THE CORE PROTOCOL SET FOR THE GLOBAL GRID*

Joseph Rajkowski, Lead Networking Systems and Distributed Systems Engineer,
The MITRE Corporation, Bedford Massachusetts, 01730
Kenneth Brayer, Principal Engineer,
The MITRE Corporation, Bedford Massachusetts, 01730

ABSTRACT

The protocol set for the Global Grid is addressed. A rationale for specifying a core protocol set, the methodology for determining the protocols included, and a discussion of the extensibility of the core protocol set to address support for user-specific applications are provided.

BACKGROUND

One of the principal goals of the Global Grid is to specify/define a communication infrastructure that supports integrated voice, video, and data services and that will allow command and control (C2) decision makers to get information to or from anyone, anywhere, and at any time. The Global Grid must support connectivity for a diverse user community and diverse organizational elements: main operating bases, barebases, deployable and mobile operating nodes, and fixed and mobile subscribers. In addition, the Global Grid must support the transfer of information of all classification levels. The development of the Global Grid must address many challenges that are a consequence of the nature of current military communications that are often based on mission-specific communication systems. These challenges include the following a wide variety of mission-specific links with little interconnectivity between systems at all functional levels: communications, management, and security; limited connectivity and/or limited bandwidth implying limited data rates to airborne platforms; limited support for mobile subscriber devices or nodes comprising the networked infrastructure; limited adaptability in response to changes in the mission; and limited flexibility in accommodating upgrades to benefit from technological advances.

In summary, current Air Force data communications were designed to provide for specific message traffic among identified users, and not as a general data communications capability for common use.

The Global Grid architecture implementation will evolve to address these limitations through a phased development approach. Phase 1 consists of providing basic connectivity among all users. This phase includes providing support for links that connect users to a network and providing interconnectivity among these networks. It is expected that at least initially, gateways will be required for establishing network connectivity for some mission-specific links. Phase 2 will be a longer, evolutionary phase that incorporates features such as efficient link utilization and increased capacity, self-management and configuration, improved quality of service, and minimal vulnerability/maximum security.

RATIONALE

The Global Grid will consist of interconnected networks that rely on both fiber optic or wireline and wireless links, employing various protocols such as Point-to-Point Protocol (PPP), Ethernet, and Asynchronous Transfer Mode (ATM) as well as various transceivers, including line-of-sight (LOS) or beyond LOS (BLOS) radios and satellite terminals. Users will connect to the networked infrastructure with computers, terminals, handsets, and other subscriber devices. The subscriber devices contain applications that implement user-to-user communication functions, such as file transfer, electronic messaging, voice communications, and bit stream transfers (e.g., weather data). Additionally, these devices will include a subset of the networking functions that are required for access to the networked infrastructure. Interconnectivity among the networks and point-to-point

Research reported in this paper was supported by the U.S. Air Force Electronic System Center under contract number F19628-99-C-0001

links is achieved using devices such as routers and switches. These devices ensure that information is routed properly among communicating users.
A number of protocol suites have been developed to support data communications among widely dispersed users connected by networks consisting of a heterogeneous mixture of wireline and/or wireless media. Important examples of these protocol suites include the Transmission Control Protocol/Internet Protocol (TCP/IP) and the International Standards Organization (ISO) Open Systems Interconnection (OSI) suites. A common characteristic of these protocol suites is that they are based on layered architectures. In a layered architecture, specific communications or networking functions are contained within specific layers, with upper layer protocols relying on services provided by lower layer protocols. In addition, specifications define the data that are passed between these layers. An advantage of this approach is that development of and enhancements to a protocol at a given layer may be done independently of those at other layers.

The Global Grid infrastructure will also be based on a standardized layered architecture to meet its communications requirements. This paper will focus on specific protocols that will be included at the various layers of the architecture.

The ultimate goal of the Global Grid is to support the exchange of information among users. An important facet of meeting this goal is the set of application layer protocols that are directly involved in the information exchange. These protocols, which are installed within the end user systems (subscriber devices), must use standardized, compatible mechanisms for the transfer of information. The Global Grid protocol set will specify a small number of recommended application layer protocols to be included on all subscriber devices attached to the Global Grid to ensure that a standardized method exists for communications among users. Another facet of information exchange is the use of standardized formats for the content exchanged by subscriber applications so that the interpretation of the information and its conversion to a form that is intelligible to users can be achieved. Although this is an important facet of information exchange, this requirement will be considered as the responsibility of the users and is outside the scope of Global Grid requirements.

