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**Virtual Markets in Wireless Grids:
Peering Policy Obstacles**

Professor Lee W. McKnight
School of Information Studies
Syracuse University
Syracuse, NY
Email: lmcknigh@syr.edu

Diana Anius
PhD candidate (interdisciplinary)
Tufts University
Medford, Massachusetts
Email: diana.anius@verizon.net

Ozlem Uzuner
PhD candidate
Technology, Management and Policy
Massachusetts Institute of Technology
Cambridge, Massachusetts
Email: ozlem@mit.edu

Introduction

The “peer-to-peer” architecture – the sharing of computational resources by direct exchange between computers – has been in existence in various forms for at least thirty years. Building on the concept of peer-to-peer computing, grid computing has recently emerged as a field of research and standardization in high performance computing. Grid computing offers a solution to the challenge of ‘flexible, secure, and coordinated resource sharing among dynamic collections of individuals, institutions and resources’¹. The ultimate vision of the grid is that of an adaptive network offering secure, inexpensive, and coordinated real-time access to dynamic, heterogeneous resources, potentially traversing geographic, political and cultural boundaries but still able to maintain the desirable characteristics of a simple distributed system, such as stability, transparency, scalability and flexibility.

This paper explores the regulatory and policy implications of a ‘wireless computation grid’ designed for a virtual market space for the commercial trading of computational and information resources. We expect the remote trading of goods and services, enabled by evolving wireless technologies, will become a strategic issue for many private businesses in the future. In this future scenario for a wireless grid, many information policy questions are raised. First, and perhaps most importantly, how can policy be agreed to across such a network of networks, or in this case a network of grids? This is a variant on the question which is already bedeviling ICANN, as it struggles to keep its focus on a much narrower set of issues. The design of a regulatory regime for wired and wireless networks, for content and conduit, linked through computational grids will be a substantial challenge.

Wireless resources are relatively scarce, costly, and valuable compared to cheap computational cycles. Hence, the motivation for this paper and our related research efforts is the hypothesis that research on wireless grids can sharpen the focus and provide insights into critical wireless policy questions for virtual information markets in which organizations meet and exchange goods and services.²

¹ Ian Foster, Carl Kesselman, Steven Tuecke, *The Anatomy of the Grid – Enabling Scalable Virtual Organizations*, 2001

² The lead author of this paper is the proposed Principal Investigator of a project on these issues which was recently submitted to the National Science Foundation, by Tufts University, Department of Computer Science; Boston University, the Massachusetts Institute of Technology, and Northeastern University, working with British Telecom, Cisco, Diaout.net, Fractal Antenna, and Telmarc, among others, in cooperation with TeleCom City. See Lee W.

This paper explores the technical features of grid computing, considers how they may translate to a wireless realm of heterogeneous systems and services, and begins to consider a few of the many research and policy challenges likely to emerge if wireless grids move from theoretical possibility to practical reality.

Background

The Internet has been an enormous source of information and viable medium for economic transactions. As the potentials of this medium keeps growing, using its services and benefiting from it requires improvements to its infrastructure. As more people become “connected”, the number of bottlenecks increase and the quality of the service decrease, unless the communications infrastructure is also improved. We propose a “Wireless Grid” that is built on the concept of an open communications infrastructure to help solve this problem.

An open communications infrastructure distributes the information sources so that information is shared between many different sources, as in the case of peer-to-peer systems. For example, interdisciplinary institutions are no longer limited to research projects that were once fulfilled by resources within a university community. Instead they can now turn to a community of universities in order to apply the breadth of knowledge to accomplish their interdisciplinary goals. Currently, such institutions have been able to use the grid for scientific and engineering research, like the TeraGrid and GriPhyN (Grid Physics), and the European Data Grid, where resources for data-intensive computational tasks are required.

Efforts are underway towards a global standardization for the field of grid computing; for example The Globus Project has focused on setting standards and best practices for the area of grid computing. Several grid developers have already settled on the Globus Toolkit on the standard for assisting in the development and/or implementation of existing and future grid

projects³. Our research focuses on and adopts this layered grid architecture proposed by Globus rather than adopting the use of the somewhat hazy term - ‘middleware’ aptly described as “*the intersection of the stuff that network engineers don’t want to do with the stuff that applications developers don’t want to do.*”⁴

The proposed Globus grid protocol architecture is illustrated in Figure 1. The diverse (and heterogeneous) resources of the grid are provided at the Grid Fabric layer. This layer in turn communicates with the Resource and Connectivity Layer which provides services such as secure access, QoS, and security mechanisms for authentication and authorization. The Collective Layer provides protocols and services for the coordination of resource sharing, and the final layer, the Application layer, represents the wide variety of applications available such as email and access to the WWW.

