

Internet protocol integration with mobile grids : Current Research

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Abstract— This paper focuses on integrating Internet protocol functionality into Grid systems. We outline the advantages of Internet protocol and the benefit to Grid systems. We then introduce our methodology and our efforts to provide Internet protocol support on Grid systems using the Globus Toolkit Version 3 as our concrete working example. The status of global Grid Internet protocol version 6 activities is introduced. We conclude by summarising how to bring Internet protocol version 6 into Grid systems.

I. INTRODUCTION

Grid systems are normally considered as network middleware [1], since they lie between applications and network resources. The data of Grid systems is transported over TCP/IP currently using Internet Protocol Internet protocol version 4 [10], now twenty years old. The next generation IP - Internet protocol version 6, is expected to replace Internet protocol version 4 with a number of improvements.

Since Internet protocol version 6 is expected to become the core protocol for next generation networks, Grid computing systems must track the migration of the lower layer network protocols to Internet protocol version 6. The period of transition from Internet protocol version 4 to Internet protocol version 6 will be long. Hence, it is important that Grid systems allow both Internet protocol version 4 and Internet protocol version 6 networks to be used.

II. CURRENT RESEARCH

The Globus Toolkit [7, 21], developed mainly in the Argonne National Laboratory (ANL), provides the libraries and services for and Grid computing. The current edition of Globus Toolkit – Version 3 (GT3) is based on the latest Grid standards – the Open Grid Services Architecture (OGSA) and integrates the Grid services with the Web services.

GT3 is designed to work with Internet protocol version 4, though many aspects are compatible with Internet protocol version 6. We discuss our attempts to provide dual-stack, Internet protocol version 4 and Internet protocol version 6, facilities in Grid systems in this paper. When the Grid systems are Internet protocol version 6-enabled,

we will be able to experiment with the several features that become possible with Internet protocol version 6 support like mobility, security and auto-configuration

We have structured the paper in the following way. First we consider the potential advantages of Internet protocol version 6, from which Grids could benefit. Then we discuss the general Internet protocol version 6 host and environment. During the discussion, we survey the general steps needed to build up an Internet protocol version 6 experimental environment. In Section 4, we discuss our experience of implementation of Internet protocol version 6 within Grid systems using the Globus Toolkit as example. We keep the consideration as general as we can, so that others could use our approach in other Grid systems. In Section 4.6, we introduce the current status of global activities for getting Internet protocol version 6 in Grids. Finally, we end this paper by briefly summarising how to bring Internet protocol version 6 into Grid systems.

As network middleware, the current release of Globus Toolkit uses Internet protocol version 4-based network resources to serve the upper layer applications and users. Like all widespread applications, the Globus Toolkit should be prepared to move into the Internet protocol version 6 era.

The bulk of the Internet protocol version 6 standards were ratified in the Internet Engineering Task Force (IETF) in 1998. Internet protocol version 6 fulfils the future demands on address space, and also addresses other features such as multicast, encryption, Quality of Service, and better support for mobile computing. In comparison to the current Internet protocol version 4 protocol family, Internet protocol version 6 offers a number of significant advantages. Most of these advantages will also be very useful for Grid purposes. The Internet protocol version 6 data format does not really provide most of these advantages by itself. However, the design of the Internet protocol version 6 protocol suite has taken the opportunity to re-design the relevant protocols with a better and more logical system; for example the Internet protocol version 6 renumbering mechanism could simplify dynamic mergers and acquisitions of Virtual Organisation in Grid systems.

Three major advantages are : bigger address space, mobility support and security support – ignoring the many other advantages and potential benefits of Internet protocol version 6, such as auto-configuration [15], hooks for QoS, etc.

A. Bigger Address Space

With its 128-bit address space and much better address aggregation properties, Internet protocol version 6 potentially makes massive scaling of Grid networking possible; this is important in view of the aims to deploy Grid computation globally.

With the enlarged address space, workarounds like NATs (Network Address Translators) [14] are no longer needed. This allows full, global IP connectivity for IP-based machines as well as upcoming mobile devices like PDAs and cell phones – all can benefit from full IP access through end-to-end services. There can be multiple addresses for a single interface; where the addresses can be used for different functions. The large address space allows for simpler end-to-end security, Internet protocol version 6 renumbering mechanism, separated addressing and routing, etc.

