Layered Communications Architecture for the Global Grid*

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ABSTRACT

A layered communications architecture is advocated for the military's Global Communications Grid (GCG) or Global Grid (GG), the communications infrastructure of the Global Information Grid (GIG). A seven-layer reference model consisting of Mission, Application, Service, Transport, Network, Link, and Physical Layers is introduced; the GG corresponds to the Transport and Network Layers. The fundamental concept for military interoperability inherent in the GG architecture, viz., network-centricity, is explained. The importance of "layering" communications protocols and functions is discussed. Examples of layering communications, management, and security functions are provided.

BACKGROUND

Fig. 1 illustrates the ultimate military objective of providing total global connectivity for all information sources and information users with a military internet or network of networks called the Global Grid. The GG in this idealized vision is a "publish and subscribe", "plug and play" network, in which any application can be "plugged" into the network anywhere, at any time, to help achieve warfighting objectives.

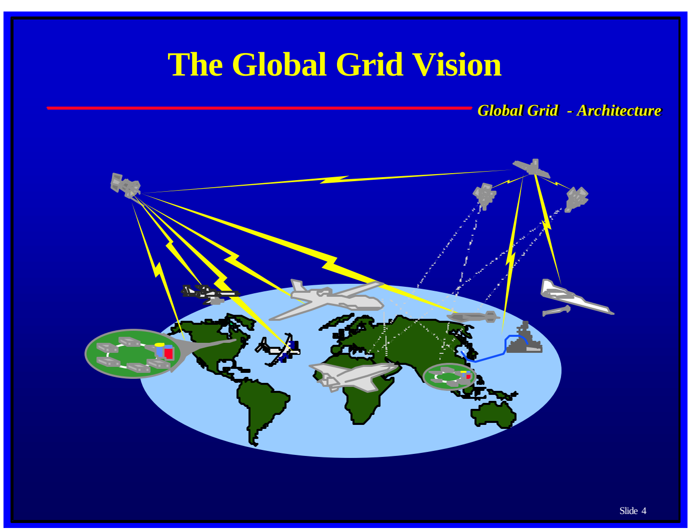

Figure 1. The Global Grid Vision

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This GG vision and top-level layering concepts, has been briefed by Mr. Leonard J. Schiavone, the former Chief Communications Architect of MITRE's Air Force Center, up through the three-star level of DoD. This has resulted in considerable acceptance of layering as a good way to help achieve the GG.

The GG layered model is introduced to provide a framework for layering all the communications-related functions and protocols, and facilitating communication upgrades as technology advances. Layering can be viewed as a technical architecture, not an operational or systems architecture, that is intended to foster understanding and illustrate the GG "building codes".

The overarching goal of this GG layered architecture is to improve interoperability among users by fostering the horizontal integration of military communications systems. GG architectural tenets for supporting this interoperability include three time-phased steps – connectivity, capacity, and control. First, we advocate a way for any user to connect with any other user through a common networking protocol, namely, the Internet Protocol (IP). Secondly, we propose more capacity, or a higher degree of efficiency, through adaptive communication links that attempt to realize user quality of service (QoS) requirements on a packet-by-packet basis. Thirdly, we plan automated management control techniques to minimize the need for intensive manual interventions.

The principal advantage of layering is the ability to upgrade the technology applied within any given layer without disrupting the implementation of the other layers. This critically depends on the interfaces between layers being relatively simple and very well defined.

When we look at today's DoD's communication systems, many are vertically integrated to satisfy a specific set of user requirements. Interoperability and the sharing of resources with other systems are not considered driving needs. Many "legacy" military systems have built-in, unique communication equipment. Users still insist on applications having their own set of dedicated

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communication channels. Although these applications may operate over the same physical media, the available bandwidth is not shared.

These systems are not designed to partition their functionality among the layers of a "layered" architecture. The sharing of resources or the application of common protocols among similar system segments is the exception rather than the rule. Consequently, most systems do not interoperate at any level. Later, when information exchange is required among systems, often one must resort to some sort of "gateway" for each system pair. Appropriate gateways are generally not available since they require development efforts. The layered architecture of the Global Grid provides the opportunity for horizontal integration flexibility to interoperate without gateways.