Architecture and Infrastructure for the Grid

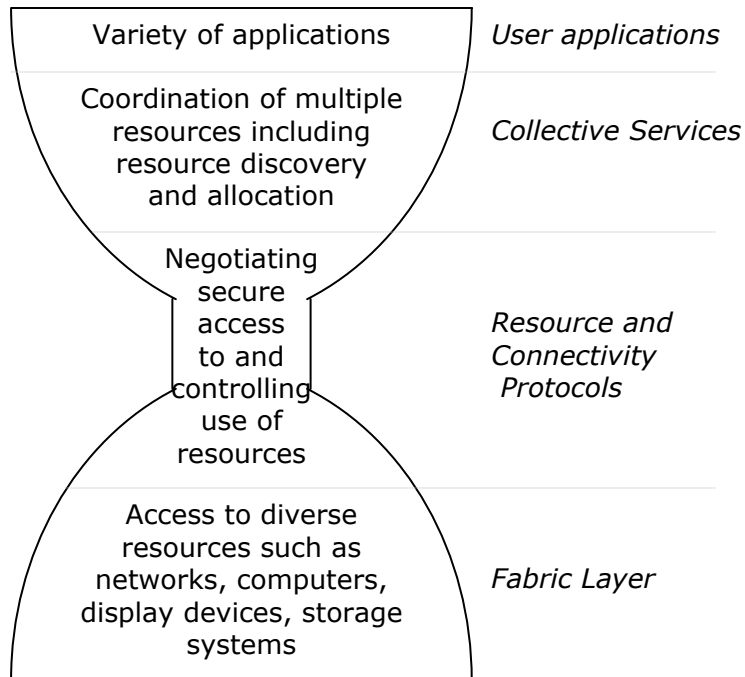
In developing the infrastructure for the grid, several key issues need to be addressed such as (1) Service Discovery – which addresses such variables as service agent discovery and location, and the types of communication mechanisms between users and service agents; (2) Economy – which entails the determinism of a pricing mechanism for available resources (whether a free, bartered or sale mechanism for resource exchange), and how payment for resource utilization can actually be fulfilled; and (3) Resource transfer – which governs the protocols needed for access to the requisite resources and the transfer of information, etc.

³ Apart from Globus, several other grid infrastructures have been proposed such as UNICORE and Legion

⁴ Kenneth Klingenstein, *Middleware: The Second Layer of IT Infrastructure*

Figure 1

Proposed Globus Grid Protocol Architecture⁵



⁵ Source: Foster, et. al, *The Anatomy of the Grid*, 2001

From a market perspective, equally challenging aspects include:

- Service discovery – what mechanisms are needed for accessing the required resource? And at what cost? The question of security, especially in the context of wireless network architecture, would also be a major concern.
- Pricing – the determination of a pricing mechanism for available resources. How is this determined? (The possibility of an auction-style pricing mechanism in the future?)
- Payment – Which brings into question the arrangement for payment of resources (that are being accessed dynamically)
- Fulfillment – The eventual transfer of or access to the resources over the wireless network

These and related issues are discussed below. Distributing scarce network resources across multiple applications and users with widely different valuations for the underlying services presents a challenging technical and economic resource allocation problem; solving this problem across multiple networks spanning several carrier domains in a fashion that is compatible with competition is even harder. However, a computational grid for seamless resource sharing among virtual organizations offers greater capacity than centralized resource sharing, allows for greater extensibility, easily accommodates access by an increased number of users, facilitates component interoperability, and addresses added challenges such as unique user authentication and authorization.

Can Existing Technology and Protocols Be Used for the Wireless Grid?

The extent to which it is feasible to use the existing protocols for the grid is unclear. For example, consider using Internet protocols for the transmission of data. Although the protocols for the Internet are robust, and have enabled the Internet to scale by supporting ubiquitous connectivity across heterogeneous networks of varying quality and technology, network resources can become congested. When such congestion occurs, anything seeking to traverse that portion of the Internet suffers more or less equally as packet delays increase. Nonetheless, it is the assumption of most grid researchers that the Internet will be the primary data transmission network for computing grids.

