Virtual Internets for Lab and Class Experiments[1]

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August 10, 2002

Abstract— **The X-Bone is a system for deploying and managing virtual Internets (VIs). VIs, sometimes referred to as overlay networks or VPNs, are used for testbeds, demos, and lab experiments, to provide a virtual topology on which to examine routing protocols and distributed applications. Current use of shared lab and testbed resources often requires explicit reservation in fixed time slots; the X-Bone automates resource reservation, and also supports concurrent shared resource use.**

1. Introduction

Virtual Internets enable concurrent shared use of network resources for class and lab experiments [10]. The X-Bone system is designed to support such Virtual Internets, providing virtual IP-based networks on FreeBSD and Linux OSes, and is currently available [9][12].

Most current network testbeds, whether restricted to a single lab or distributed across departments or organizations, are used for experiments using out-of-band reservation systems that hearken back to 1960's OS batch scheduling. Specific machines are reserved for fixed blocks of time, and users are often expected to restore "safe" configurations. This type of sharing is inefficient and costly, in terms of equipment, lab space, and user efficiency.

Such dedicated reservation of resources is required where experiments require OS modification. More recent techniques, such as divert sockets in FreeBSD, and loadable kernel modules, allow application-layer implementation of network experiments. Other uses require deployed network topologies, without deploying new protocols – such as testing routing configurations, or developing distributed applications.

[1] Effort sponsored by the Defense Advanced Research Projects Agency (DARPA) and Air Force Research Laboratory, Air Force Materiel Command, USAF, under agreements number F30602-98-1-0200 entitled "X-Bone" and number F30602-01-2-0529 entitled "DynaBone". The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Defense Advanced Research Projects Agency (DARPA), the Air Force Research Laboratory, or the U.S. Government.

The X-Bone is a system for automatic deployment and management of Virtual Internets - also known as IP overlays. It requires no new protocols, and works with existing applications and operating systems. USC/ISI is currently developing the X-Bone research prototype, already available as a FreeBSD port (/usr/ports/net/xbone) and Linux RPM, into a tool for education and research. It can be used to deploy networks, and also to coordinate and deploy applications on those networks, which can be useful for distributed system experiments [9].

2. Concurrent shared use

The X-Bone deploys and manages configurations of FreeBSD and Linux hosts and host-based routers. These overlays use IP encapsulation, and are achieved by the careful configuration of virtual interfaces and routing table entries. The result supports concurrent shared experiments and applications.

In conventional VPNs, a host is a member of only one VPN at a time. The VPN connects that host to a preexisting secure network. By contrast, the X-Bone supports multiple, concurrent overlay networks. Each network is deployed as a whole, and both hosts and routers can be members of multiple overlays at once.

This version of concurrent overlays is a network equivalent of Virtual Memory, we call Virtual Internets (VIs) [10]. Like their VM counterparts, VIs provide protection and abstraction. Protection prevents traffic from one overlay from being seen on other overlays, and is achieved by per-hop IPsec encryption, as well as partitioned forwarding at routers. Abstraction allows users and applications to view the network as a simple, convenient topology (*e.g.,* a ring), regardless of the actual connectivity.

Protection enables tests of new protocols without affecting the rest of the Internet, or other VIs. It also provides VPN-like privacy, notably securing network management (*e.g.,* routing protocols, monitoring).

Abstraction allows applications to use the network in a "do what I mean" fashion. Current distributed applications often embed network awareness, *e.g.,* neighbor discovery and organization into trees or rings. VIs allow this capability to be offloaded, much as VM offloads page management from programmers. In one recent example, this abstraction was used to support geographic network overlays in ways that would be impossible in the base network [6].

3. Virtual Testbed and Lab Infrastructure

VIs support distributed virtual testbeds, as well as increased shared use of lab facilities. Because the X-Bone supports recursive VIs, a virtual testbed network can be created and individual experiments deployed in that testbed.

A variety of distributed testbeds have been developed or are currently being developed. One of the earliest was DartNet, a "testbed you can break."[2], which evolved into CAIRN [3]. DartNet and CAIRN were composed of dedicated links connected to dedicated routers, which could be arbitrarily reprogrammed. This infrastructure was useful, but very costly – the links consuming the majority of the expense.

One of the more significant used of DartNet was to develop multicast IP [5]. Multicast IP was deployed there by modifying all the routers, but this limited its reach to only a set of contiguous (connected) routers. To overcome this constraint, and enable more dispersed incremental deployment, first source routing, then later IP encapsulation tunnels were used. This is the first example of an overlay network.

Similar overlays have been used to deploy other network protocols, *e.g.*, IPv6 and Active Nets [1][2]. Application-layer tunnels (UDP) have been used to deploy peer networks in a similar fashion. VIs are a generalization of this architectural extension, which enables more widespread experiments in protocol and network architecture, without (contrasted to peer nets) recapitulating network capabilities not under test. [10] Other examples of emerging overlay infrastructure include the Grid and PlanetLab; both build on the VI capability of the X-Bone, providing resource location and process management [7][8]. Emulab provides similar capabilities in a directly-connected environment [4].

The X-Bone's VIs can also be used to support shared use of lab equipment. Experiments that do not require exclusive use, such as router configuration experiments and tests of routing protocols, can utilize the partitioning of VIs to allow concurrent experiments.

Where exclusive use is required, the X-Bone's access control capability can limit the number of concurrent users to 1, effectively isolating performance-based experiments. In this latter case, exclusive bandwidth interconnectivity is provided by a local Ethernet switch. The result limits each component to a single user at a time, but abstracts the user from explicit resource allocation and management.

The X-Bone is currently being extended for testbed and educational lab use under a grant from the NSF. Of particular interest is an opportunity to inform the educational community of its capabilities, and to obtain feedback on how to further enhance its utility for these communities.

4. References

Information on the X-Bone is available at http://www.isi.edu/xbone

[1] 6-Bone – http://www.6bone.net
[2] A-Bone – http://www.isi.edu/abone
[3] CAIRN – http://www.cairn.net
[4] Emulab – http://www.emulab.net
[5] Eriksson, H., "MBone: The Multicast Backbone," Communications of the ACM, Aug. 1994, pp.54-60.
[6] Finn, G., Touch, J., "Network Construction and Routing in Geographic Overlays," (submitted).
[7] Grid – http://www.globus.org
[8] PlanetLab – http://www.planet-lab.org
[9] Touch, J., "Dynamic Internet Overlay Deployment and Management Using the X-Bone," Computer Networks, Jul. 2001, pp. 117-135.
[10] Touch, J., Eggert, L., Wang, Y., "Virtual Internets," (submitted), also ISI tech report ISI-TR-558, July 2002.
[11] Wang, Y., Touch, J., "Application Deployment in Virtual Networks Using the X-Bone," Proc. DARPA Active Nets Conference and Exposition (DANCE), May 2002, pp. 484-493.
[12] X-Bone URL – http://www.isi.edu/xbone

[2] Excluding the ARPAnet, as it was not intended for ongoing experiments in network or transport protocols.