GLOBAL GRID LAYERED REFERENCE MODEL

The well-known Open Systems Interconnection (OSI) and Transport Control Protocol/Internet Protocol (TCP/IP) models [Ref. 1] are shown in Fig. 2, along with the GG reference model (GGRM) that we have created. The GGRM is based upon the OSI and TCP/IP models but has some features that emphasize military communications. We introduce a Mission Layer that has no corresponding layer in the other two models. Also, we rename a Service Layer from elements of the other two models. In the widest sense, the GG can be thought of as the communications transport medium consisting of the bottom four layers of the GGRM. However, the essence of the GG is in the Transport and Network Layers that are essentially common to all these reference models.

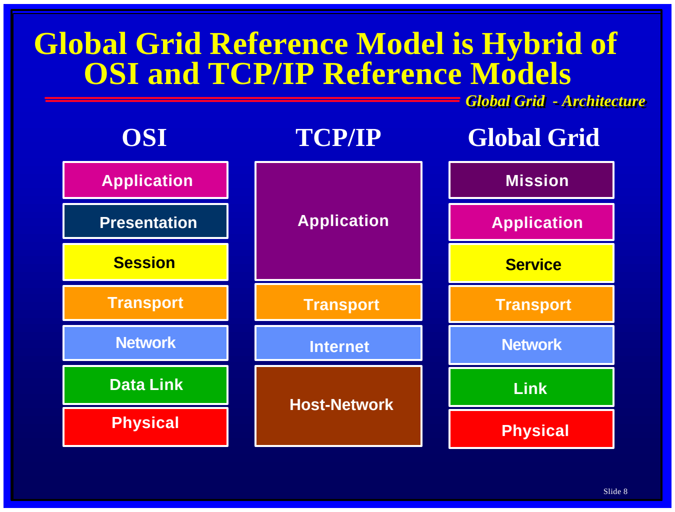

Figure 2. Global Grid Reference Model

We add a Mission Layer to emphasize the concern for assuring that needed capabilities that are uniquely military are provided to the warfighter. Much commercial internet technology can be leveraged in the GG but the commercial world has not yet solved all of the military's management, security, and mobile routing protocol needs, for example.

Before giving brief definitions of each layer of the GGRM, it should be understood that any layer and/or interface between two layers may contain applications, programs, protocols, algorithms, services, or utilities that perform some function or functions. We will most often use the term application, protocol or function for these abstract entities without saying how they are implemented, e.g., whether they are realized in software, hardware, or firmware. Even if we attribute functionality to the interfaces between layers, these interfaces are assumed to be relatively simple compared to the functionality within the layers themselves.

GGRM Layer Definitions

The **Mission Layer** provides the specific aggregation of applications from the Application Layer necessary to perform a particular military mission.

The **Application Layer** provides common and mission-specific applications that are employed as utilities by users or other programs at the Mission Layer. For convenience in partitioning applications, by definition, the Application Layer contains only those applications directly accessible by a user.

In the OSI model, the Presentation Layer resolves differences in data format among applications, and the Session Layer provides the control structure for connections and dialogues between applications. The Presentation and Session Layers together are included in the **Service Layer** of the GGRM. Again, for convenience in partitioning applications in the GGRM, by definition, the Service Layer contains only applications not directly accessible by a user.

The **Transport Layer** provides for reliable end-to-end data transfer, flow control, error recovery, and may be concerned with QoS and/or optimizing network resources.

The **Network Layer** consists of Internetwork and Subnetwork Sublayers that provides for data transfer across a network of networks or within a network, respectively. This includes addressing, congestion control, and associated usage accounting functions. These sublayers are the same as in the OSI reference model.

The **Link Layer** provides point-to-point data transfer. The Link Layer includes the addition of an Adaptation Sublayer (not present in the OSI or TCP/IP models) that serves to make Link Layer implementations network-centric, i.e., compatible with a common networking protocol, viz., IP. In addition, the Link Layer consists of the OSI model's Link Management Entity (LME) and Data Link Services (DLS) Sublayers that operate in parallel, and the Media Access Control (MAC) Sublayer. The LME Sublayer handles management (as opposed to communication or security) functions. The DLS Sublayer attempts to present the sublayer above with error-free data; breaks the data into frames; transmits/receives those frames sequentially with the necessary synchronization, error, and flow control; and returns acknowledgements back to the sender. The MAC Sublayer controls interactions with the physical media; multiplexes/ demultiplexes, and multiple-accesses/releases.