Current distributed computing systems do not offer the flexibility and de-centralized resource sharing of computational grids however few initiatives have actually been implemented for utilizing the grid for public commercial purposes. The concept of a virtual market within the grid environment goes beyond the current collaborative problem solving use of the grid and focuses on the relationships between entities (companies, organizations, educational institutions, individuals, etc.) participating in the grid. These dynamic relationships whether business-to-business, business-to-consumer, or consumer-to-consumer, are constantly being built and destroyed. Examples of such relationships are:

- a) an individual can use the grid to contact a rental car service agent that is able to compile pricing and location information (from diverse resources including other mobile devices) for the user and download that information to the user's mobile device; as part of the grid network the user is not constrained by geographical location

- b) a business can dynamically obtain and utilize information from its global research and industrial centres

- c) global university-industry research relationships can be forged and coordinated for the compilation and analysis of data

The application for grid services is extendable to a number of different sectors, whether educational services (for example for computational purposes, resource sharing and scientific research), financial services (whether for remote trading, banking and commerce), or retail services (such as e-commerce).

Peering Problems in Wireless Grids and Virtual Markets

We assume a grid virtual market space comprises a number of organizations, companies and individuals who participate in the grid for the purpose of sharing resources. These sharing relationships are governed by pre-defined rules dictating how these resources are shared, and take into consideration issues such as service discovery and location, quality of service, pricing, etc. In this section, we review some of the issues that need attention for the virtual markets to work seamlessly.

The focus of our research is on defining a controlled ‘sharing level agreement’ a ‘streamlined’ set of peering protocols as part of the middleware of the architecture which would not only provide a flexible mechanism for service providers and customers to specify the QoS that will be delivered but also govern the attainment and fulfilment of requested resources. This can be thought of as a sharing level protocol.⁶ Defining such a protocol would entail addressing unique challenges such as service discovery, user interface definition, user behaviour, network management and security, and inherent economics and policies. An added challenge is defining such protocols for a *wireless grid*, mobile resources so to speak. This paper discusses some of the key policy issues that must be addressed when conceptualising the implementation of a virtual market for a wireless computational and communications grid.

⁶ Term coined by Lee McKnight and Michael Shrage, *Virtual Worlds and Simulation Conference*, January 2002

a) Peer to Peer Problems in Virtual Markets

At the application level there are several issues that need to be addressed with respect to peer-to-peer computing for virtual markets, many of which have been considered by researchers and firms already operating in electronic markets. Some of these issues are security and privacy, intellectual property, resource sharing, protocols for payment and fulfilment of resources, etc.

Security and Privacy: Security and privacy are the foremost issues that must be addressed within the grid. Authentication and authorization of users across multiple organizations and companies can be inherently complex but are of paramount concern within a commercial environment. Current grid technologies seek authentication solutions primarily providing for single user authentication (i.e. an authentication mechanism which does not require the user to logon multiple times to various sites so that access to the grid implies access to resources at the local level).

In addition to authenticating users to the grid and authenticating the grid to users, protocols for authenticating users to each other and providing private communication between users has to be considered for the wireless grid. Cryptographic primitives and protocols can be used for authentication, digital signatures, anonymous payments, and micro-payments however there are the usual tradeoffs between efficiency, security, robustness, collection of data that may make the grid more useful or efficient, and protect the privacy of users. The added complexity of accommodating different entities using different local security solutions (and security between grids) also presents a challenge.

The Globus Security Architecture proposes the following features that should define security policy for the grid network:⁷

- (a) Local operations are subject to a local domain security policy only
- (b) Mutual authentication is required for transactions between entities in different domains
- (c) Global authentication requires local authentication (it is assumed that each local domain has its own security policy)
- (d) Controlling access to resources is subject to local security only

⁷ See Andre Tanenbaum and Maarten van Steen, *Distributed Systems: Principles and Paradigms*

(e) Users can delegate access rights to processes

The main assumption of Globus is that definition of the level of access and security rights of users at the grid level to the distributed resources must be determined and agreed to by grid participants without the added requirement of defining more complex security mechanisms at the local level. However, the main difference between existing grid technologies and the commercial environment being proposed is the introduction of the e-commerce paradigm, which current grid technologies do not address. What types of security mechanisms are available for protecting a consumer's data (such as credit card information) from fraud by users/entities within the grid environment? If the user allows personal data to be stored at the grid level to be utilized by different service agents when requested, how can the grid ensure the security and integrity of that data?