B. Mobility Support

Until recently, most Grid research has focused only on fixed systems. However, the mobility support within Grid systems will be needed as mobility takes an ever more important role in modern life. In our research, the Mobile-Grid-specific auto-configuration mechanisms are proposed to allow a Grid Mobile node to use the Grid resources available locally. As regards next generation mobile networks, Internet protocol version 6 is mandated by the 3rd Generation Partnership Project [20]. Mobile Internet protocol version 6 [8, 11] is accessible using general Internet protocol version 6 APIs, appearing transparent to the application layer.

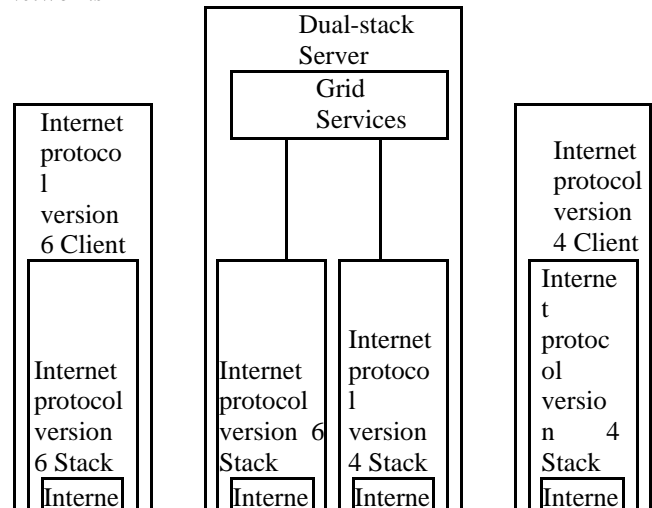
Thus, in an Internet protocol version 6 implementation, there is potential support for roaming between different networks, with global notification when you leave one network and enter another. Support for roaming is possible with Internet protocol version 4 too, but it is generally less efficient.

C. Built-in Security

While scalability, performance and heterogeneity are desirable goals for any distributed systems, including Grid systems, the characteristics of computational Grids lead to security issues. Though the security improvement from Internet protocol version 6 does not solve all the security problems, Grid systems can benefit from Internet protocol version 6's security features. The Internet protocol version 6 security and Grid Security Infrastructures are running at different levels. They can be employed together to provide better security granularity.

Besides support for mobility, security was another requirement for Internet protocol version 6. The Internet protocol version 6 protocol stacks are required to include IPsec [12], which allows authentication and encryption of IP traffic. With IPsec all IP traffic between two nodes can be handled without adjusting any applications. Alternatively application-level security can be employed per service if required. However, using IPsec all applications on a machine can benefit from encryption and authentication, and policies can be set on a per-host (or even per-network) basis instead of per application/service. Full IPsec security operates over Internet protocol version 4 today – when there is a full end-to-end connection. If NATs are used, as often occurs in Internet protocol version 4 networks, but are not needed in Internet protocol version 6 ones, it is not possible to use full IPsec on the end-to-end communications.

D. Communication in Heterogeneous Internet protocol version 4/Internet protocol version 6 Networks



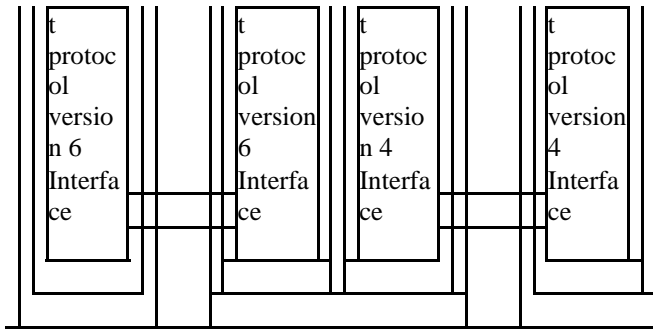


Fig. 1. IP Communication in heterogeneous Internet protocol networks

Since there will be a period of IP transition, consideration must be given to an interim coexistence of Internet protocol version 4 and Internet protocol version 6 [6]. Our effort to integrate Internet protocol version 6 into Grid systems takes an IP-protocol independent approach, i.e. it supports both Internet protocol version 4 and Internet protocol version 6. The IP-independent server, shown in Fig. 1, has to be able to respond to client calls according to the IP family that the client uses. Since Internet protocol version 4-only machines will exist for many more years, while Internet protocol version 6-only machines are starting to appear, it is necessary to provide support to both Internet protocol version 4-only and Internet protocol version 6-only environments.

