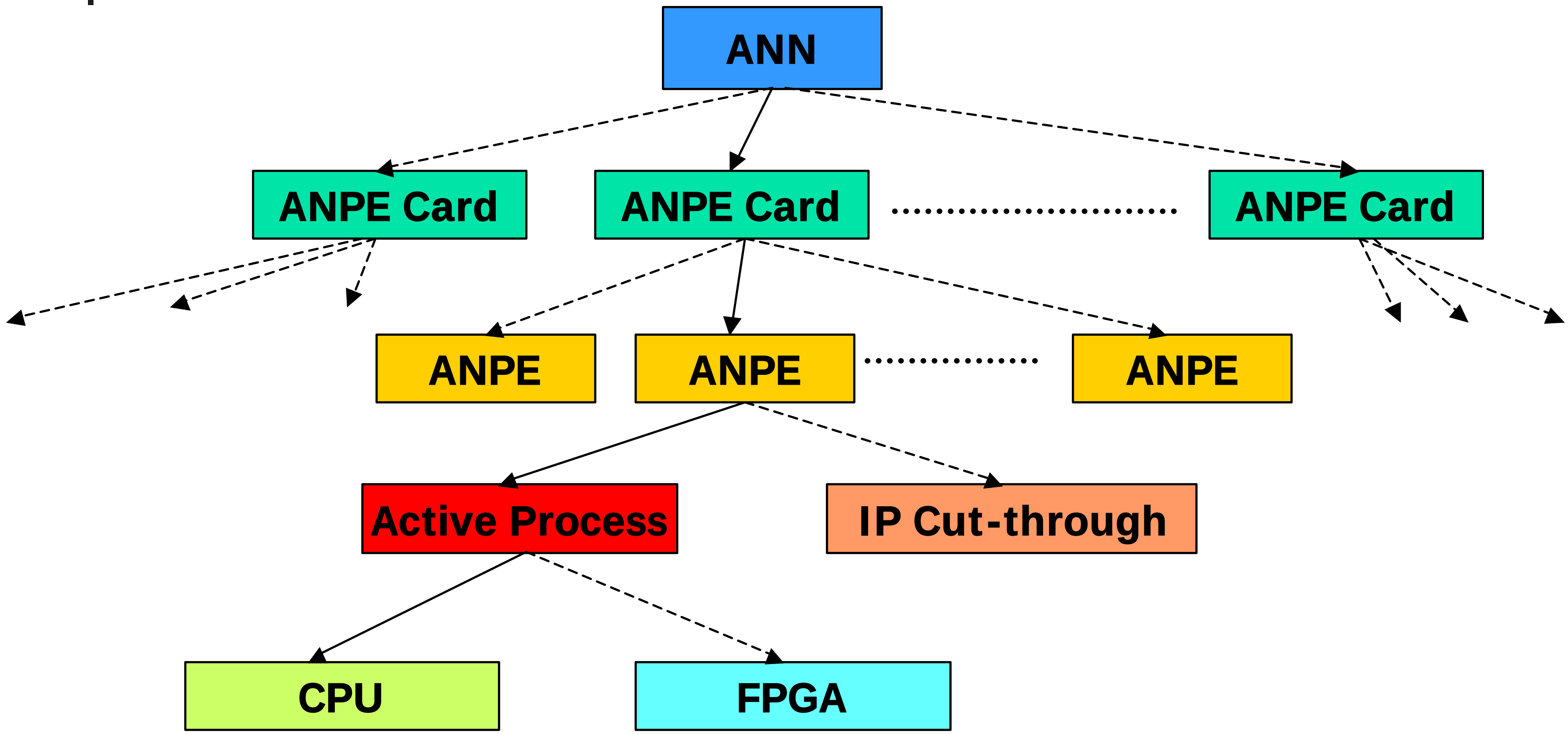
ANPE – Active Node Processing Elements

- ANNs are interconnected through ANPE
- ANPE are connected to the ATM backplane via ATM port interconnect controller (APIC)
- Number of ANPE per ANN is configurable
- Backplane is scalable
- Load-sharing algorithm distribute load by configuring APIC in each ANPE
- Data flow can be routed between ANPE, sharing or pipelining the process on packets

