Recursive Networks

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Internet Architecture

Accused of ossification, but:

- Ossification = stability
- Flexibility is abundant:
  - Shim layers:
    - HIP, SHIM6, IPsec, TLS
  - Muxing layers:
    - SCTP, RDDP, BEEP
  - Connections:
    - MPLS, GRE, IKE, BEEP, SCTP
  - Virtualization:
    - L2VPN, L3VPN/X-Bone/RON/Detour, L7-DHTs
Motivation

- Layers of a stack becoming more similar
  - Security, soft-state, pacing, retransmission
- Desire to support new capabilities
  - Interlayer cooperation, dynamic layer selection
- Desire to support emerging abstractions
  - Overlay layers don’t map to 1-7
  - Support for recursive nodes (BARP, LISP, TRILL)

Is layering more than a coding artifact?
Net Arch - Assumptions

- **Internet-Compliant Architecture**
  - Hosts add/delete headers
  - Routers transit (constant # headers)

- **Supports New Capabilities**
  - Concurrence (multiprocessing)
  - Revisitation (multiple roles in one net)
  - Recursion (to hide topology and/or mgt.)
Virtual Networks

- Internet-like
  - Internet = routers + hosts + links
  - VIs = VRs + VHs + tunnels
  - Full architecture (vs. VPNs, PP-VPN, etc.)

- All-Virtual
  - Supports VNs on VNs
  - “Reality” is undecidable

- Recursion-as-router
  - Some of VRs are VI networks

- See Globecom 1998 (running code 2000)
  - 15 layers deep, 800 wide, app. deploy, P2P integration
Recursive Internet (2003)

- Recursion as a router
  - L3 = BARP (X-Bone), LI SP (IRTF)
  - L2 = Rbridges/TRILL
Recursion requires new layers – where? Why?

- Wedge between (IPsec, left) or replicate (virtualization, right)
RNA Stack (2006)

- One MP, many instances
  - Needed layers, with needed services
  - Layers limit scope, enable context sensitivity
  - Scope defined by reach, layer above, layer below
RNA Metaprotocol

- Template of basic protocol service:
  - Establish / refresh state
  - Encrypt / decrypt message
  - Apply filtering
  - Pace output via flow control
  - Pace input to allow reordering
  - Multiplex/demultiplex
    - includes switching/forwarding
MDCM from *Choices*

**Structured template w/plug-in functions**

- Layer address translate/resolution
  - ARP, IP forwarding lookup
  - BARP/LISP/TRILL lookup
- Layer alternates selection
  - IPv4/IPv6, TCP/SCTP/DCCP/UDP
- Iterative forwarding
  - IP hop-by-hop, DNS recursive queries

```
LAYER(DATA, SRC, DST)
  Process DATA, SRC, DST into MSG
  WHILE (Here <> DST)
    IF (exists(lower layer))
      Select a lower layer
      Resolve SRC/DST to next layer S’,D’
      LAYER(MSG, S’, D’)
    ELSE
      FAIL /* can’t find destination */
    ENDIF
  ENDWHILE
/* message arrives here */
RETURN {up the current stack}
```
Click Implementation

Composition Graph

Conf File

Compose What

mux  demux  buffer

Scheduler  Composition Logic

Data API  Control API

Utilities  Parser

Click

Protocol

Compose Recursively

e3  e4

m1  m2

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Recursion supports Layering and Forwarding

- **Layering (left)**
  - Heterogeneity via $O(N)$ translators
  - *Requires successive recursive discovery*

- **Forwarding (right)**
  - $N^2$ connectivity via $O(N)$ links
  - *Requires successive iterative discovery*
Related Work

- Recursion in networking
  - X-Bone/Virtual Nets, Spawning Nets, TRILL, Network IPC, LI SP
  - RNs natively include resolution and discovery

- Protocol environments
  - Modular systems: Click, x-Kernel, Netgraph, Flexible Stacks
  - Template models: RBA, MDCM
  - RNs adds a constrained template with structured services

- Context-sensitive components
  - PEPs, Shims, intermediate overlay layers, etc.
  - RNs incorporates this into the stack directly

- Configurable über-protocols
  - XTP, TP++, SCTP
  - RNs make every layer configurable, but keeps multiple layers.
Conclusions

- Virtualization requires recursion
- Recursion supports layering
- Recursion supports forwarding

One recurrence to bind them all...

- Recursion is a native network property
  - Integrates and virtualization, forwarding and layering in a single mechanism