Bandwidth on Demand over Carrier Grade Ethernet Equipment

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***Abstract*—This paper presents the prototype implementation of a Bandwidth on Demand (BoD) service over equipment using Carrier Grade Ethernet. The BoD multi-domain service is based on AutoBAHN (Automated Bandwidth Allocation across Heterogeneous Networks) software. The paper describes the steps that have taken place for designing and implementing a prototype technology proxy that is able to match the Carrier Grade Ethernet with AutoBAHN, based on the implementations of the relevant standards and technologies by Extreme Networks. The equipment in particular is comprised of BlackDiamond 12804 switches, running ExtremeXOS version 12. The paper demonstrates how a suitable testbed can be created and utilized and how a new technology at the data plane can be supported by a Bandwidth on Demand tool.**

Keywords-Carrier Grade Ethernet; BlackDiamond switches; Bandwidth on Demand; AutoBAHN

I. INTRODUCTION

The GN3 European project [1] is a research project funded by the European Union and Europe's National Research and Education Networks (NRENs). It is a continuation of the previous GN2 project and aims at building and supporting the next generation of the pan-European research and education network, which connects universities, institutions and other research and educational organizations around Europe and interconnects them to the rest of the Internet using high-speed backbone connections.

In the context of this project, a BoD service is being developed and the service is supported by the AutoBAHN tool.

The AutoBAHN system [2] is capable of provisioning circuits in heterogeneous, multi-domain environments that constitute the European academic and research space and allows for both immediate and advanced circuit reservations. The overall architecture of the AutoBAHN system, its goal and the network mechanisms it employs are thoroughly presented in [3].

This paper presents the prototype implementation of a Technology Proxy (TP) for Carrier Grade Ethernet (CGE) equipment. AutoBAHN may support multiple underlying technologies, and Carrier Grade Ethernet features a promising set of characteristics for network carriers. This is one of the first attempts at using a CGE network within a multi-domain Bandwidth on Demand service, and the conclusions of this work are therefore useful in order to determine the effectiveness and required effort of using CGE as the underlying technology for such purposes. It also enables us to compare the degree to which CGE implementations lend themselves to participation in a multi-domain automated reservation service.

The rest of the paper is structured as follows:

Section II presents the Carrier Grade Ethernet technology and related standards, while Section III introduces the general architecture of the AutoBAHN system with an emphasis on its lower levels that interact with the underlying equipment. Section IV describes the TP framework that has been used for handling the creation of the interface towards the underlying network technology. Section V focuses on the implementation that took place including the testing to verify our work. Finally, Section VI concludes the paper and presents future fields of related study.

II. CARRIER GRADE ETHERNET

Carrier Grade Ethernet (CGE) in general refers to the enhancements to Ethernet standards in order to be suitable as a carrier-grade and transport technology [4].

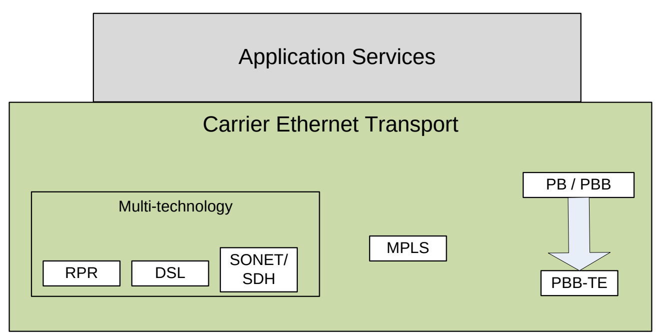

Figure 1. Carrier Ethernet technologies

This section presents briefly the main standards and how these relate to the Carrier Grade Ethernet concepts. There are several aspects of Ethernet that need to be modified or enhanced in order for a technology that was initially designed for local area networks to be suitable for carrier grade deployments ([5][6][7]). In general, several technologies can be considered Carrier Ethernet, including solutions based on carrying Ethernet over Resilient Packet Ring (RPR), SDH or DSL technologies, or over MPLS. All these approaches can be used to carry applications over Ethernet backhaul. However we are focused on so-called pure Ethernet centric solutions (Figure 1). Below we give a brief overview of the main related protocols that comprise a CGE deployment based on pure Ethernet centric solutions.