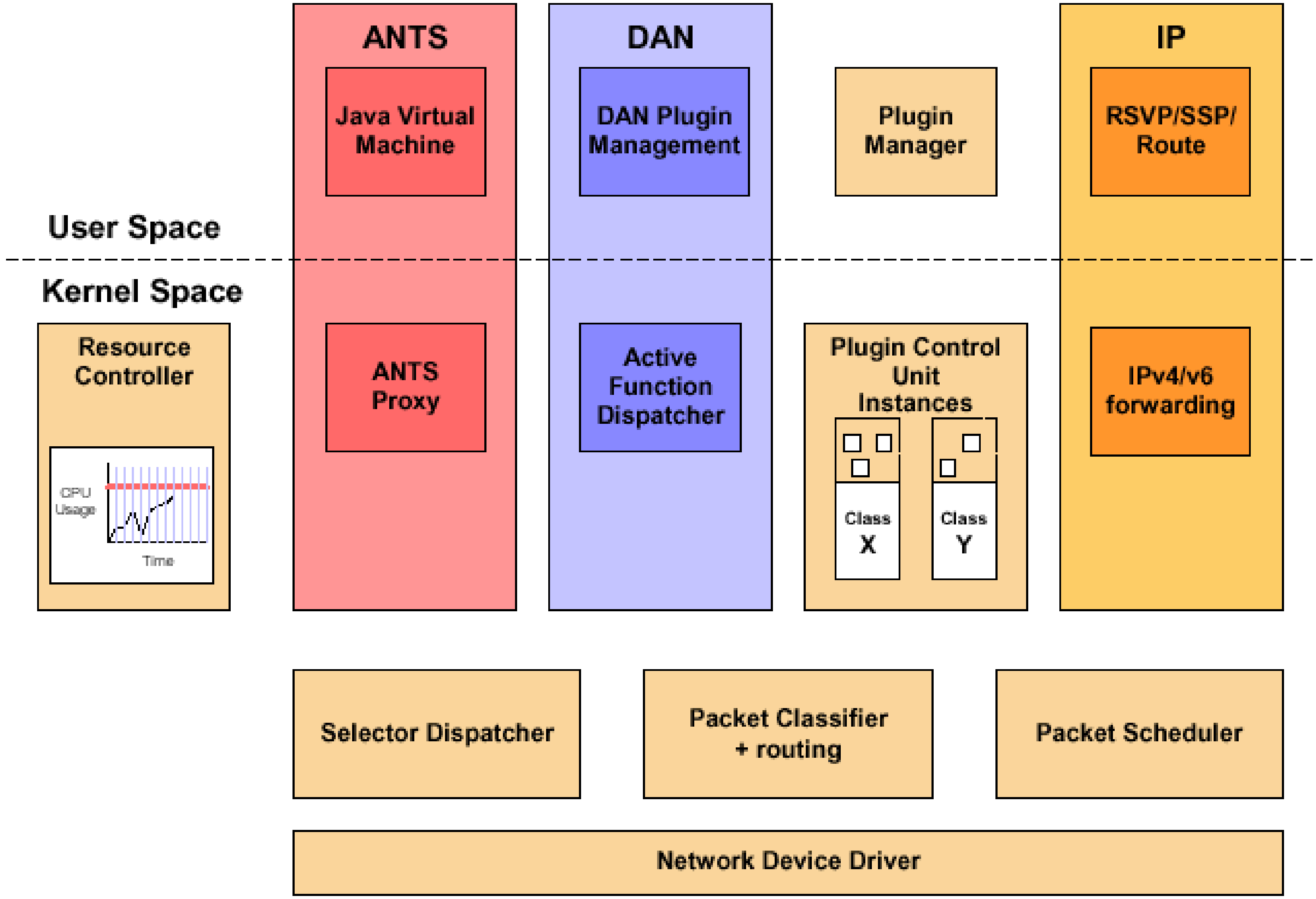
ANPE Details

- APIC – ATM host-network interface, two ATM ports and a built-in PCI bus interface, implementing VC switching (allow load-sharing and cut-through IP traffics).
- CPU runs NodeOS (optimized NetBSD)
- FPGA can be programmed by CPU on the fly
- Packet can go into either CPU or FPGA

