

# WOS: an Internet Computing Environment

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## Abstract

Given the current development of the Internet, the Web, mobile communications and services, we are clearly heading towards an era of widely integrated ubiquitous services sharing some kind of global operating system. This article describes the idea, the objectives and the current state of the development of the WOS-project. The Web Operating System (WOS<sup>TM</sup>) consists of a series of versioned servers where each one can offer different services, themselves versioned. Each node can act as a server or a client. A common protocol, itself versioned, is used for communication among WOSNodes. Requests for services can be passed on to other servers as appropriate. The WOS is defined by the combined actions of different nodes.

## 1. Introduction

### 1.1. The Context

With the emergence of widespread computing and telecommunication networks, an explosion of networked and mobile computing is taking place; in turn there is a permanent growth in areas such as electronic-commerce, multimedia applications, or large-scale high-performance scalable distributed computing. These developments lead to the conclusion that the global computing infrastructure is in a permanent process of *evolution*.

Because of the rapid changes in the underlying infrastructure, it is clear that component-based systems are best suited for large-scale distributed systems, since, as needs change, components can be replaced or adapted more easily than can entire systems. However, components can themselves be programmed to act differently according to the context in which they are immersed; we call this *versioned programming*, and we assume that as a context evolves, the collaboration between components may change and evolve. We call these evolving contexts and collaborating components – along with their interactions –

*communities*. Programming models and techniques based on the above principles require an infrastructure that supports versioned, dynamic and adaptive resource management. Communication between versioned components can provide answers to these challenges. The goal of the proposed Web Operating System (WOS) initiative is precisely to create such an enabling infrastructure for distributed applications. In a technical sense, this middleware can be viewed as a Network Operating System for ubiquitous computing that spans the higher layers on top of the enabling communication network infrastructure, to provide applications and users with easier access to the advanced network services.

Ubiquitous computing, information and multimedia services, high performance large-scale cooperative distributed computing, and electronic commerce are among today's most relevant wide-area distributed systems. Therefore, the programming models and distributed computing infrastructure investigated should specifically target these applications.

### 1.2. The Web Operating System

The Web Operating System (WOS) approach for global computing relies on the novel concept of dynamically defined (or versioned) *communities* of components (software and hardware). For example, a community of nodes acting as a parallel computer may now be defined by searching the node's information warehouses (or catalogs) for the resources necessary to define the virtual parallel computer. This will thus define a new context of computation. To deal with change, generalized software configuration techniques, based on a demand-driven technique, called *education*, are used for the WOS. The kernel of a WOSNode is a general educative engine, a reactive system responding to requests from users or other educative engines using the warehouses' information to provide the necessary components for fulfilling service requests. This approach allows interaction with many different warehouses, each offering different versions of services, resource-management tech-

niques, applications, platforms, hardware, and so on. Undoubtedly this approach will help to overcome restrictions of other middleware structures such as CORBA, Java/RMI (and Jini), Globus or Legion, which require user configuration and complete resource catalogs, and therefore restrict change and dynamism to a controlled deployment of changes in components' functionalities.

The concept of the WOS calls for a generic communication framework as its central component instead of a central server (or a fixed set of servers) on which clients rely. Therefore a communication layer supporting versioned protocols was developed to support communications within a community considering the negotiation of appropriate protocol selection, communication set-up, QoS and security issues.

### 1.3. Communities in computing

Networked or distributed computing means that *multiple* components, arising from several sources, will be put together in a single context; furthermore, objects will not necessarily remain in a given context, and may migrate to other contexts. Intuitively, these contexts may be understood as supporting the creation of communities. Different communities may agree to trade, meet, or discuss, depending on the communication protocols they can agree upon. For instance, human or software agents trading and brokering in electronic marketplaces may form communities of common interests. Other examples of communities are Internet chat-rooms or dynamic intra- and extranets of large companies. We believe that this concept of evolutive communities exhibits a potentially very rich model for ubiquitous computing. The required infrastructure to support communities, versioned resource management and communication between versioned objects will be provided by the WOS.