The Link Layer Discovery Protocol (LLDP) is a vendor-neutral Link Layer protocol used by network devices for advertising their identity, capabilities, and neighbours on an IEEE 802 local area network. The protocol is formally referred to by the IEEE as Station and Media Access Control Connectivity Discovery specified in standards document IEEE 802.1AB [8]. There are several proprietary protocols that perform functions similar to LLDP, such as Cisco Discovery Protocol, Extreme Discovery Protocol, Nortel Discovery Protocol (also known as SONMP), and Microsoft's Link Layer Topology Discovery (LLTD).

IEEE 802.1ad (Provider Bridges) [9] is an amendment to IEEE standard IEEE 802.1Q-1998 (aka QinQ or Stacked VLANs) [10], intended to develop an architecture and bridge protocols to provide separate instances of the MAC services to multiple independent users of a Bridged Local Area Network, in a manner that does not require cooperation among the users, and requires a minimum of cooperation between the users and the provider of the MAC service. The idea is to provide, for example, the possibility for customers to run their own VLANs inside service provider's provided VLAN. This way the service provider can just configure one VLAN for the customer and customer can then treat that VLAN as if it was a trunk.

Provider Backbone Bridges (PBB) or IEEE 802.1ah-2008 is a set of architecture and protocols for routing of a customer network over a provider's network allowing interconnection of multiple Provider Bridge Networks without losing each customer's individually defined VLANs. It was initially created as a proprietary extension by Nortel before being submitted to the IEEE 802.1 committee for standardization. The final standard was approved by the IEEE in June 2008. [11]

Provider Backbone Bridge Traffic Engineering (PBB-TE) is an approved networking standard, IEEE 802.1Qay-2009 [12]. PBB-TE adapts Ethernet technology to carrier class transport networks. It is based on the layered VLAN tags and MAC-in-MAC encapsulation defined in IEEE 802.1ah (Provider Backbone Bridges (PBB), but it differs from PBB in eliminating flooding, dynamically created forwarding tables, and spanning tree protocols. Compared to PBB and its predecessors, PBB-TE behaves more predictably and its behavior can be more easily controlled by the network operator, at the expense of requiring up-front connection configuration at each bridge along a forwarding path. PBB-TE operational administration and maintenance (OAM) is usually based on IEEE 802.1ag. It was initially based on Nortel's Provider Backbone Transport (PBT).

PBB-TE's connection-oriented features and behaviors, as well as its OAM approach, are inspired by SDH/SONET. PBB-TE can also provide path protection levels similar to the UPSR (Unidirectional Path Switched Ring) protection in SDH/SONET networks.

IEEE 802.1ag IEEE Standard for Local and Metropolitan Area Networks Virtual Bridged Local Area Networks Amendment 5: Connectivity Fault Management [13] is a standard defined by IEEE. It defines protocols and practices for OAM (Operations, Administration, and Maintenance) for paths through 802.1 bridges and local area networks (LANs). It is an amendment to IEEE 802.1Q-2005 and was approved in 2007. IEEE 802.1ag is largely identical with ITU-T Recommendation Y.1731, which additionally addresses performance management.

III. Architecture Description

The aim of the BoD service, as defined in GEANT, is to provide dedicated channels for data transport, which are necessary for demanding applications and research fields with strict demands for the provisioning of guaranteed and dedicated capacity and high security level in the sense that the carried traffic is isolated from other traffic. This service is offered collaboratively by GÉANT and a set of adjacent domains (NRENs or external partners) that adhere to its requirements. These joint networks form a multi-domain area where the service is provided between two end points, which may belong to the same or different domains.

The AutoBAHN system operates in a multi-domain environment and consists of several modules that take over the resource negotiation, pathfinding, topology abstraction and exchange, admission control and other necessary operations in order for a multi-domain circuit reservation to be processed. At the final stage of processing, a circuit has to be realized by sending the appropriate configuration commands to the network devices. The AutoBAHN software stack is shown in Figure 2 and it is repeated at each domain that participates in the BoD service. Domain instances communicate with each other via the Inter-Domain Manager (IDM) module.