Redundancy Provides Scalability



ANN Software Infrastructure



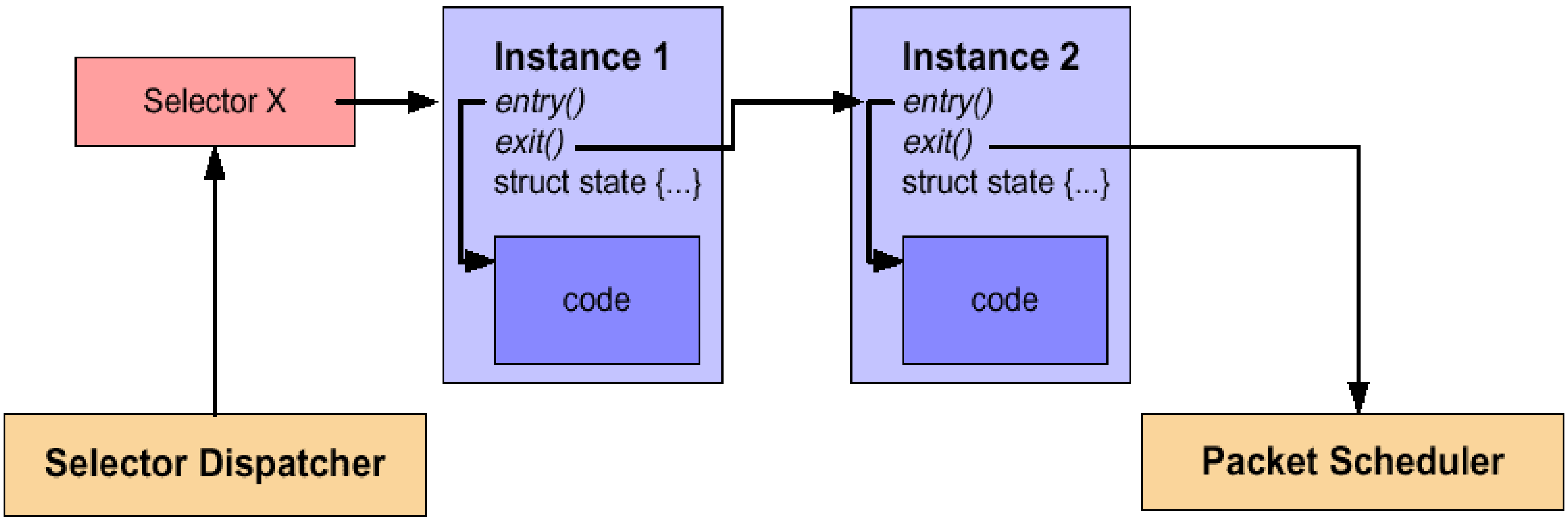
Node OS

- Execution Environment (EE) runs on top on NodeOS, example:
  - ANTS, Smart Packets, SwitchWare
  - DAN – Distributed Code Caching for Active Network
- Code blocks implementing application-specific network functions are Active Plugins.
- Active Plugins can create object instances.
- API **`enter()`** is called to pass packet to instance.
- API **`exit()`** is called by instance when finished processing packet.
- Designed to favor DAN architecture while compatible to other EEs

Object Daisy Chain

- 1st packet of a flow will cause plugin to create instances while the subsequence packets won't.
- If a packet is needed to process by multiple instances, in each instance's **`exit()`** will call method **`enter()`** of the next instance.
- Chains are labeled by a Selector
- Last element of a chain is a Packet Scheduler that send packet back to the network.

Object Daisy Chain



Node OS Components

- Device Drivers (DD)
  - Standard NetBSD on send and receive packets.
  - exception on using packet scheduling instead of using packet queue.
  - If packet contains a selector, it goes to Selector Dispatcher instead of the IP stack.