In the GGRM the **Physical Layer** is partitioned into four Processing Sublayers that are present but not so explicitly identified in the OSI model. The Baseband Processing Sublayer organizes/transmits/receives channel symbols at appropriate rates and converts them between digital and analog signal representations. The Baseband-Intermediate Frequency (IF) Processing Sublayer performs frequency translation and analog processing. The IF Processing Sublayer performs filtering and amplification. The IF-Radio Frequency (RF) Processing Sublayer performs frequency translation and analog processing. The RF Processing Sublayer performs filtering, amplification, and transduction with the physical media.

GG's Transport and Network Layers

As indicated in Fig. 3, the principal protocols of the GG's Transport Layer are TCP and the User Datagram Protocol (UDP). TCP is a "reliable" connection-oriented protocol that allows a data stream originating on one host to be delivered essentially without error to any other host. TCP also handles the sequencing and flow control of the messages and/or message segments. UDP is a flexible, but "unreliable", connectionless protocol that can be employed by upper layer applications that provide their own error correction, sequencing and/or flow control.

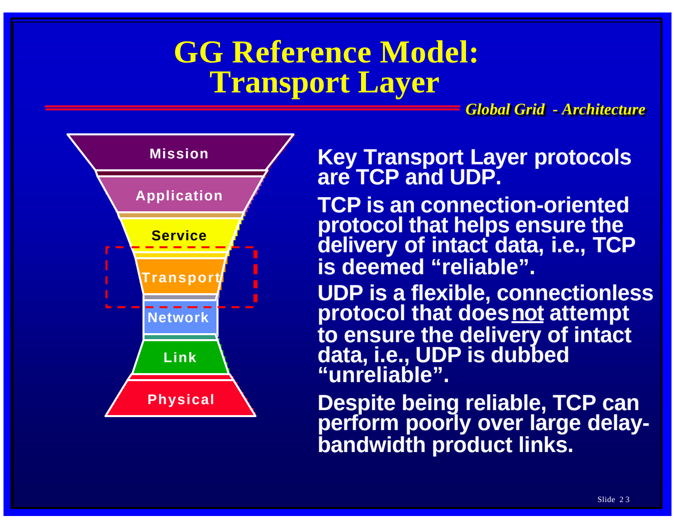

Figure 3. GG's Transport Layer

TCP implementations have parameters optimized for low error rate and relatively low transmission delays as typically encountered on wired terrestrial links. However, there are ways to improve TCP if there are higher error rates and/or longer propagation delays such as those encountered in geostationary satellite links performance [Refs. 2-3]. TCP can also perform poorly when available bandwidth is being underutilized. Rather than "fix" TCP or provide alternative transport layer protocols, we favor making links more efficient, i.e., by adapting each link to the fundamental QoS parameters of latency, reliability, and throughput on a packet-by-packet basis.

The Network Layer of Fig. 4 handles the routing of data packets (called IP datagrams in the TCP/IP reference model) within the GG. A principal architectural tenet of the GG calls for a common network protocol to maximize the potential connectivity and interoperability among users. Since IP is the *de facto* commercial internet standard and is widely used in the military, it is prudent to select IP as the GG's standardized protocol for the network layer.