Assurances of security and privacy are especially critical to the implementation of a wireless grid. The owner of a mobile device will want to be certain that the device will not be attacked and that private data on the device will not be compromised. Conversely, the grid will need to be protected from malicious or malfunctioning devices. In defining our security policies, we also need to consider how security mechanisms can be achieved for users with personal mobile devices such as PDAs. How can the same security mechanisms be achieved on the micro-level for small wireless devices? How can data protection for the mobile user be assured?

The Wireless Grid

Wireless communications is a rapidly evolving and promising sector of the communications arena, and even in a challenging time for the telecommunications industry, represents a significant development opportunity for companies and organizations in creating a global market. Our research focuses on the introduction of wireless services within the grid, a concept that will not be satisfied by current grid technologies and protocols. Extension of the concept of a grid towards the wireless domain happens in two senses; the inclusion of small wireless/mobile digital devices into the grid and the inclusion of tangible and intangible infrastructure such as spectrum/transmission licenses, transmitters, receivers that can be shared on demand (flexibly) by service providers via grid protocols.

Current mobile devices are constrained by power issues and allow for limited computational capability. Also, these devices pose several challenges because of their mobility such as IP addressing and possible non-fulfilment of services due to a failed or intermittent network connection. However their inclusion within our grid environment is primarily for their mobility, position and user accessibility, with the anticipation that there will be an increase in the computational power of these mobile devices in the near future. Our research does not focus merely on the utilization of these devices for the download of information, or accessing resources on the grid, but for allowing the grid to tap into the computational power of these devices.

The main challenge is in the implementation of a virtual market within a computation and communication grid using an existing or emerging wireless technology standard such as Wi-Fi (based on IEEE 802.11b standard) or 3G (Third Generation Cellular) that encompasses the concepts of worldwide roaming and provision of high data rate services.

3G and Wi-Fi technologies have fundamental technical differences, due to the different design objectives of their developers. Development of local area communications grids using Wi-Fi technology is already on-stream. The Ethernet local area network technology that underlies Wi-Fi has been deployed extensively for business networking for many years and is a mature

technology. However, since Wi-Fi uses shared, unlicensed spectrum, users do not have exclusive property rights and so congestion is a potential problem. The interference paradigm associated with operating on an unlicensed basis, requires all users to tolerate background noise and limits each user's contribution to this background noise. With more users, more congestion and more interference conflicts with a carriers' ability to offer QoS guarantees.

3G is a mobile cellular technology that stresses ubiquitous coverage and continuous mobility, which imposes severe restrictions on the available bandwidth. 3G promises faster speeds, greater security and improved reliability than current 2G technologies. In contrast, Wi-Fi is a local area network technology that offers much higher bandwidth but only over short distances. For example Wi-Fi supports up to 10 Mbps within 300 feet of the base station and coverage is typically limited to, at most, a campus-wide environment (via the linking of multiple base stations). In contrast, 3G systems are expected to offer 100-400 Kbps rates over the serving area of the cellular provider, which may be quite extensive. Although the two technologies appear to address quite separate market niches – 3G for mobile, ubiquitous access and Wi-Fi for wireless local network access – both could provide the basis for competing services that could support quite different industry structures and philosophies.

Our research focuses on wireless technologies for the wide area network, in this case 3G⁸. One of the main issues within the wireless realm is the relative lack of global technological standards governing the area. Theoretically 3G should work within North American markets and European markets, however each of the regions have adopted differing standards. In Europe there is only one 3G specification, WCDMA (also known as UMTS – Universal Mobile Telecommunications System), however in the U.S. there is no universal standard for wireless cellular access.

Several concerns must thus be considered when looking at mobile devices within a wireless grid. One of the most challenging is coordination between international regulatory bodies for regulation of the wireless spectrum. Current standardization efforts in 3G are being spearheaded by the International Mobile Telecommunications beyond the year 2000 (IMT-2000) – the goal of which includes support for higher data rates (2Mbps indoor, 384Kbps outdoor stationary and

⁸ 4G has also been touted as the next generation of wireless networks; because of the difficulties companies have faced in moving from current 2.5G to 3G, some predict that there will be a jump from 2.5G directly to 4G

144Kbps in moving vehicles) that can support multimedia applications, make many of the interfaces standard as possible, and provide wider global roaming services.