Node OS Components

- Packet Classifier (PC)
  - For packets without selector
  - Every new flow has a flow record
  - Classified by src and des {IP, port} and protocol
  - Tags all incoming packets with flow index (FIX)
    - contains MBUF and points to flow record
  - Plugins can access the flow record by FIX

Node OS Components

- Selector Dispatcher (SD)
  - Scans packet for selector
  - Use selector to find FIX
  - Stores a pointer to the first instance of the chain
- Packet Scheduler (PS)
  - Can use both Deficit Round Robin or Hierarchical Fair Service Curves for scheduling packets

Node OS Components

- Resource Controller (RC)
  - Responsible for fair CPU time sharing
  - Implements selection of a queue
  - RC in an ANN exchanges information with each other over a reserved VC to provide input for the load-sharing algorithm
  - Also keep tracks of memory consumption on per-instance basis
  - Can deny additional memory demanded by greedy instance

Node OS Components

- Plugin Control Unit (PCU)
  - Manages plugins
  - Forwards control path messages,
    - E.g. instance creation, registration information
- Plugin Manager (PM)
  - User-space utility to configure system
  - Provide interface to kernel space components

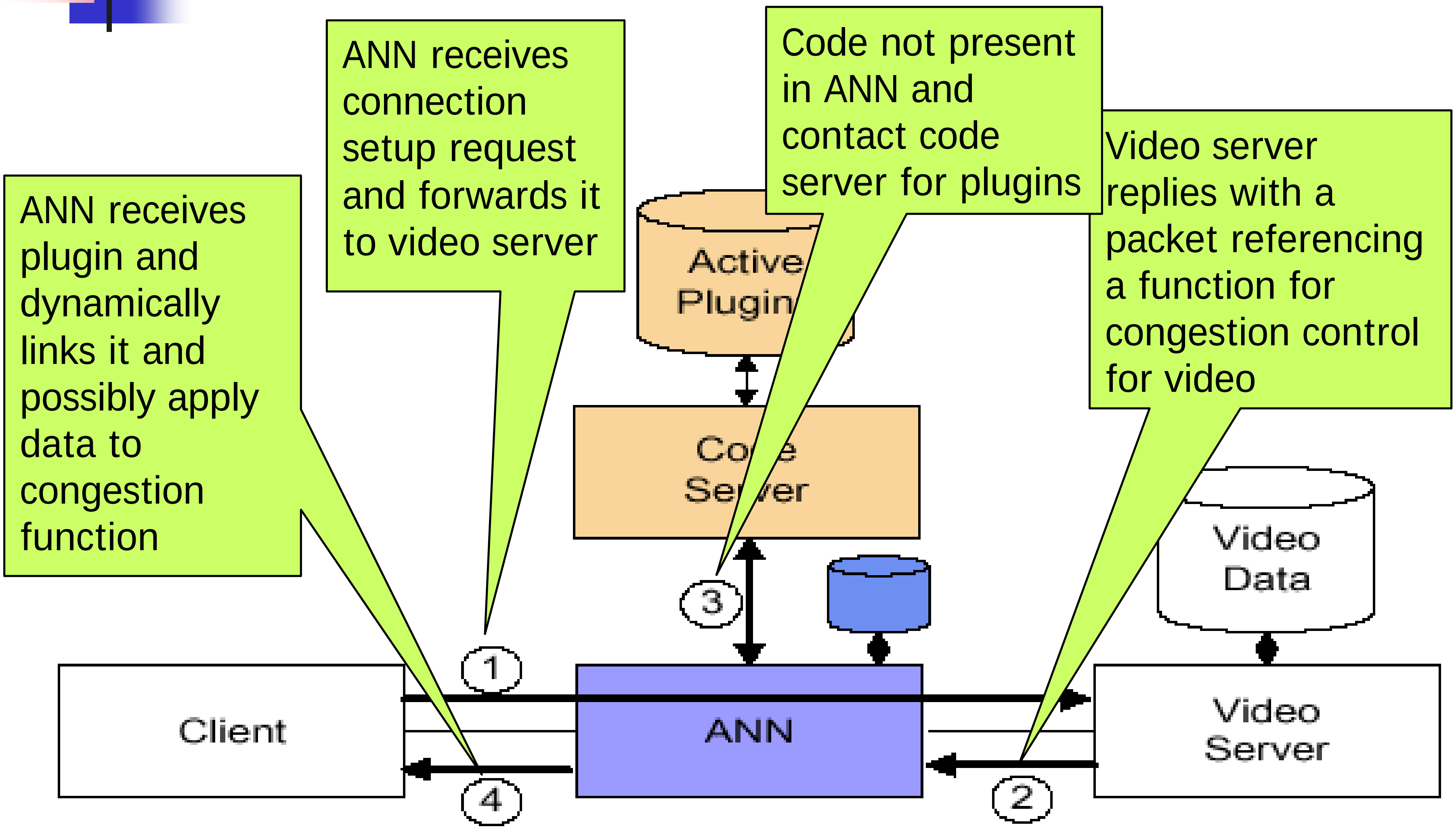
Distributed Code Cache for Active Network (DAN)