The client decides which version of IP is to be used. The Grid server responds to the client calls according to which IP family the client uses. For instance, in Fig. 1, an IP-independent Grid server starts and listens on both its Internet protocol version 4 and Internet protocol version 6 interfaces. When an Internet protocol version 4 client connects over Internet protocol version 4, the Grid server uses Internet protocol version 4 interface to callback; only Internet protocol version 4 communication takes place – similarly with Internet protocol version 6. With dual-stack servers, the client can choose which IP family is the default or preferred.

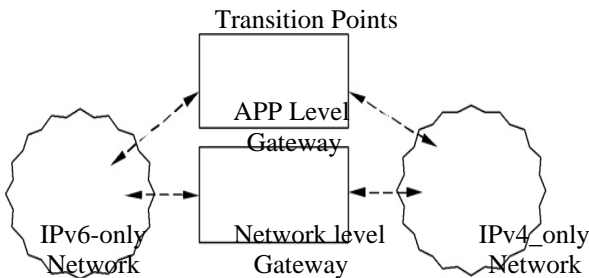


Fig 2. IP Transition between IPv4-only and IPv6-only networks

For communication in heterogeneous Internet protocol version 4/Internet protocol version 6 networks, there are a number of network transition aids [5, 13], which essentially translate the packet headers between Internet protocol version 4 and Internet protocol version 6, leaving the payload untouched. These approaches may work in certain circumstances for Grid applications. A higher level approach, which is employed by other services for transition, is application level gatewaying. This operates in a dual-stack node and actually does an application level translation of the payload of the packets between the two communicating nodes. (See Fig2.)

III. INTERNET PROTOCOL ENVIRONMENT FOR GRID

The Internet protocol version 6-capable application API libraries are required in order to run the Internet protocol version 6-enabled applications or IP-independent applications over Internet protocol version 6. All network-associated applications, such as network-sharing database applications and web containers, need to be Internet protocol version 6-enabled to run Internet protocol version 6 tests. In order to run tests over a network rather than only on local hosts, Internet protocol version 6 support on the network is essential.

A. Operating System Support on Hosts

The Internet protocol version 6 support on hosts depends on the operating system and its kernel. For the time being, we restrict ourselves to the LINUX/PC platform since GT3 is only fully working on Linux systems. UCL has set up an Internet protocol version 6-enabled Grid testbed, which includes 5 nodes running Linux Red Hat 8 and 3 nodes running Linux Red Hat 7.3 with recompiled kernel, for Internet protocol version 6 support.

From Linux Red Hat 8 (kernel 2.4.18), the Internet protocol version 6 module is provided with auto-load as default. On the earlier distributions of Linux, users had to re-compile the kernel to get the Internet protocol version 6 support [16]. On Windows 2000, an Internet protocol version 6 preview package (free download [17]) is available with limited functionality. The Internet protocol version 6 package in Windows XP, which provides a better Internet protocol version 6 support, is distributed with the edition, but requests individual installation [18].

B. Internet protocol version 6-capable Application API Libraries

Internet protocol version 6-capable application API

libraries need to provide support for upper-layer applications. GT3 is mainly written in Java. For the Internet protocol version 6 support, we use Sun Java SDK 1.4.1 on our Internet protocol version 6

With the Internet protocol version 6-compatible kernel and the Internet protocol version 6 module loaded, Linux system libraries provide a few Internet protocol version 6 data structures, such as `sockaddr_in6`, `in6_addr` and `in6addr_loopback`, and Internet protocol version 6 system functions, such as `inet_ntop()` and `inet_pton()`, are available to be used. But they are not IP-version-independent. To be IP-independent, IP-independent data structures, such as `addrinfo` and `sockaddr_storage`, and functions, such as `getaddrinfo()` and `getnameinfo()` should be used on dual-stack servers and server applications.