### 1.4. Related Work

There are several approaches to integrate the computational resources available over the Internet into a global computing resource. The closest approach to the WOS is the Jini architecture proposed by SUN Microsystems [9]. Jini allows one to build federations of nodes or distributed objects offering different services each relying on its own service protocol. Lookup services provide localization and discovery functions. These lookup services, however, require the knowledge of all lookup attributes. Moreover, what is looked for must be exactly specified, which means that only attributes to be exactly matched may be specified. For example, a search for *the nearest printer* cannot be realized. The WOS approach is qualitatively different and more general in that communities, i.e. subsets

of WOSNodes, defining a specific environment and context are dynamically and autonomously created. This is achieved with versioning and powerful lookup/discovery protocols and generalized service communication protocols. Every service is versioned in the WOS, and a suitable version is selected according to a 'best fit' strategy. This allows the implementation of smart lookup services where attributes need not be exactly matched.

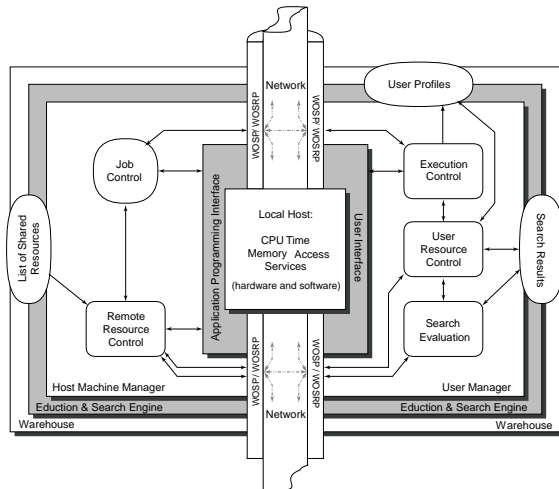
Other efforts to exploit distributed resources for wide-area computing include Linda, PVM, MPI, Netsolve [5], Globe [11], WebOS [10], Legion [8] and Globus [7]. In contrast to the WOS approach, most of these systems require login privileges on the participating machines, or require operating system or compiler modifications. Furthermore, they usually require architecture-specific binaries. The use of Java addresses the latter issue in a number of projects including Atlas [1], ParaWeb [3], Charlotte [2], Javelin [6] and Popcorn [4]. Those projects aim mostly to provide Java oriented programming models for Internet-based parallel computing. Our approach is orthogonal to these proposals in that Java oriented programming models could be integrated into the WOS through gateway interfaces. But the WOS is different in that it does not require any global centralized catalog of resources as it is, for example, necessary in Javelin, ParaWeb, Atlas or Globus.

## 2. General Characteristics of a WOSNode

The entire WOS is written in Java. This programming language was chosen to achieve a highly portable system. Because the WOS makes heavy use of the communication capabilities of the operating systems, Java was the best choice in view of its rich features for communication and security.

A WOS communication layer [14] was created to optimize the communication speed while saving resources, e. g. bandwidth, at the same time. Each WOSNode operates as a server as well as a client. The WOSNet consists of a series of versioned servers or nodes [15] which can provide a set of services and resources. There are no central catalogs of resources in the WOSNet. Each WOSNode stores information about other nodes locally in its own resource warehouse [30]. In other words, no machine has global information about all other nodes in the WOSNet. The information stored in the warehouses is updated each time the node finds other, previously unknown nodes. Using such decentralized resource warehouses, the system achieves a high flexibility and avoids some of the bottlenecks of systems with a central information management.

The structure of a WOSNode is shown in figure 1. The left side of this figure shows the server, while the right side represents the client features of each WOSNode.



**Figure 1. Structure of a WOSNode**

Services available on the WOSNode are described using *profiles*. Profiles describe resources with a list of key-value pairs, each pair defining a special feature of a resource. For instance, a printer has a special type (inkjet, laser etc.), is able to print black and white or color, and may handle Postscript files. Each resource also has a corresponding access-object describing its methods; e.g., for a printer, we might have self test, economy mode, etc. That means that the user does not need to use the commandline anymore. Restrictions on resource usage are described using the same data structure.

### 3. The WOS prototype

The WOS prototype consists of four major components:

- the *User Interface* (UI),
- the *Resource Control Unit* (RCU),
- the *Remote Resource Control Unit* (RRCU),
- the *Communication Layer* (WOSCL).