Payment for Wireless Grid Services: Several economic models have been proposed for use on the grid. We propose that really there are three categories of pricing mechanisms, into which all others can be categorized:

1. Free exchange – this implies a one-way exchange of services. An entity willingly provides access to resources at no cost. A typical scenario may be companies that provide mobile users with information about requested services.
2. Bartered – This implies a two-way non-monetary exchange of resources. Entities can negotiate as to the mechanisms for access to a specific resource – for example companies may negotiate in time resources, or for exchange of services (a possible auction-style pricing mechanism?)
3. Sold – In this scenario entities have pre-defined pricing mechanisms for access to services. Services at the grid level need to determine, on behalf of users (especially mobile users requiring real-time access to resources) how service provision can be implemented. Would confirmation be required before service provision? Can the user set specific price-levels beforehand?

A sharing level agreement needs to identify and establish the economic policies governing the pricing mechanisms for all participating entities within the grid network. Policies also need to be defined to determine the actions required when resources have not been adequately provided by the service agent(s), or the mechanisms for protecting the consumer if a particular resource does not offer Qos guarantees.

Intellectual Property;

Wireless grid and the potential peer-to-peer transactions raise the issue of intellectual property and proper compensation of the content producers. In an environment where people can freely exchange, share or barter the information they have purchased, it is very unclear who owns what and how the revenues should be transmitted to the “rightful owner”? Would the existing, mostly geography-based copyright laws still work and, if so, how would they be enforced?

b) Some Policy Problems for Wireless Grid Infrastructure

At the infrastructure level, the wireless grid that supports the virtual markets has to address problems like quality of the service, reliable delivery of goods and services through a high-performance, scalable and extensible system and interoperability of the involved devices in order for the grid and the markets to function properly.

Quality of Service (QoS): Another concern is that of the provision of end-to-end QoS for all available resources at all levels within the wireless grid. There is only a limited understanding of how the quality of end-to-end broadband services might be assured in today’s nascent multi-service, multi-provider environment. The absence of generally accepted and standardized mechanisms for assuring service quality is a significant barrier to competitive broadband access. A key question is how to optimally manage QoS for virtual markets in a wireless communications grid.

In implementing a framework which encompasses all the QoS requirements, we need to define the mechanisms which will govern the requirements. Our framework will need to effectively map the pre-defined QoS requirements to the actual resources on the network. Ideally some of these QoS requirements will be defined at the local system level to minimise protocols utilized at the middleware layer, however we need to address the problem of combining different kinds of QoS from the multiple resources available in the grid and between multiple grids.

Service Discovery: A critical part of the defining the QoS requirements of the grid involves the challenge of determining the mechanisms for accessing a required resource. Specifically, how

can an efficient and cost-effective service be located quickly out of the potentially millions of services that may be available on the grid? Are the existing service-discovery protocols for wireless networks - push-based (where a particular entity advertises its services to other entities on the network), or pull-based (where an entity expressly requests service from other entities on the network) – feasible within our wireless grid environment?.

Apart from determining the cost of the available resource (discussed above) service discovery also encompasses the user-communication interface, whether text-based, speech recognition or other new interactive techniques, with which the user communicates with the network. Another central concern is the mechanisms of the communication links between the user and service agents (especially critical when examining this within a wireless context which is discussed in the next section). Protocols defining the priority level that users have to grid resources must also be established. The interface through which the mobile user can communicate with the grid must also be defined (a ‘grid browser’ perhaps) that enables users to potentially locate required resources or service agents, etc.

Guaranteed Service and/or Differentiated Service: Current internet protocols offer simple point-to-point delivery service, based on the best effort delivery model as the network’s guarantee that the data will be delivered using the internet protocols. However within the grid, where dynamic relationships are continuously being created and destroyed, and where real-time access to data is required⁹, the traditional best effort model is no longer adequate. Differentiated service (though service for priority traffic is not guaranteed) offers a more reasonable solution for the grid network than Guaranteed service, however the challenge lies in defining the policies governing priority levels within a wireless commercial grid.