- A combination of capsule and programmable switch solution
- Capsule code => Reference to active plugins
- Reference of unknown code is downloaded from a code server
- Code fragments are dynamically linked and executes like native code on node
- Cryptography techniques are used for security to replace slow VM

DAN Mechanics

- Packets consist of sequence of IDs of functions and input parameters
- Demultiplexing packet to obtain the unique identifier (e.g. 0x0800 for IPV4)
- Hardware interface where packet arrive determines first function
- Last function (set) implemented in application
- Function ID act as pointer to code fragment
- Each function has option of not calling the next function
  - E.g. Forward packet to next hop w/o error detection
- Code fragments (plugins) are acquired from Code Server

Code Downloading Example



Security

- Active plugins are digitally signed by developers.
- Code Server serves as trusted, well-known node for the plugins and send authenticates plugin before sending.
- ANN only stores authenticated plugins.
- ANN can check plugin sources and developer before installation and running.

Minimizing Code Download Delay

- Download only happens once on first occurrence of a new function ID
- Probe Packet – Sent from server and down the packet path to each node to initiate download at each node (Parallelism).
- Optimal Code Server arrangement – Code servers should be close to ANN by using hierarchy similar to DNS servers.
- Administrator to select or find unicast address of a code server.
- Data server can also maintain a database of active plugins.