We describe these components in the following paragraphs.

The *User Interface* is subdivided in three parts, the profile editor, the resource editor and the request menu. As mentioned before, each resource is described through a profile. The Profile Editor helps the user generate profiles of resources he wants to make available for other users. The user has to define descriptive features of these resources, the object which the remote user needs to access and the parameters for this object. All profiles are stored in the local profile warehouse. The restrictions for each

profile are stored in the resource warehouse (see figure 2). The user can assign more than one restriction set to one resource. These restrictions will be checked before a user can access the resources. The third part of the UI, the request menu, provides an easy-to-use interface to resources of the WOSNet (figure 3). The user can access all resources stored in the local warehouse and may also initiate a search for new resources to update the warehouse.

The *Resource Control Unit* (RCU) accepts service requests from the user interface and contacts several known warehouses to find a WOSNode, where the requested service can be executed. First, the local warehouse is contacted, then other known warehouses in the WOSNet. If no service was found, a search for the requested service will be started. If an answer is found, the RCU asks for the service execution and returns the results to the user. After successful execution, the local warehouses are updated.

The *Remote Resource Control Unit* (RRCU) accepts service requests from other WOSNodes and examines whether the execution is allowed or not. Therefore, the resource warehouse is accessed. The RRCU transmits the answer to the client-side RCU. The service execution itself is also managed by the RRCU, which contacts the resource warehouse a second time to verify access rights. After that, the service is executed and the results are passed to the client-side RCU.

The *WOS Communication Layer* (WOSCL) uses a two-level approach [14]. The first level, the *WOS Protocol* (WOSP), allows WOSNode administrators to implement a set of services, called a *service class*, dedicated to specific users' needs. WOSP is in fact a generic protocol defined through a generic grammar. A specific instance of this generic grammar provides the communication support for a service class of the WOS. This specific instance is also referred to as a *version of WOSP*; its semantics depends directly on the service class supported by that version. Several versions of WOSP can cohabit on the same WOSNode.

The WOSP is used to execute a service, to transmit the results of the execution, and to search the WOSNet. It allows three types of commands:

1. Query commands are used by a WOS client to interrogate another WOSNode's warehouse.
2. Setup commands are used to change the execution parameters of a WOSNode.
3. Execution commands allow a WOS client to use resources from another node.

An example of the syntax of a WOSP version is given in figure 9 and the API of the communication layer is described in detail in [31].