Performance: The peer-to-peer platform¹⁰ offers some amount of fault-tolerance since no single entity can bring down the entire system. However, beyond the issues of availability, latency and bandwidth when measuring network performance, certain characteristics of wireless transmission

⁹ IPv6, the ‘next generation’ internet protocol, is being flagged as the next level of protocols offering a better range of support for real-time data traffic

¹⁰ Several initiatives have been taken to combine working groups in peer-to-peer computing and grid technologies. The ideal is an environment combining peer-to-peer with grid technologies and web services.

– such as shadowing, multi-path effect, fading, interference, etc – need to be addressed. For a specific station to transmit successfully, a proper power level is required. In cellular systems, every mobile station has to communicate through a base station; therefore it is feasible to achieve uniform SINR (Signal to Interference and Noise Ratio) for all communication links. Power control in existing cellular systems is easier than that of systems that utilize a shared broadcast channel, as ad hoc networks typically do; the higher the power level, the better the transmission (or throughput) for the link. However, a powerful link may interfere and limit the ability of other stations to receive from other transmitters, thus reducing the total throughput of the network.

Interoperability: Another issue is to provide compatibility across a heterogeneous network of resources; a network comprised of a wide range of resources from those at the high-end such as supercomputers to ‘low-end’ devices such as PDAs and cellphones.

Maintenance: Last but not least, the maintenance of the wireless grid presents a challenge that is unique due to the efficient hourglass model of the proposed grid architecture.

c) Public and International Policy Issues

A wireless grid, and virtual markets based on the wireless grid, present numerous interesting technical and policy challenges. Some of these challenges have already been identified as they also apply to the Internet. But, most of these issues have so far not been addressed satisfactorily.

The Internet is a geography-independent system. The wireless grid shares this property of the Internet. Jurisdiction based laws and regulations such as taxes, for example, are more complicated to administer in these domains.

Clear Jurisdiction and Geography: The grid environment places service providers on a global competitive basis – users and service providers are no longer restricted to providing service for users based on their geographical location. Would grid entities operate within the regulatory framework of the local location? Currently the legal and regulatory framework governing online transactions (across geographical borders) is still evolving. How can consumer protection and

antitrust laws be adequately enforced (by a country's local federal agencies such as the FTC in the U.S.) within the grid environment?

Major Stakeholders

In deciding on a proper policy architecture for the wireless grid, we need to consider the concerns of the following stakeholders.

- consumers, and end-users: In order for consumers to get the most out of the grid experience, the grid has to offer them the levels of security and privacy they are accustomed to. In addition, the service has to be reliable and the delivery of the goods and services to the right person at the right time has to be guaranteed. Of course, the cost of using the grid is also factors into the decision of the consumers to use the grid. Finally, the laws and regulations governing the grid and the transactions that take place over it affect the quality of the grid experience for the consumers. Some related laws are intellectual property laws and tax laws.
- commercial entities that want to provide goods and services through the grid: These entities have overlapping concerns with the consumers. They are concerned with security of the transactions and the correct delivery of the goods and services to the right place at the right time. Also, the grid has to provide them with proper profit incentives if the commercial entities are to provide services over the grid, i.e., the cost of delivering over the grid should not be greater than the profits obtained from using the grid. Also, due to the vague definition of jurisdiction in a wireless environment, the laws and regulations that protect the commercial entities from improper interceptions, fraud and theft should be clearly defined.
- the owners of the grid infrastructure: The grid provides an exciting challenge for the infrastructure owners. In order to be worth the cost and the effort, the infrastructure has to meet certain criteria. It has to be secure, both for the end users and for the infrastructure owners. It has to be scalable and extensible. It has to be able to accommodate a heterogeneous set of devices and a heterogeneous set of services, addressing the diverse needs of different users. It has to ensure interoperability and it has to do all of this in a cost efficient way.

- the service providers operating on the grid: Service providers, i.e., the connectivity providers, face interesting challenges with respect to proper pricing of the services they are providing. Do they charge by connectivity time? Or, does it make more sense to charge based on the kind of data that is being transferred? How do people choose which service provider to use and how do the service providers co-operate and collaborate to provide a better service over the grid?
- local, national and international entities, including organizations involved in setting global standards: The grid offers different challenges for the standards organizations, international entities as well as local governments. For example, how do tax laws apply in the grid? More importantly, whose tax laws apply? On the intellectual property side, if peer-to-peer becomes really prevalent, then who keeps track of what belongs to whom and how? How are the correct amounts of compensation transmitted to the right people in the grid? And finally, assuming we are able to come up with laws that make sense on a global level, who enforces these laws and how?