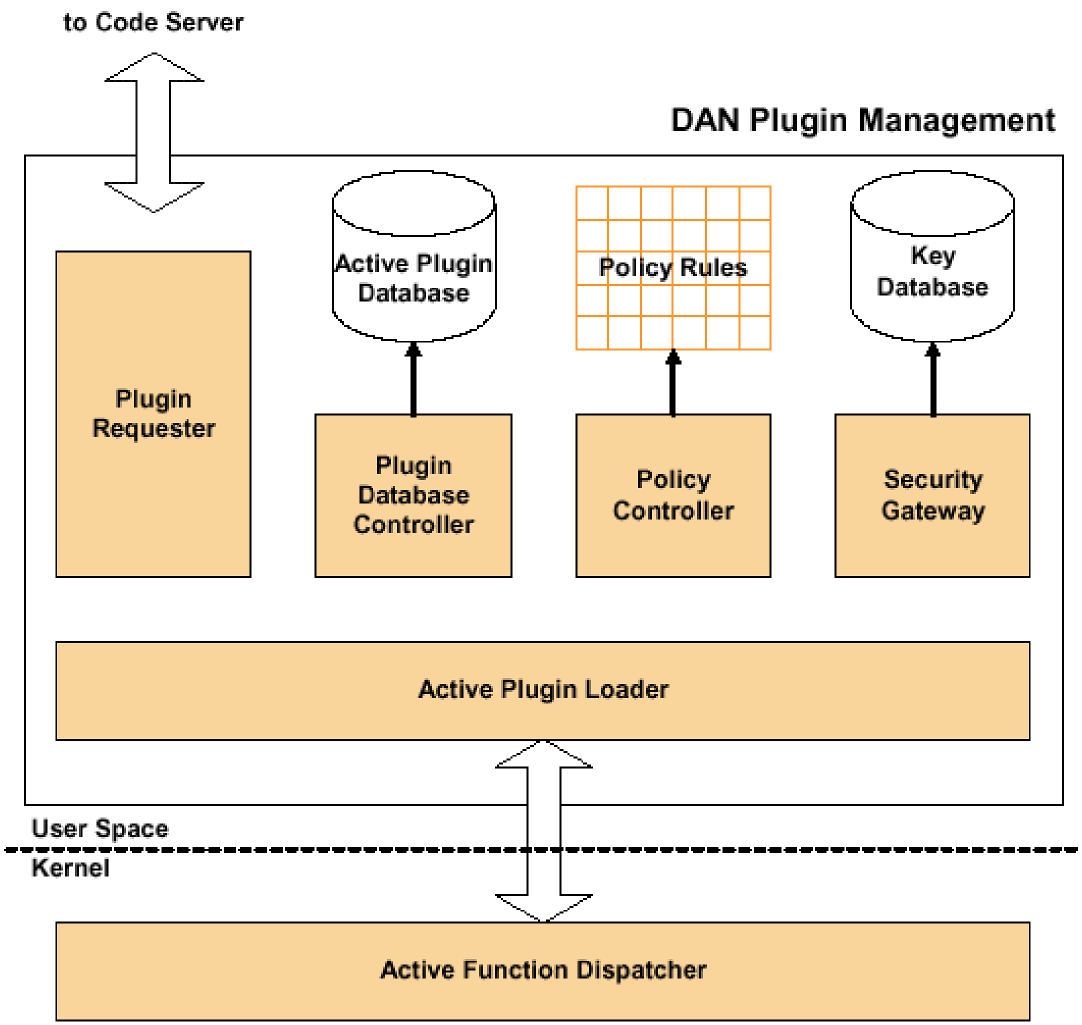
User Level Policies

- Acceptance Policy
  - Administrator is allowed to deny plugin even if plugin is trusted.
- Caching Policy
  - Timeout duration should be set by administrator to decide when a plugin expires.
  - Timeout can be set to infinite for non-expirable plugin.
  - Possibly treakable caching scheme (?)

Integration

- Integration by inserting new function ID at different layer.
- Data Link Layer
  - Use Link Layer Control SNAP field
- Network Layer
  - Use IP option, IPv6 option field is more extensible than IPv4
- Transport Layer
  - Function ID to replace or in addition to TCP/UDP function ID

DAN Execution Environment



DAN EE Components

- Active Function Dispatcher (AFD)
  - Scan packet for function ID
  - DAN function ID embed in ANEP header (or many other places)
  - Keeps track of all known function ID and a pointer to corresponding instances per flow.
  - Packet with a selector passed directly to first instance and does not go through AFD.
  - For unknown function ID
    - contacts Active Plugin Loader
    - Enqueue the packet in a dedicated queue
    - Proceed with next packet

DAN EE Components

- Active Plugin Loader (APL)
  - Dedicated kernel subsystem socket interface (like routed)
  - Talks to Policy Controller first and then possible contacts the plugin database
  - If plugin locally available, loads into subsystem
  - If not, contacts plugin requester to send request to code server.
  - If received plugin is verified and valid at the Security Gateway, loads into subsystem and stored by Plugin Database Controller.

DAN EE Components

- Policy Controller (PC)
  - Maintain policy as previously described.
- Security Gateway (SG)
  - Maintains a database of public keys
  - Implements full RSA public-key encryption using RSAREF library.
  - Library provides MD5 one way hash as RSA public key encryption.
    - ANN receives $\{\{Plugin\}_{MD5}\}_{Priv.Deve}$ and {Plugin}
    - Gets Pub.Deve and get $\{Plugin\}_{MD5}$ and calculates MD5({Plugin}) and see if
    - $\{Plugin\}_{MD5}$ =? MD5({Plugin})
- Security extension to DNS can be avoid by using IP address directly(?)
- Or can use IPv6's IP security
- Or associate DNS by public/private key scheme.