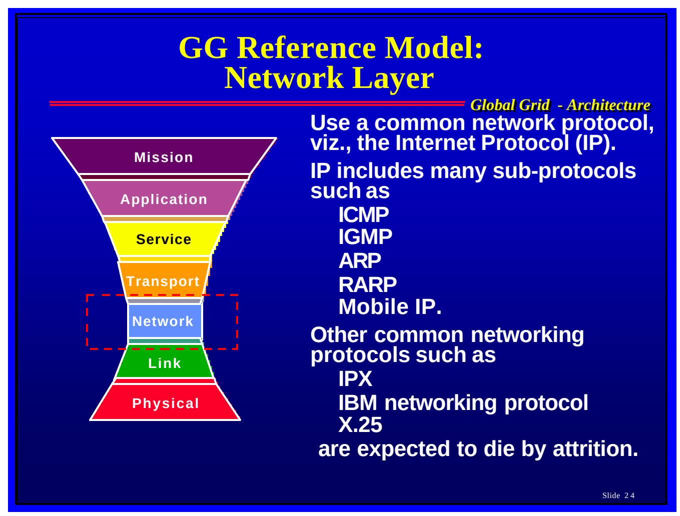

Figure 4. GG's Network Layer

IP includes several supporting routing protocols such as the Internet Control Message Protocol (ICMP), Internet Group Management Protocol (IGMP), Address Resolution Protocol (ARP), Reverse Address Resolution Protocol (RARP), etc. ICMP provides for the reporting of packet errors and other information regarding IP packet processing back to the source. Messages are intended for the TCP/IP software itself, rather than any particular User program. IGMP, a host-to-gateway communications protocol, supports one-to-many (multicast) transfers of data for improved network utilization. ARP can be used dynamically in a broadcast mode to discover MAC Sublayer addresses corresponding to IP addresses. RARP can map MAC sublayer addresses to IP addresses. RARP needs an RARP server with a table of entries of MAC sublayer-to-IP address mappings. Mobile IP, the mobile routing protocol of the TCP/IP protocol suite, will not be adequate for all military scenarios, especially when all nodes can move. Mobile routing protocols require further research and, eventually, standardization [Refs. 4-5].

Other network protocols such as IPX, the IBM networking protocol, and X.25 are expected to be gradually phased out through disuse and/or natural attrition. In our opinion, given current technology trends, circuit-switched networks and message-switched networks eventually will merge into a single packet-switched IP-based network.

FUNNEL VIEWPOINTS THROUGH THE GGRM

Fig. 5 depicts a "barbell" image of the GGRM *sans* the Mission Layer. One should imagine this layer as "riding" on top of the figure and influencing which funnel viewpoint is most appropriate under a particular operational scenario. The other layers are shown as colored disks of constant thickness but variable diameters. The narrowest part of the barbell is at the Network Layer. This is intended to convey the idea of network "convergence", i.e., that all users should adopt IP. We think the military should model its GG communications after the internet.

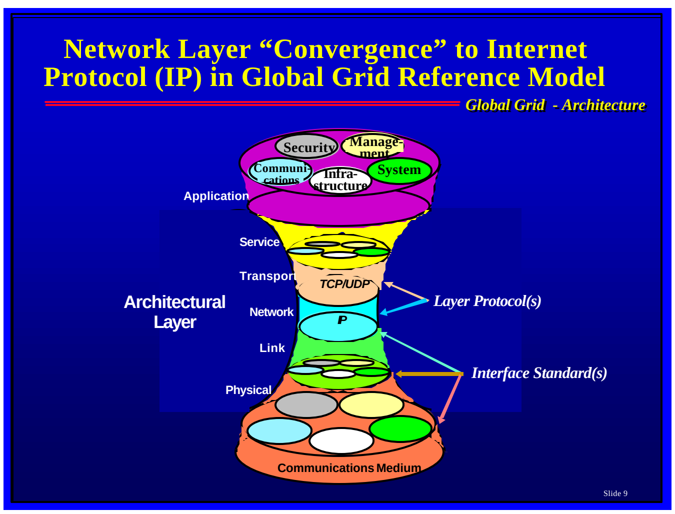

Figure 5. Network Layer "Convergence" to IP

Note that TCP and UDP are also indicated at the Transport Layer. This disc is drawn somewhat larger to indicate that there is not necessarily as much convergence to be expected at the Transport Layer. As already mentioned, TCP may have performance problems over communication links that have large delay-bandwidth products. There are various methods to deal with this problem, some of which could involve alternative protocols. Similarly, as one moves to higher layers there tends to be more variety in the protocols that might be employed to advantage. This is also true at the lower Link and Physical Layers.

Normally, communications-system layered-architecture, reference models are represented by their communications applications, functions, protocols, and interface standards. Nevertheless, it is possible and instructive to take other points of view in applying a model. Some might want to focus on only the individual devices and/or particular equipment that implements the communication system, i.e., the communications infrastructure. Others may wish to concentrate on the system viewpoint including vertically integrated subsystems performing aggregate functions represented by cartoons, block diagrams, "black boxes", modular units, etc. Those concerned with control and management functions might want to concentrate on those aspects. Finally, information assurance (IA) people may view the architecture from a security perspective.