Proposed Approach for a Solution and the Primary Issues to Consider

We propose to approach the problem of designing and implementing the wireless grid in three main steps:

1. First we need to explore the capabilities of wireless grids to determine protocol options for integrated wireless networks that account for diverse user and device access. At this stage, we will design protocol platforms and models for network performance, service detection and negotiation, security and confidentiality, resource allocation, and device extensibility. The technical feasibility of grid services will be considered based on existing and emerging wireless infrastructure, propagation, software, and embedded architectures.
2. Second, we will explore market issues to determine fair and efficient policy guidelines and profitable business models in the new wireless grid access paradigm. We will develop protocol rules and economic models to predict market performance under multiple wireless grid protocol designs. The presence and role of market failures in wireless grid network economies will be considered as will the potential role of regulation in solving those failures. Fair and efficient policy guidelines will be proposed and profitable business models for network operation and utilization will be considered.

3. Finally, we will establish virtual and community test-beds or simulation environments in order to examine technical performance and market behaviour. We will build virtual and/or physical testing environments. Economic modeling scenarios will be overlaid on the end-to-end technical characteristics to create a well-defined picture of the wireless grid environment. Educational and commercial environments may be tested in physical grid-enabled geographies. Regional, national and international markets will be tested in virtual testing environments

Within the three stages outlined above, we will evaluate different network architectures for the optimal power levels for uninterrupted transmission of data and services, the optimal levels of security and privacy, and the ease and effectiveness of using cryptographic primitives and protocols for authentication, digital signatures, anonymous payments, and micropayments. In addition, network architectures need to be evaluated for the usual tradeoffs between efficiency, security, robustness, collection of data that may make the grid more useful or efficient, and protection of the privacy of users.

Management of the grid is another consideration. There are many ways to manage a grid of computing devices, from very centralized, to completely distributed, each style of which has advantages and disadvantages. The grid must promote experimentation with new applications, which implies a need for distributed structure, but the grid must also be efficient, and secure, which argues for centralized management architecture. These tradeoffs must be investigated and an infrastructure designed for wireless grid computing that is both flexible enough to allow innovation, yet still efficient and secure.

Conclusion

Grid computing focuses on the large-scale sharing of computing resources such as software, hardware, databases and data sources. A ubiquitous wireless grid will face policy problems on a larger scale than has ever been seen as diverse heterogeneous market and policy requirements must be simultaneously resolved. Governments seek to strike a *balance between public rights to access information and communication networks and commercially viable models of network operation*. The radio spectrum, over which networks operate has traditionally been a public good that could

be utilized in the public interest, or bought and assigned as a property right for commercial use. The emergence of technologies that efficiently utilize unlicensed spectrum or co-exist with the existing users of assigned spectrum presents a challenge to the established policies. The fair use of a grid network must be determined based on research on how to reconcile the needs for public rights of access and private ownership of network and information resources. Network and information resources and services must efficiently be traded in a virtual market if a wireless grid is to function.

Last but not least, a wide variety of national and international policies will affect the viability of wireless communication and computation grids. Spectrum management and national telecommunications policies will be crucial for the eventual commercial success of wireless grid services. Other grid requirements significantly affected by public policy choices include easy public access to the grid infrastructure, and legal and economic frameworks for managing property rights for networked resources. Research on viable architectures, appropriate software systems and policy decisions will have to go hand-in-hand with examination of viable scenarios for deployment of the wireless grid based upon the restrictions of the service-level requirements of the markets.

Idealistically, the grid puts global computing power in the palm of your hand. The main difference between the data-distribution concept of peer-to-peer networking and that of grid computing is that grid computing allows for the controlling and scheduling of shared information and computation resources. The main policy difference for wired and wireless grids is that the complexity of the wireless grid is now compounded by the differing expectations and ownership structures of wireless infrastructure, including the extremely diverse ownership and control structures for wireless local area networks. Can a wireless grid really be created which can extend across such heterogeneous networks and computational resources?

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