The fundamental components of the Global Grid architecture are the transport and network layer protocols, which provide the infrastructure that supports the information transfer. The transport layer protocols provide the services required for end-to-end communication. Services provided by the transport layer may include reliable delivery and end-to-end flow control. The network layer protocols provide services required for forwarding packets of information, on a hop-by-hop basis, along a path or paths connecting the information source with any end user systems receiving the information. This paper will specify the transport and network layer protocols that must be implemented in the routers and switches that comprise the Global Grid infrastructure as well as in the subscriber devices that will attach to the Global Grid.

The final components of the Global Grid architecture are the link layer protocols that provide the connections that comprise the path(s) between the user devices that are involved in the information exchange. The Global Grid layered architecture will ensure that the routing of information among communicating users can be achieved over any of the links that may be used to provide a user's local network connection to the Global Grid. The nature of the support for user-selected links will be detailed in the next section, entitled The Global Grid Model.

Table 1 provides a high-level representation of the Global Grid layered architecture, showing color-coded application, transport, network, and link layers. The table also depicts a three-tiered set of protocol suites that cover the complete range of communications requirements for the Global Grid user community. Tier 1 consists of the primary set of protocols to be implemented universally across the Global Grid to support communications among any group of users. Tiers 2 and 3 consist of extensions to the primary protocol suite to accommodate the unique requirements of successively more restricted groups of Global Grid users. The intent of Tiers 2 and 3 is to include all users that could interoperate if they utilize agreed-upon protocols. The main idea, however, is to encourage all users to migrate their protocol suite towards the Tier 1 set to maximize the potential interoperability among users. Additional details of the tiered structure of the Global Grid protocol set will be provided in The Global Grid Model section.

The paper will be limited to a discussion of the Tier 1 protocol set of the Phase 1 implementation of the Global Grid architecture. It will include recommended application layer protocols and support for user-selected links; however, its focus will be the core protocol set. The core protocol set, which supports the fundamental communication requirements of the Global Grid, consists of the protocols of the transport and network layers of the Global Grid architecture, as highlighted in dark gray in Table1.

	TIER 1 PROTOCOLS	TIER 2 PROTOCOLS	TIER 3 PROTOCOLS	ARCHITECTURE LAYER
	Application Protocols	Application Protocols	Application Protocols	**Application**
Core	**TCP/UDP**	**Transport Protocol(s)**	**Transport Protocol(s)**	**Transport**
	IP	**IP**	**Non-IP Protocol(s)**	**Network**
	Link Protocol(s)	Link Protocol(s)	Link Protocol(s)	**Link**

Table 1. Tiered Structure of Global Grid Layered Architecture

THE GLOBAL GRID MODEL

The Internet provides a candidate architecture that satisfies many of the requirements for and includes many of the desired characteristics of the Global Grid. The Internet supports a variety of links that connect users to a network and that establish interconnections among networks. It also includes a diverse set of applications that support basic communication functions among large communities of users. The communication capabilities and connectivity of the Internet are based on open standards and protocols. A benefit of the reliance on open standards is that it results in a competitive development and refinement of communication capabilities at reasonable costs.

A potential drawback of the use of the Internet as the model for the Global Grid and the use of its protocols as the basis for communications within the Global Grid is that Internet protocol development is often dictated by economic self-interest of the vendors. This can lead to protocol implementations that do not address the requirements of the military community. Current implementations that either do not fully address all military requirements or do not address them in a standardized way include message precedence, quality of service (QoS), security, and mobile networking.

The fact that the Internet is based on a layered architectural model minimizes the potential drawbacks. The layered structure facilitates the replacement of a current implementation of a protocol with one that addresses new requirements or that incorporates other technological advances, such as performance improvements. This extensibility facilitates the modification of the Internet's suite of protocols to satisfy military communications needs that are not fully addressed in current, commercial implementations of the protocols. Because of the extent to which the Internet satisfies Global Grid requirements, the pervasiveness of the protocols, the degree to which they are familiar to many users, and the reliance on a layered, extensible architecture, the Internet and its protocols will be used as the basis for the Global Grid.

As with the Internet, the central protocol of the Global Grid's core protocol set will be IP, the well-known network-layer internet protocol; however, the standardization on IP is not intended to imply a static infrastructure or one that does not accommodate protocols that are not IP-based. Although initially the routing functionality will be limited to that provided by commercial implementations of IP and IP-based protocols, it will evolve over time to address the limitations of these protocols with respect to military requirements. The evolution of the protocol suite will be driven by either the military's involvement in the standards bodies to influence the protocol evolution or through support for custom protocol developments.