Referring to Fig. 5, each of these five different viewpoints can be thought of as a vertical "funnel" through all the layers of the architecture. Four cross-sections (having the same distinct color) of each funnel are drawn in Fig. 5.

Most people probably are familiar with the GG in terms of infrastructure or system viewpoints. Consequently, we focus here on the communications, management, and security viewpoints and their associated protocols. In particular, we show how any specific communications, management, or security function can be layered, i.e., allocated to one layer or sublayer of the GGRM.

By way of definition, a communications function is an operation that directly affects the data being processed and communicated from one place to another. A management function is an operation that facilitates the communication process but that is not a communications function. Finally, a security function is an operation that is intended to handle IA issues but that is neither a communication function nor a management function.

There are several reasons for layering these three types of functions. First, layering serves to make the GG vision more specific. Secondly, layering facilitates learning and discussions among interested parties working on technical communication architectures. Thirdly, these viewpoints provide the basis for the layering legacy and future communication systems. We strongly believe that a layered architectural approach to the GG is most beneficial for achieving the GG's goals of interoperability among disparate systems and technological extensibility of the communications infrastructure.

Communication Functions

Application Layer communications functionality: This includes all applications that have a direct user interface. The Netscape browser is an example. Applications that support the appropriate communication function Application Program Interfaces (APIs) between the Application Layer and Service Layer may be included in the Application Layer. TCP/IP model applications might interface to the Transport Layer directly because there is no Service Layer in that model; in this case the Service Layer function of the GGRM is “transparent” to the application.

Service Layer communications functionality: This includes applications not directly accessible by users but Service Layer functions called by Application Layer applications. For example, the Domain Name Service (DNS) protocol provides the translation of internet addresses from the name domain to the IP address domain.

Transport Layer communications functionality: This includes connection-oriented services that ride on top of the connectionless IP Network Layer functionality. The Transport Layer deals with data segments that “travel” in IP datagrams (packets). The Transport Layer may provide functions that provide datagram sequencing, error control, and flow control. Multiplexing/demultiplexing functions permit the handling of multiple concurrent applications based on the Unix concept of a “protocol port” and associated port number. For example, Port Number 25 is assigned to the Simple Mail Transfer Protocol (SMTP) in support of E-mail applications, and Port Number 21 is assigned to the File Transfer Protocol (FTP).

Network Layer communications functionality: This essentially encompasses packet routing and all its ramifications.

Link Layer communications functionality: This, as a minimum, includes data framing and translation between network addresses and link addresses. Optionally, the Link Layer can provide error control and/or flow control.

Physical Layer communications functionality: This includes the production and processing of bit streams. The Physical Layer may involve one or more of the typical functions:

- Bit scrambling
- Error detection and correction
- Channel/symbol encoding and decoding
- Channel symbol processing
- Interleaving/deinterleaving
- Digital-to-analog/Analog-to-digital conversion
- Burst processing
- Modulation/Demodulation
- Amplification, filtering, and frequency tuning
- Transduction with physical propagation medium

Management Functions

Management functions provide for the monitoring and control of communications resources and processing. Such functions typically provide the “smarts” for controlling system states and coordinating with other network entities.

A principal long-term objective of the GG is autonomous network management to alleviate the current need for skilled network managers who require extensive training. As this ultimate state is approached it will be possible to better view overall network infrastructure status and provide for more automated control of specific devices to dynamically improve QoS.

Application Layer management functionality mirrors the capability of the software tools and processes adopted. Commercial software is generally available to support this function, e.g., Hewlett-Packard (HP) OpenView.

Service Layer management functionality is currently not well distinguished from Application Layer functionality, at least in terms of the TCP/IP model where the Application Layer includes everything above the Transport Layer. In the GGRM, we still need to better separate Service Layer applications that are not accessed directly by human beings from those applications that are, i.e., those in the GGRM Application Layer.

Transport Layer management functionality: This includes the potential selection of the Transport Layer protocol to be employed and related parameters based on network characteristics of the transport connection. This type of choice may be used to alleviate the limitations of TCP over large delay-bandwidth product links. The management functions at the Transport Layer supports data flow control and adjustment of any data acknowledgment “sliding window”.