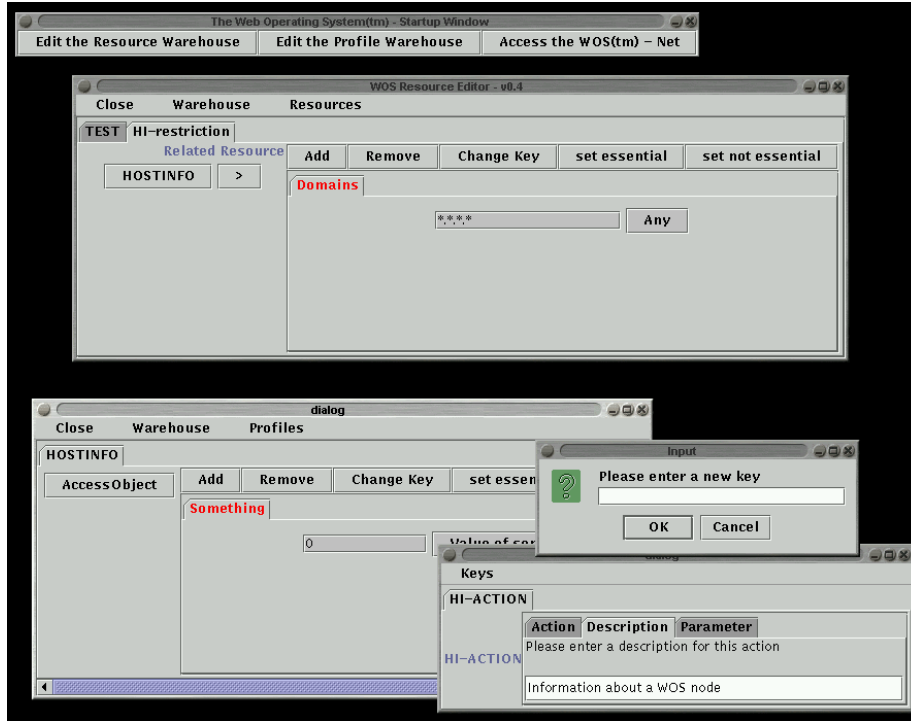


Figure 2. GUI of WOS version 0.4: The warehouse editor, profiles and actions.

The second layer, the *WOS Request Protocol* (WOSRP), support discovery/localization of service classes, implemented by WOSP versions. The rationale behind WOSRP is to provide mechanisms for WOSNodes to exchange information about WOSP versions they support. It is also used to obtain information about other WOSNodes that understand specific WOSP versions.

A WOSNode may “speak” a certain version of the WOS protocol, which means that it can interact with other nodes using that version. A WOSNode may also “know” a version of the WOS protocol. That means, that even if cannot interact using that version, it can refer a WOSNode to other WOSNodes which might have this capability.

WOSRP also serves to establish connections between WOSNodes. A WOSP message may be encapsulated in a WOSRP message. This way, a generic server may receive all the requests and select the appropriate version to process them.

## 4. WOS services

As described above, the system services of the WOS make it possible to setup services and to make resources available to a WOSNet through the profile editor. A number of additional services and functions have been developed which

are briefly described in the following sections.

### 4.1. WOSForward service

The localization of services in a WOSNet is based on the mechanism of multiple sequential chains [40]. Based on the knowledge of the WOSNet, a node searching for a service is building lists of nodes to be visited. These lists define sequences of nodes to visit along disjunct paths. The search may thus be performed in parallel along these paths. Theoretical as well as empirical investigations have shown the efficiency of this mechanism [19]. The WOSForward service exploits the principle of multiple search chains to transfer data from a source node to a target node in the WOSNet in parallel along disjunct paths as shown in figure 4.

The speedup achieved with this service depends on the available bandwidth in the local area (near), the bandwidth available on the Internet, and the amount of data to be transferred. In general, we obtain a better speedup, if the bandwidth in the local area is large and if the combined bandwidth of all the disjunct paths in the Internet is large as compared to one single transfer channel. The data to be transfer is divided into chunks of data which are transfer along the different paths. It is clear that those

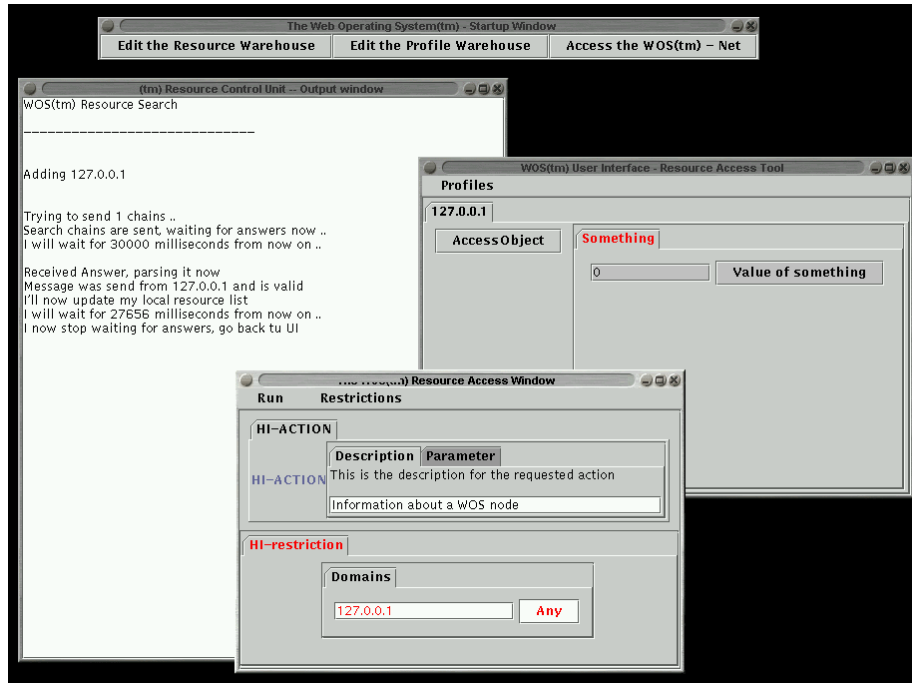


Figure 3. GUI of WOS version 0.4: Accessing the WOSNet.