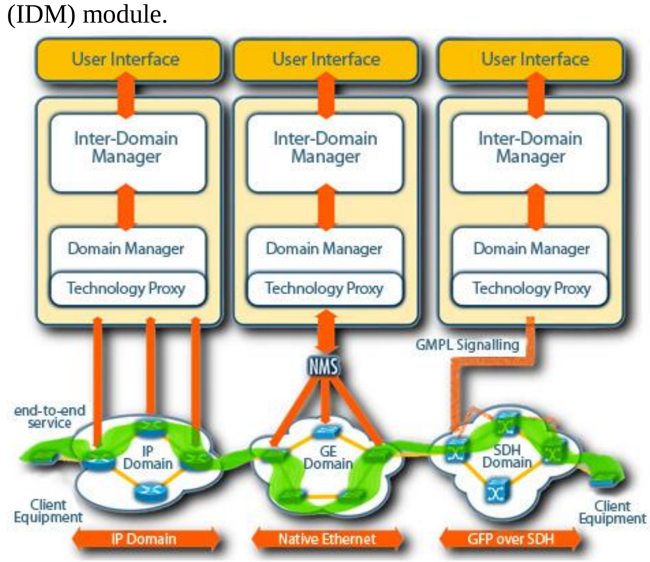

Figure 2. AutoBAHN architecture [2]

Network device configuration may take place via a Network Management System (NMS) or with direct application of configuration commands on devices. In both cases, the AutoBAHN module that is responsible for bridging the generic AutoBAHN software stack with the technology-specific NMS or network devices is called Technology Proxy (TP). The TP translates the reservation requests, received from the DM, to the appropriate commands to be sent (usually via SSH) to a network or an NMS. Each domain participating in the BoD service, depending on the underlying technology, uses a customized version of the TP module.

IV. TP FRAMEWORK

Developing a customized Technology Proxy module for each domain participating in the BoD service is time-consuming and may be difficult to accomplish as the necessary development manpower may not be available. Therefore, AutoBAHN provides the TP framework [2], which enables the creation of a customized TP without the need to develop software. Instead, all that has to be done is to edit the TP configuration with the appropriate network configuration commands for setting up and tearing down circuits. The TP framework then takes care of generating a TP that is capable of bridging the AutoBAHN software with the underlying data plane equipment. The TP framework configuration is based on XML, and allows the definition of several communications methods (such as Telnet or SSH), which can also be customized or extended. It can also accommodate various vendors, equipment models and Operating System versions, using an extensible loader architecture. Furthermore, it provides scripting functionality for more complicated command structures. Finally, the TP framework provides detailed logging so that the network administrator may troubleshoot erroneous behavior or failed requests.

V. IMPLEMENTATION

The Carrier Grade Ethernet TP was prototyped for the case of a network implemented with ExtremeNetworks equipment and especially with BlackDiamond 12804 switches. The BlackDiamond 12800 switches allow a single Ethernet network to deliver both residential and business services. They are chassis-based, Ethernet service core switches designed for core applications. Their features include hot-swappable I/O modules, Management Switch Fabric Modules (MSMs) that provide the active switching fabric and CPU control subsystem, auto-negotiation for half-duplex or full-duplex operation on 10/100/1000 Mbps ports and load sharing on multiple ports. They are running ExtremeXOS operating system, which supports PBB and PBB-TE.

The PBB-TE technology in particular is the one chosen for implementing the dynamic circuit service. PBB-TE allows the creation of a traffic engineered service instance path that behaves much like a dedicated service line and operates over an Ethernet network. A PBB-TE path is a static path through a Provider Backbone Bridge Network (PBBN), which is a 2 network that supports 802.1ad frames (also called Q-in-Q or vMAN in Exterme Networks terminology). If a vMAN connects to a PBB-TE path, vMAN frames always follow the same path to the egress PBB. If a vMAN connects to a PBB, vMAN frames are switched based on the configuration of the PBBN switches. PBB-TE changes the existing forwarding behavior as defined in 802.1Q to a new forwarding behavior by introducing a new port state: forwarding with address learning disabled. On a PBB-TE link, all broadcast, multicast, and unicast packets with an unknown destination MAC address are discarded. PBB-TE relies on Ethernet OAM (CFM) for fault detection and restoration of provisioned paths. CFM actively monitors all provisioned (working and protection) paths. A protection path is selected by mapping a Service VLAN (SVLAN) to a different BVLAN, which defines all the switch ports that link the tunnel endpoints.

Each switch offers a command line interface which can be used by the CGE TP to independently configure each switch in the network. This means that the CGE TP needs to have knowledge of the underlying network and make complicated decisions. Access to the command line interface is provided via Telnet, from a strict set of machines within the internal testbed network (Figure 3). The testbed, as shown on figure 2, consists of three Extreme BlackDiamond 12804 Carrier Grade Ethernet switches and virtual machines as traffic source and destination. MAC addresses of all switches and of the virtual machine are either already known or discovered through the LLDP protocol supported in the switches. Connectivity to the outside world is provided over JANET, the research and education network of the UK.