As a platform-independent runtime environment, JDK 1.4 provides the Internet protocol version 6 support on Solaris and Linux. JDK 1.5 is planned to provide Internet protocol version 6 for WinXP. Within Java SDK 1.4, the class `java.net.InetAddress` has two direct subclasses: `java.net.Inet4Address` and `java.net.Inet6Address`. They provide the support for Internet protocol version 4 and Internet protocol version 6 addresses. The `InetAddress` class uses the Host Name Resolution mechanisms to resolve host names to their appropriate host address type. Additionally there are various system preferences that can influence protocol preferences, such as `preferInternet protocol version 6 Addresses` and `preferInternet protocol version 4Stack`.

C. Associated Applications

The Globus system also utilises external applications. All network associated applications need to be Internet protocol version 6-enabled as well. In GT3, the Java run-time environment needs to be Internet protocol version 6-enabled as mentioned earlier. Java DataBase Connectivity, which is used for Reliable File Transfer, needs an Internet protocol version 6 patch. As recommended by the Globus Implementation Group, Jakarta Tomcat is used as the web container for the Grid services on a Grid server. The container environment needs to provide Internet protocol version 6 Web services for Grid services. Tomcat version 5 has been tested with Internet protocol version 6 capabilities.

D. Networking Support for Internet protocol version 6

In order to run Internet protocol version 6 tests over a network rather than only on local hosts, Internet protocol version 6 support for networking is essential. It requires Internet protocol version 6-enabled routers, which provide forwarding and dynamic routing, and support from Internet protocol version 6-enabled network services, such as Internet protocol version 6 DNS, Web services, etc. A number of the major router manufactures provide now

basic Internet protocol version 6 support and are beginning to provide more advanced support such as hardware forwarding. Support for Internet protocol version 6 in the DNS – provides hostname and Internet protocol version 6 address resolution which may be provided over Internet protocol version 4 and/or Internet protocol version 6 connection. For the communication in heterogeneous Internet protocol version 4/Internet protocol version 6 networks, there are many approaches to the provision of transition aids. They need to be considered when building an Internet protocol version 6 environment within or around current global Internet protocol version 4 networks.

IV. INTEGRATION OF INTERNET PROTOCOL VERSION 6 INTO GLOBUS

The integration of Internet protocol version 6 into the Grid systems starts with finding IP-version-dependencies in the network protocols. The implementation of network APIs within applications may involve a few IP-dependent functions. We introduce our methodologies in later sections using Globus Internet protocol version 6 porting as an example. A number of modifications need to be made for IP-dependent operation. In order to operate in heterogeneous Internet protocol version 4/Internet protocol version 6 networks, a few configuration options are needed.

A. Methods of Finding IP Dependencies

To find out exactly which lower-layer protocols and APIs are being used, two approaches are taken – firstly the ‘top down’ approach where we execute some upper layer applications. Secondly the ‘bottom up’ approach where we monitor all the data traffic between nodes and on the Loopback interface. The following have been identified as relevant; they have been modified to be IP-independent:

- Which network protocols are involved and whether they are IP-dependent
- Where to get or generate IP addresses
- How to generate URLs [3] and URIs [4] with IP addresses
- How to create sockets and network connections
- Hard-coded Internet protocol version 4 addresses

B. GT3 Protocols Modification for Internet protocol version 6

The specifications of a few protocols have needed to be modified to suit Internet protocol version 6. In the Globus Toolkit, Grid FTP is being modified in a way similar to FTP (RFC2428 [2] – “FTP extend for Internet protocol version 6 & NATs”). Correspondingly, the specific implementations of these protocols need modification as well. Within the Globus project, GridFTP is currently

implemented in standard C. A new IP-independent network module known as `globus_XIO` is being developed for use by for GridFTP.

In our porting, all protocols involved must be examined, we are in contact with the Globus implementation group on this, and have examined most. The GGF Internet protocol version 6-WG is surveying all GGF specifications for IP version dependence. This is also happening with the Internet Engineering Task Force.