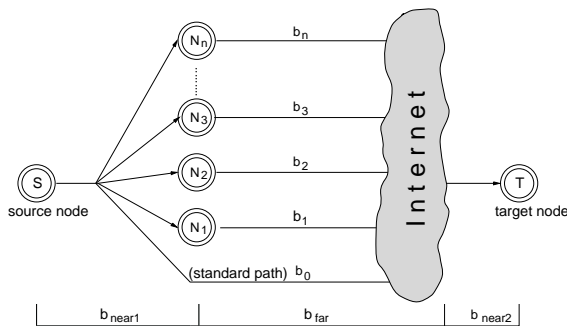


Figure 4. Communication along disjunct paths.

chunks may not become too small, otherwise the overhead introduced by this method will neutralize the speedup. Figures 5 and 6 show preliminary results obtained with a data transfer between two machines in Europe and North America respectively using two distinct paths.

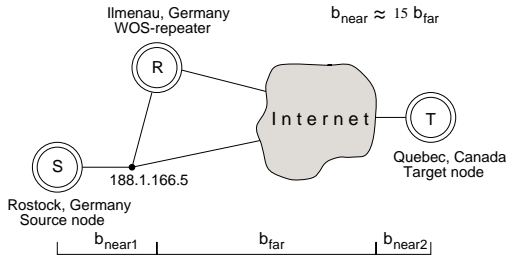
## 4.2. CORBA – WOS integration

WOS and CORBA both achieve interoperability through a well defined protocol. CORBA makes use of the Internet Inter-ORB protocol (IIOP) to exchange General Inter-ORB

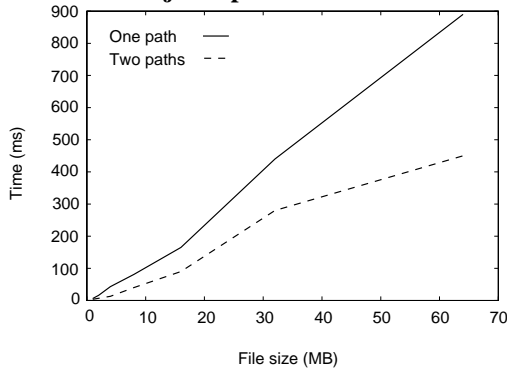
protocol (GIOP) messages over a TCP/IP network. The GIOP then uses the Common Data Representation (CDR) to map IDL types onto a raw, networked message representation. The WOS in turn uses the WOSRP/WOSP protocol and the principle of warehouses to store information about services. The profile warehouse stores service profiles consisting of a name and an access object (i.e., the executable invoking the service). The access object is identified by a key and uses a set of input and output parameters for the execution. The two systems may run simultaneously using a (protocol)-bridge which has been developed and implemented in Java [33]. The triplet [CORBA module, interface name, parameters] is mapped onto [WOS profile name, access object key, access object parameters] enabling access to the service from within both systems.

A generic WOSAadapter as shown in figure 7 provides a CORBA client with the usual view of an ordinary CORBA service, when accessing a WOS-based service.

A specific version of the RRCU (Remote Resource Control Unit) of the WOS allows a WOSNode to directly access a CORBA service through the CORBA API. The invocation of a CORBA service (instead of a WOS resource) is completely transparent for the client as it is the case for the generic WOSAadapter. Figure 8 describes how a CORBA service is invoked from within the WOS.