The Domain Manager (DM) of AutoBAHN submits its requests for reservation or deletions of reservations and the CGE TP sends its responses using a pre-defined Web Services (WS) interface for the DM-TP communication. The reservation request as sent by the DM fully describes the desired route and request parameters (such as required VLAN, capacity, start and end times), leaving to the TP only the configuration of the relevant switches.

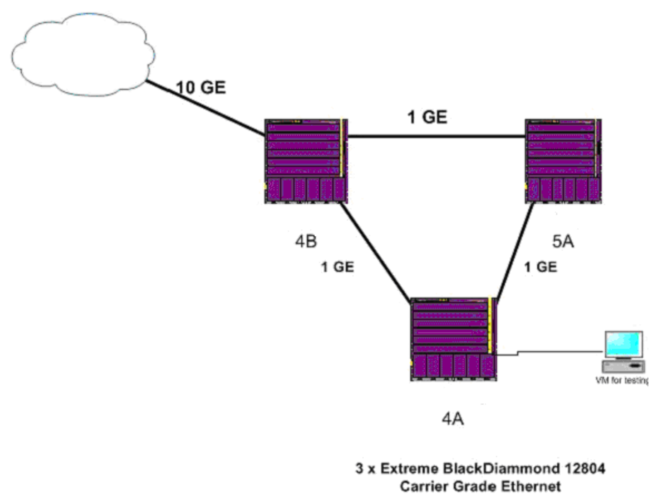

Figure 3. The testbed network, provided by University of Essex

For the purpose of the PBB-TE tunnel function, we initially defined two BVLANs, creating them statically on the interface, so that the TP does not have to recreate them every time it processes a reservation request from AutoBAHN. The first BVLAN consists of edge switches 4A and 4B, while the second includes core switch 5A. Edge switches receive customer VLAN traffic from virtual machines and transform it into SVLAN traffic, to be inserted into the PBBN. By disabling address learning on the switches, we gain complete control over the PBBN path, since each path is a static route. On a PBB-TE link, all broadcast, multicast, and unicast packets with an unknown destination MAC address are discarded. The PBB-TE trade-off is that it takes away the Ethernet self-configure and self-healing mechanisms. We rely on AutoBAHN for the selection of the desired route. By disabling flooding we ensure that all path traffic is limited to the configured path. Finally, by configuring FDB entries on the egress port of each switch along the route, we define the possible paths.

The implementation described above was tested using a simplified client application that provided the TP with incoming requests. The TP was able to successfully configure the testbed switches as described in the relevant sections, setting up a PBB-TE tunnel and enabling layer 2 connectivity between the desired end points. The implemented architecture allows the network administrator to define pre-determined paths (using the BVLAN configuration described above), which leads to predictable traffic management and load balancing. AutoBAHN is then used for the creation of the circuits on-demand, making dynamic use of the pre-determined paths. It is also possible for the administrator to devote a subset of the available capacity for the Bandwidth on Demand service, reserving the rest for manual configuration or other purposes.

VI. Conclusion and Future Work

Our work focused on integrating a testbed network based on equipment supporting Carrier Grade Ethernet standards with a multi-domain BoD service. The outcome of our work demonstrates that Carrier Grade Ethernet is a viable technology for such purposes, even in cases where the equipment does not provide a proprietary network management solution. Furthermore, we verified that the TP framework component that has been developed within the GN3 project greatly eases the necessary work for developing a bandwidth on demand module for a novel technology. This means that different technologies or different vendor implementations can be accommodated faster and with fewer resources because emphasis needs only to be put on properly aligning the technology with the service requirements rather than on low level programming tasks.

Our future work will focus on further testing and performance evaluation of Carrier Grade Ethernet operation in a broader Bandwidth on Demand context. There are a number of possible technology stitching requirements that may arise from the interoperation of Carrier Grade Ethernet with other technologies supporting Bandwidth on Demand in a multi-domain environment, and we plan to investigate them in both testbed and production settings. Another aspect that we were unable to cover was the one of bandwidth limiting or shaping techniques, since VLAN tag was the only information available to identify and separate network traffic, but BlackDiamond 12804 series switches did not support VLAN based traffic groups. We intend to investigate solutions to this issue in the future either with the equipment under consideration or different equipment.

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