The overall Global Grid architecture and the upper layer protocols that are involved in end-to-end communications will be represented as a tiered model. Figure 1 below illustrates the general layout of the tiers of the Global Grid's layered architectural model. This is another way of viewing the architecture represented in Table 1 with the tiers one behind the other instead of side-by-side. Each of the two blocks represents a complete protocol stack in a server/router/switch or a subscriber device. The front vertical plane of the protocol stack, Tier 1, consists of the required transport layer (i.e., Transmission Control Protocol, TCP, and User Datagram Protocol, UDP) and network layer protocols (i.e., IP) that comprise the Global

Grid's core protocol set, as well as recommended application layer Protocols. The two other vertical planes are shown to indicate the protocol stack's extensibility. The second vertical plane, Tier 2, includes additional IP-based transport layer protocols and/or applications used to support user- or mission-specific communications requirements. This may include modified implementations of TCP that address some of the protocol's limitations in high delay- bandwidth-product military environments. The third vertical plane, Tier 3,

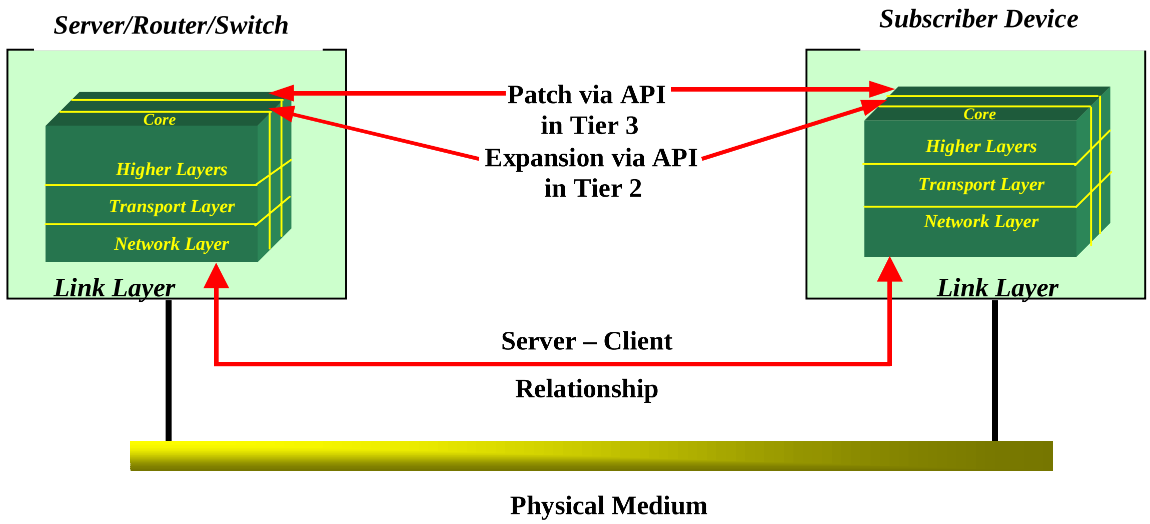

Figure 1. Global Grid's Extensible Layered Model Architecture

includes additional transport and application layer protocols used to support even more restrictive user- or mission-specific requirements. For the third tier, the network layer protocol is something other than IP.

The vertical extensibility of the Global Grid architecture – the addition of higher layer protocols over IP – is achievable because of the explicit inter-layer interface definitions specified by the Internet standards. The vertical extensibility is further simplified through the use of an Application Programming Interface (API) that has been developed for use in the Internet protocols. The API specifies the mechanisms by which the application layer accesses the functionality of the transport and network layers. For example, Berkeley Software Distribution (BSD) sockets for UNIX systems and the Microsoft WinSock API, which was derived from BSD sockets, are APIs in common use.

The vertical extensibility of the Global Grid architecture can also be accommodated below the IP layer to support a broad range of links; however, the inter-layer interface specification necessary for this has not been as extensively or completely specified by the Internet standards. In order to address this limitation, the specification of the Global Grid infrastructure will include an interface definition for the network- link layer interface. This interface definition will specify the required functionality of both layers and the information exchanged across the interface in support of the required functionality. Any data link that satisfies the requirements of the interface definition can be used to connect users to the Global Grid.