**Figure 5. Experimental setup for the communication with two disjunct paths.**



**Figure 6. Transmission times for one path and two disjunct paths.**

### 4.3. WOS for HPC

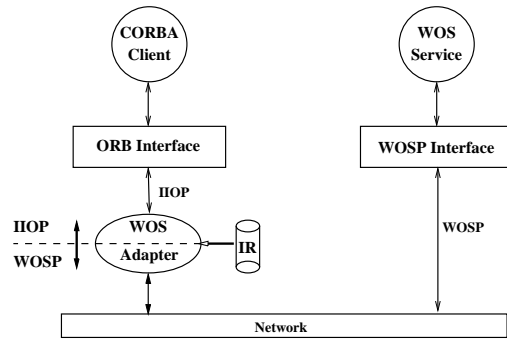
Tools for wide area, high performance computing usually require all the computing resources to be known in advance. Often, this information is even directly compiled into the parallel applications. The computing resources must therefore be exactly configured to match the applications' requirements. This configuration task may involve tedious setup procedures or scripts requiring login privileges, exact knowledge of the resource locations etc.

A version of WOSP, called HPWOSP, has been defined to ease this task [38]. It automatically configures and executes HPC applications in the WOS environment, i.e. on resources of a WOSNet. Specifically, it supports the communication requirements for HPC applications, which are:

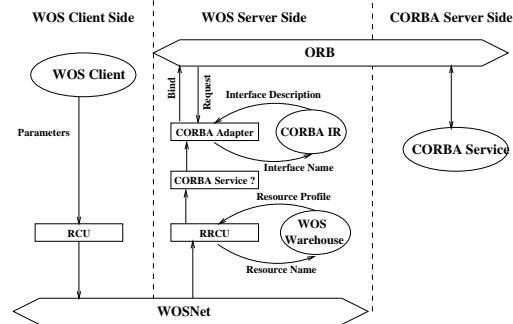
**Configuration stage:** the localization of suitable WOSNodes with the appropriate set of resources (hardware and software) for an application and the reservation of those resources.

**Setup stage:** the code distribution and launch of the application.

Figure 9 shows the syntax of the HPWOSP protocol version. The information about the properties of the resources



**Figure 7. WOSAdapter in CORBA - generic server.**



**Figure 8. CORBA service invocation from within the WOS.**

and the requirements of the application are again specified with the help of profiles and are kept in the corresponding warehouses. The HPWOSP implementation has been successfully tested for large MPI and PVM applications.

## 5. Conclusion and Future Work

At its current state of implementation, the Web Operating System (WOS) is useful to demonstrate the possibilities of this approach and to test its major functionality. The lack of security mechanisms and clearly defined programming interfaces foils an application of the WOS in a production environment. However, a security system based on automatic trust evaluation has been designed [26, 36] and is currently being implemented. The WOS version 1.0 is scheduled to be released in the last quarter of the year 2000. It will include the yet missing components such as the security module, a complete API and a refined job control module. The experience gained so far with the WOS system and services clearly indicate its potential for future ubiquitous computing, because any device can be a WOSNode and any service can be implemented. The concept of versions applied throughout the entire WOS system allows for the necessary flexibility required by ubiquitous computing. The section *WOS References* gives an overview of WOS

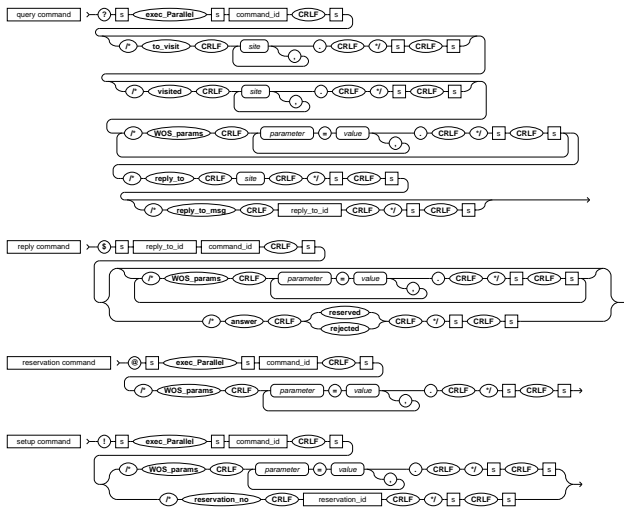


Figure 9. Syntax of the HPWOSP version

related publications.

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