C. *Internet protocol version 6 Modification in GT3 Implementation*

While modifying the IP-independent protocols and their implementation, the implementation of the Globus Toolkit has needed to be modified as well. Corresponding to the IP network functions found using the method we mentioned in Section 4.1, the following modifications have been made to various modules to realise Internet protocol version 6 functionality in GT3 while Java SDK has provided the IP-independent data structures and functions:

- “Localhost” or particular hostname are used in both the Globus configuration file and Globus initial functions. Then IP-independent functions (`InetAddress.getByName` in Java, `getaddrinfo` in standard C) are used everywhere need to translate hostname into IP address.
- All URLs and URIs generating functions have been modified in order to handle the particular format of the literal Internet protocol version 6 addresses in URLs [9]. It ensures the literal Internet protocol version 6 addresses in URLs are included by square brackets.
- Hard-coded Internet protocol version 4 address. All hard-coded Internet protocol version 4 addresses have been replaced by “localhost” or particular hostnames. Then use IP-independent functions look up the IP addresses when need to translate hostname into IP address.

D. *Configuration for IP Operations*

In GT3, a few configuration options are available to allow the user to choose the startup IP bindings. To use hostname instead of IP address, the user needs to set up the configuration option “`publishHostName`” be “true” in the `globalConfiguration` section of `server-config.wsdd`. If there are other IP addresses that are associated with a host, such as a particular Internet protocol version 6 hostname, the user needs to set up which the hostname is used with the configuration option “`logicalHost`”. By Java default options, Internet protocol version 6 address has higher

priority on dual-stack machines. To operate in Internet protocol version 4-only network or set Internet protocol version 4 be higher priority, user needs to set Java system properties “`preferInternet protocol version 6Addresses`” be “false” and “`preferInternet protocol version 4Stack`” be “true”.

E. *GT3 Version Dependency*

Mainly work has been done on the GT3 alpha version because it provided the most verbose debug information. We have demonstrated successfully Internet protocol version 6 functionality and run our tests on the GT3 alpha version. More components are involved in GT 3.0; some of GT 3.0 components involved more IP-dependent issues. Globus Resource Allocation Manager (GRAM) have been identified as not working in GT 3.0, which worked in GT3 alpha, due to Java Internet protocol version 6 reverse looking up bug.

Internet protocol version 6-only porting has been done with the minimal modification. During this stage, as much as possible, IP-independent functions and data structures have been used instead of Internet protocol version 4-only or Internet protocol version 6-only one. The situation becomes much more complicated for Internet protocol version 4/Internet protocol version 6 dual stacks. In the dual-stack environment, parallel independent support for both Internet protocol version 4 and Internet protocol version 6 must be provided. The Grid server starts with the IP-independent hostname and respond the client calls according to the IP family user used. After modification has been made, we do run Internet protocol version 4-only tests as well, since most Globus users are obviously still Internet protocol version 4.

The services or applications that are distributed with GT3 are used as general initial test services in our test scenarios. Grid Services can be accessed through Internet protocol version 6 interfaces by using the OGSA graphic user interface service browser. Remote GRAM jobs can be submitted through Internet protocol version 6 interfaces. These tests were also successfully run with Internet protocol version 4 in our heterogeneous IP Grid testbed.

The E-Protein project had developed a remote executing service based on GT3 GRAM. It was successfully transplanted to the Internet protocol version 6-enabled Globus infrastructure.

F. *Grid Internet protocol version 6 Standardisation Status*

Since February 2003, when the Global Grid Forum (GGF) and the Internet protocol version 6 Forum announced a liaison relationship to drive New Generation Applications deployment worldwide, Internet protocol version 6 has become relevant to Grid activities.

An Internet protocol version 6-Grid Working Group has

been set up in GGF. The GGF Internet protocol version 6 WG [19] is currently working on two drafts: "IP version dependencies in GGF specifications" and "Guidelines for IP independence in GGF specifications", which have been presented in GGF9. UCL makes contributions for both of drafts. UCL is currently involved with a number of activities that bring Internet protocol version 6 into other Grid systems, such as Sun Grid Engine.

CONCLUSION AND FUTURE WORK

The mechanisms and approach for integrating Internet protocol version 6 into Globus introduced in this paper could benefit other research to integrate Internet protocol version 6 into other Grid systems.

Some modifications are needed, which will make Internet protocol version 6 configuration and operation easier and smoother. This will be implemented on the stable Globus Toolkit distribution.

We plan to look into issues of mobility and security in Grids. Mobility support in Grid computing systems will be achieved based on using Mobile Internet protocol version 6. Our proposed Mobile-Grid-specific reconfiguration mechanisms will be developed to meet the particular requests for transparent, dynamic and automatic network services in Grid computing systems.

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