In addition to the vertical extensibility that is accommodated through inter-layer interface specifications and APIs, the Global Grid core protocol set is horizontally extensible, in that set of protocols supported at the transport and network layers may be expanded as well. As an example for Tier 2, transport protocols such as enhanced versions of TCP/UDP that have been developed to that address specific communications requirements such as improved efficiency of communications over large time delay – bandwidth product links, e.g., satellite links. As an example for Tier 3, OSI's Connectionless Network Protocol (CLNP), which is used in the Aeronautical Telecommunications Network (ATN), may be added to support OSI-based transport and application layer protocols. These protocols can be implemented on the same hardware that supports IP-based communications.

This expanded set of network layer protocols, however, will not be considered part of the core protocol set for the Global Grid. Again, to become more compatible with the Global Grid, users are encouraged to migrate their protocol suites from Tier 3 to Tier 2 to Tier 1.

CORE AND RECOMMENDED PROTOCOLS

The Global Grid will include a core set of IP-based communication, management, and security functions and protocols. This will consist of a small set of protocols that support basic communications functions and will be used as the basis for satisfying the Global Grid requirement of ensuring communications among any users. This core set of protocols will comprise the transport and network layers of the primary, or first tier (Tier 1) of the Global Grid infrastructure. Additionally, there will be recommendations made for application layer protocols to support end-to-end communications within the Global Grid, but, these will not be considered part of the core protocol set. Protocols associated with Tier 2 and Tier 3 extensions of the Tier 1 set will not be specified in this paper. Again, the purpose of Tier 2 and Tier 3 is not to exclude any user of the Global Grid but rather to show each user the extent to which they should migrate towards Tier 1, the recommended set of Global Grid protocols.

The process for determining the core set of protocols for the Global Grid will include surveys that determine protocols that are in common use by the Internet community and the military. These surveys will include a review of the Joint Technical Architecture (JTA) as well as of Internet Engineering Task Force (IETF) Requests for Comments (RFCs) that specify Internet protocols and their level of maturity, protocols commonly supported by networking device manufacturers (Cisco, Nortel, 3Com, Cabletron, etc.), and protocols that address specific military requirements. In addition, determinations will be made of the minimum set of features and functions that must be supported by the Global Grid architecture for end-to-end communications. Assessments of the protocols will be made to determine the core set of protocols required to support the minimum functionality and candidate protocols for augmenting the core set. For features and functions that are addressed by the JTA, protocol selections will be made that are consistent with JTA-mandated standards unless there are compelling reasons to recommend alternative protocols. Finally, the limitations of the protocols with respect to supporting all military communication requirements will have to be made in order to determine how the protocol sets would have to be modified or augmented for military use, and whether the costs justify implementing the modifications. In order to address some of these limitations, the organizations fostering the Global Grid, e.g., ESC/MITRE, the Air Force and other Services, DISA, the MCEB, etc., should become more involved in standards bodies. This would provide additional opportunities to influence the development of protocols and increase the likelihood that cost-effective solutions are implemented. In addition, these organizations should become more involved in the JTA process, which would allow for the dissemination of information about important emerging technologies that address military requirements. This would facilitate early planning for and incorporation of these technologies into military networks and communication systems when the technologies become mature.

Clearly, this needs to be an ongoing process in the years to come. The core set of protocols will reflect the current capabilities of commercial implementations of networking protocols and will evolve over time to reflect the evolution of the standardized protocols as technology changes and/or as military needs are addressed. As with the Internet, IP will be the central protocol of the core protocol set and will be used to support the networking functionality of the Global Grid routers, switches, and subscriber devices. It will be augmented by the Transmission Control Protocol (TCP) and User Datagram Protocol (UDP), which will provide both guaranteed and best-effort transport services, respectively. TCP and UDP will be the basis for supporting end-to-end communications within the Global Grid. Specific communications functionality will be provided by upper layer protocols that rely on the functionality provided by TCP/UDP and IP. These applications should be universally implemented to ensure that there is at least one guaranteed method for users to transfer a given type of information among themselves. These protocols will be selected in order to support a range of basic communication functions, such as file transfer, electronic mail, etc.; however, the selection is not intended to result in an expansive list.

Table 2 summarizes the current set of protocols that will comprise the core set. For each protocol, the table indicates the reference standard that specifies the requirements for the given protocol and, where applicable, the version number. In addition, the table indicates whether the protocol is applicable to subscriber devices and router/switches. NOTE: The referenced standards generally specify the required and optional features to be implemented in the protocols. For the Global Grid core protocol set, all required features of the specified protocols must be implemented. Optional features for each protocol that should be implemented as well as any constraints on use or configuration to address management or security requirements will be identified in the Notes field of the table. The Notes field will also summarize any deficiencies of the current implementations of the protocols with respect to meeting military communications requirements.