DAN EE Components

- Plugin Database Controller (PDC)
  - Administers local database for active plugins.
  - Database can be any database architecture and controller will be implemented to interface.
  - Store all plugin information, including keys.
- Plugin Requester (PR)
  - Responsible for requesting plugins and replying.
  - Request can be multicast, unicast or anycast.
  - And of TCP/UDP.
  - When using UDP, loss of active plugin request will cause those requesting active packet to drop.

Other Components

- Code Server
  - Can be of any architecture as long as being able to interface with requesting Plugin Requesters.
- Plugin Packages, contains
  - Code for 1+ active functions
  - Developer’s digital signature
  - Code server authentication information
  - Configuration information, e.g. Expiration time

Conclusion

- This paper proposed a complete hardware, OS and to software architectual basis for an ANN.
- All parts are designed with scalablility in mind.
- Packets and plugins code fragments of most fundamental parts allowing application to be flexible and most importantly, scalable with the underlying hardware and OS architecture.

END

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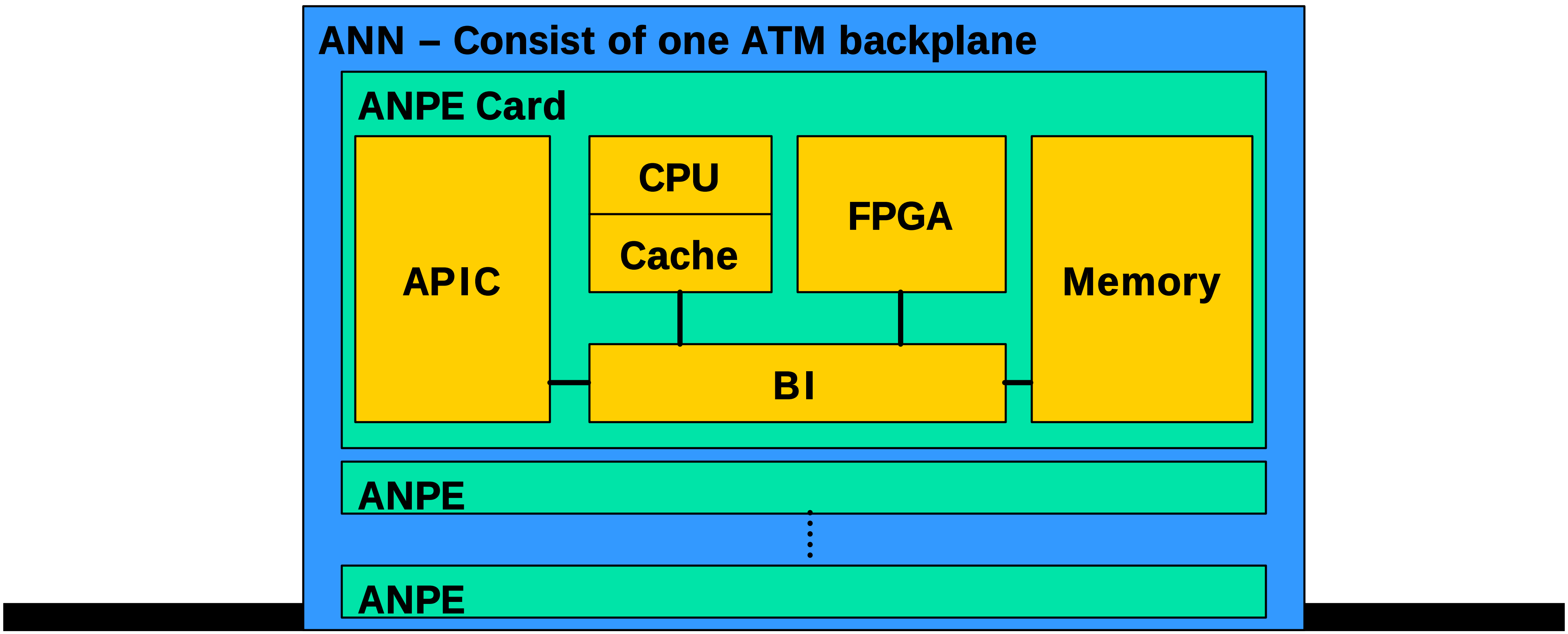