Network Layer management functionality supports the monitoring and control of configuration, performance, and health of routers, gateways, and other equipment that support IP routing functionality. Routers support different IP routing algorithms and require coordination to ensure a given router uses the appropriate algorithm. Routers typically support congestion control by discarding datagrams when an overload condition is reached.

Link Layer management functionality is generally provided in the form of “Link Layer control” or “Link Layer management”. These functions support link setup, and control of the MAC sublayer specific to a given wired, optical, or wireless data link.

Physical Layer management functionality is media/system dependent. Here are some representative functions as collected from a variety of systems:

- Algorithm selection
- Timing control/stabilization
- Interleaver/Deinterleaver control
- Alphabet size control
- Frequency stabilization
- Power-level control
- Filter control
- Frequency allocation/control
- Antenna beam(s) pointing control

Security Functions

Application Layer security functionality: Functions include User inputs for authentication and authorization for User access. Firewalls may provide an application proxy operation that forwards application traffic through the firewall. Proxies tend to be specific to the protocol they are designed to forward, e.g., Telnet, FTP, SMTP, and may provide increased access control or audit.

Service Layer security functionality: Currently defined functions include the Secure Socket Layer (SSL) protocol and other more general information security services such as key management and privacy (encryption/decryption).

Transport Layer security functionality: Transport Layer security functions are usually integrated with Network Layer security functions in the form of packet filtering.

Network Layer security functionality: This includes significant security functions. The Internet Engineering Task Force (IETF) has defined a framework for IP-level security under the heading Internet Protocol Security (IPSEC) that provides encryption/decryption within its Encapsulating Security Protocol (ESP). The Tactical FASTLANE (TACLANE) is an example of a cryptographic device that supports this type of functionality. Security firewalls provide port number and IP address filtering at the Network Layer.

Link Layer security functionality: Encryption/decryption may be performed. Asynchronous Transfer Mode (ATM) cell encryption is a common application. The TACLANE and FASTLANE are examples of cryptographic devices that support this type of functionality.

Physical Layer security functionality: This may include encryption/decryption at the bit stream level. This function is commonly known as communications security (COMSEC) and is more often applied at the Application or Service Layer. This privacy function is usually performed on an individual channel basis in multi-channel systems. When a medium, such as a satellite link, carries multiple channels it is common to further encrypt the link at the transmission point employing what is commonly known as transmission security (TRANSEC), a robustness function. TRANSEC usually has a lower level of protection than COMSEC. Other robustness functions may include low probability of intercept, detection, or exploitation (LPI, LPD, LPE), anti-jam (AJ) protection, and physical medium security such as physical protection of the transmission facilities, e.g. tamper-proof cables, and communication facility protection. Tactical Fastlane

SUMMARY AND CONCLUSIONS

We provided a detailed description of a layered Global Grid Reference Model (GGRM). The GGRM comprises seven layers that are defined somewhat differently from the standard 7-layer OSI model and 4-layer TCP/IP model. The Global [Communications] Grid corresponds to the Transport and Network Layers. The Network Layer should converge to a common standard protocol, the Internet Protocol (IP). The GGRM permits different functional viewpoints that “funnel” through all layers. Although there are a number of possible viewpoints, the communication, management, and security functions are emphasized. The “layering” of these functions is important for creating interoperable communication systems that can more easily evolve with future new technologies.

REFERENCES

1. Tanenbaum, A. S., 1996, Computer Networks, Third Edition, Prentice Hall PTR, Upper Saddle River, NJ
2. Stadler, J. S., J. Gelman, and J. Howard, 2-4 June 1999, *Performance Enhancement for TCP/IP on Wireless Links*, 9th Virginia Tech/MPRG Symposium on Wireless Personal Communications, 233-244
3. Muhonen, J., R. C. Durst, February 1998, *Space Communications Protocol Standards (SCPS) FY97 DOD Test Report*, MTR 98B0000011, The MITRE Corporation: http://info.mitre.org/edm/af/mtr-pdfs/t098b012.pdf
4. Grace, Kevin H., 11 October 2000, *MobileMesh*: http://www.mitre.org/tech_transfer/mobilemesh/
5. Ramanathan, S., M. Steenstrup, 1996, *A survey of routing techniques for mobile communication networks*, ACM/Balzer Mobile Networks and Applications, 89-104

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