The intent of the core protocol set specification of Table 2 is to provide a complete listing of the minimum set of protocols that must be installed on all Global Grid-connected subscriber devices, routers, and switches in order to meet Global Grid communications requirements. An initial assessment by an expert independent organization, which prefers to remain anonymous, indicated that the protocols of Table 2 represented a good foundation for the core protocol set specification; however, the assessment was limited to a consideration of meeting the communications requirements of non-military users. MITRE will perform a more complete assessment of the protocol set and its ability to meet current and future military communications requirements that are specified in or derived from the JTA, Joint Vision 2010 doctrine, and other requirements and policy documents. The assessments will include surveys of technical literature to identify known protocol deficiencies and experimental protocols that are being developed to address these deficiencies as well as to provide new capabilities. In addition, the assessments will include analyses, modeling and simulation, as well as experiments using MITRE's Experimental Global Grid (EGG) testbed, satellite) communication systems. The EGG as necessary. The EGG consists of IP-based network architecture with Ethernet and ATM links that interconnect MITRE labs performing research in

Name	**Ref. Std.**	**Server/Router /Switch Req.**	**Subscriber Device Req.**	**Notes**
TCP	RFC 793	Yes	Yes	Current, commercial implementations of TCP do not support efficient communications over some links – notably circuits involving large delay- bandwidth products. Although some enhancements have been identified (e.g., TCP SACK, RFC 2018), none are extensively implemented or completely satisfactory. It may be necessary to recommend specific protocol sets to address specific limitations associated with given link types. One such example is the use of ADCCPx3.66 (FED-STD-1003A) to encapsulate IP datagrams for transmission over satellite links.
TCP Scaled Window Option	RFC 1323		Yes	
TCP Congestion Control	RFC 2001	Yes	Yes	
UDP	RFC 1006	Yes	Yes	
IP	RFC 791; RFC 950 (subnets); RFC 922 (broadcast); RFC 1519 (CIDR); RFC 1108 (security)	Yes	Yes	There is only limited support for mobile subscribers, and quality of service.
ICMP	RFC 792	Yes	Yes	
IGMP	RFC 1112	Yes	Yes	

Table 2. Core Protocol Set

extending data networks to LOS (HF radio and wireless) and BLOS (commercial and military provides a flexible infrastructure that can be used to evaluate interoperability of protocol implementations and the capabilities and performance of experimental protocols as well as to identify potential data link interface issues. In addition to providing information that will result in a more complete core protocol set specification, the assessments will provide important information to support standards development activities that will potentially result in standards-based solutions and commercial implementations of protocols that meet military communications

CONCLUDING REMARKS

The effort to define the Global Grid infrastructure and the core protocol set is not intended to imply that ESC will assume responsibility for procuring, maintaining, and upgrading the routers, switches, servers servers and their core software. Responsibilities for procurement and maintenance will reside with the organizations that currently maintain specific components of the military com-munications infrastructure. For example, DISA will have overall responsibility for maintaining WAN connectivity via the Defense Information System Network (DISN), and the Services will be responsible for the local network connectivity within their own fixed and deployed bases as well as platforms. This will be done to share the costs of achieving the ultimate goal: to meet Joint Service warfighter communications and information requirements. However, it is expected that some central authority will certify a list of commercial equipment that meets Global Grid requirements, and will publish the list quarterly.

Name	Ref. Std.	Server/Router/ Switch Req.	Subscriber Device Req.	Notes
FTP	RFC 959	Yes	Yes	
SMTP	RFC 821	No	Yes	
Telnet	RFC 854; options/ extensions RFCs 855-861, 1043, 1073, 1079, 1080, 1091, 1116	Yes	Yes	
SNMP	RFC 1098	Yes	No	RFC 1098 specifies SNMPv1, which contains minimal security features to protect configuration data; SNMPv3 should be used when implementations are standardized.
OSPF	RFC 2328	Yes	No	
BGP4	RFC 1771	Yes	No	
DVMRP	RFC 1075	Yes	No	Interoperability and limited deployment in WAN environment are issues for all multicast routing protocols
MOSPF	RFC 1584	Yes	No	Interoperability and limited deployment in WAN environment are issues for all multicast routing protocols
PIM-DM, PIM-SM	RFC 2362	Yes	No	Interoperability and limited deployment in WAN environment are issues for all multicast routing protocols
MBGP	RFC 2858	Yes	No	Interoperability and limited deployment in WAN environment are issues for all multicast routing protocols

Table 3. Recommended Application Layer Protocols