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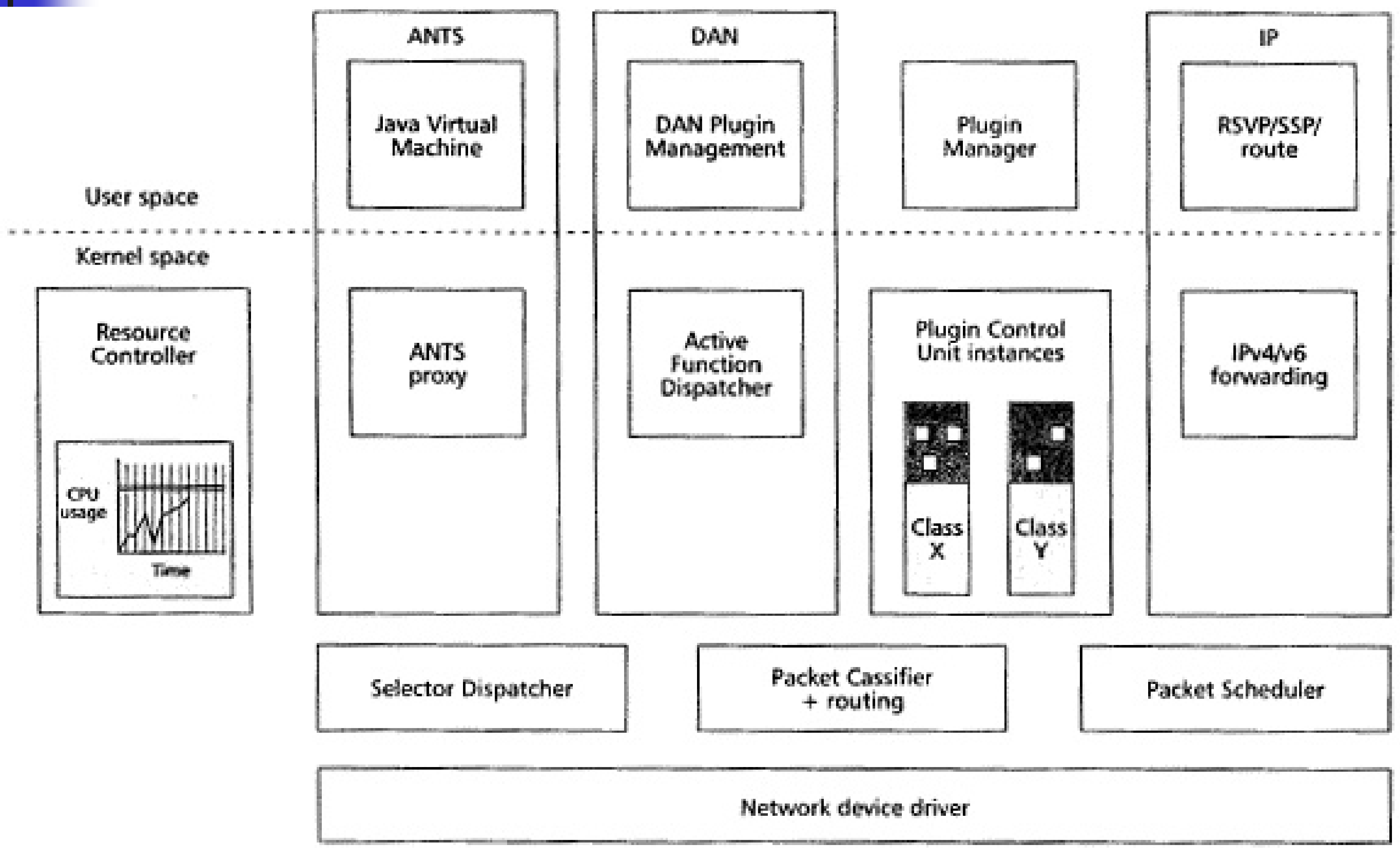

Object Daisy Chain