Implementing Windows 2000 Terminal Services and Citrix MetaFrame on IBM Netfinity Servers

Darryl Miles, Steve Russell
Take Note!

Before using this information and the product it supports, be sure to read the general information in Appendix , “Special Notices” on page 47.

Second edition (April 2000)

This edition applies to Citrix MetaFrame 1.8 for Microsoft Windows 2000 Servers.

Comments may be addressed to:
IBM Corporation, International Technical Support Organization
Dept. HZ8  Building 678
P.O. Box 12195
Research Triangle Park, NC 27709-2195

When you send information to IBM, you grant IBM a non-exclusive right to use or distribute the information in any way it believes appropriate without incurring any obligation to you.
## Contents

**Preface** ................................................................. v

**Chapter 1. Introduction** .............................................. 1

1.1 The Terminal Services component of Windows 2000 .................... 1
1.2 Microsoft Network Load Balancing .................................... 2
1.3 Citrix MetaFrame ..................................................... 2
1.4 Citrix Load Balancing Services ...................................... 4
1.5 Citrix Resource Management Services ................................ 4
1.6 Citrix Installation Management Services ............................ 4
1.7 Terminal Services and MetaFrame Licensing .......................... 4

**Chapter 2. Running a Terminal Server and MetaFrame pilot** ............ 5

2.1 Terminal Server and MetaFrame pilot phases ........................ 5
  2.1.1 Testing applications in a multiuser environment .............. 5
  2.1.2 Securing the Terminal Server .................................. 6
  2.1.3 Choose a pilot group ............................................. 6
  2.1.4 Perform the pilot ............................................... 7

2.2 Sizing IBM Netfinity for Terminal Server and MetaFrame ............ 7
  2.2.1 Evaluating CPU performance ................................... 8
  2.2.2 Terminal Server testing tools and scripts ...................... 8
  2.2.3 Using results to assess real-world requirements .............. 9
  2.2.4 Evaluating memory performance ................................ 10
  2.2.5 Evaluating network performance ................................ 13

**Chapter 3. Terminal Server and MetaFrame design examples** .......... 17

3.1 Small Terminal Server and MetaFrame environment .................. 17
3.2 Medium Terminal Server and MetaFrame environment ............... 18
3.3 Large Terminal Server and MetaFrame environment ................ 20
  3.3.1 Printing ....................................................... 24
  3.3.2 UPS configuration ............................................. 24
  3.3.3 Rack configuration ........................................... 24

**Chapter 4. Software installation and configuration instructions** ..... 25

4.1 Windows 2000 and Terminal Services installation .................. 25
4.2 Windows Terminal Server configuration ................................ 30
4.3 MetaFrame installation and configuration .......................... 31
  4.4 Group Policy Object and Profile configuration ................... 32
    4.4.1 Windows 2000 Profiles ..................................... 32
    4.4.2 Group Policy Objects ....................................... 35
4.5 Application installation and configuration ........................ 39
4.6 Application installation and configuration examples ............... 40
  4.6.1 ServeRAID administration .................................... 40
  4.6.2 Advanced system management adapter device driver ........... 41
  4.6.3 Microsoft Office 97 SR2 ....................................... 41
  4.6.4 Microsoft Office 2000 ......................................... 41
  4.6.5 Client Access Express ........................................ 42
  4.6.6 Notes R5 ....................................................... 43

**Special Notices** .......................................................... 47

**Related publications** .................................................. 49
Preface

The last few years have seen an increased interest in “thin client” technology as customers have seen real Total Cost of Ownership (TCO) savings by extending the life of existing PC hardware, centralizing administration and rapidly deploying applications through a Windows Terminal Services solution.

The process of installing the Terminal Services component of Windows 2000 and MetaFrame is quite simple, but there are many issues beyond installation that you need to be aware of. This redpaper discusses how to choose an appropriately sized Netfinity server, install applications in a multi-user environment, and secure the server. It also explores topics such as disaster recovery, load balancing, and network sizing. In addition, it includes tips and tricks gained from our experiences in implementing large MetaFrame solutions.

Note that the information contained in this document has not been submitted to any formal IBM test and is distributed AS IS. Furthermore, the use of this information or the implementation of any of these techniques is a customer responsibility and depends on the customer’s ability to evaluate and integrate them into their operational environment.

Who Wrote This Redpaper

Darryl Miles is a Systems Specialist with IBM Australia. He has worked at IBM for six years supporting various network operating systems, groupware and electronic mail. He is a Citrix Certified Administrator (CCA), Microsoft Certified Systems Engineer (MCSE), a Certified Lotus Professional (CLP), a Certified Novell Engineer (CNE), a Warp Server Engineer, and a Professional Server Engineer (Netfinity). He holds an honors degree in Electrical and Computer Systems Engineering from Monash University, Australia. Currently, his main focus is on Citrix solutions, Cisco router networks and Lotus Domino.

Steve Russell is a Senior IT Specialist at the International Technical Support Organization, Raleigh Center. Before joining the ITSO in January 1999, Steve had a Technical Marketing role, working in the UK as a member of IBM’s Netfinity organization in EMEA. Prior to that, he spent nearly 15 years managing and developing PC-based hardware and software projects. He holds a BSc in Electrical and Electronic Engineering and is a member of the Institution of Electrical Engineers and a Chartered Engineer.

Thanks to the following people for their invaluable contributions to this project:

Michael Nelson  Netfinity PartnerWorld for Developers, IBM Raleigh
Mark Aggar  Product Manager, Terminal Services Marketing, Microsoft Corporation
Bob Couto  Alliance Manager, Citrix Systems Inc.
Chapter 1. Introduction

The MultiWin technology incorporated in Windows 2000 Terminal Services was first conceived back in the late 1980s by Ed Iacobucci, the chairman and chief technology officer for Citrix Systems today.

This technology is now integrated in Microsoft Windows NT 4.0, Terminal Server Edition and Windows 2000 through an agreement between Microsoft and Citrix Systems. Citrix MetaFrame is an extension to these products, providing broader client support, management tools and greater scalability through load balancing.

The IBM family of Netfinity servers is a range of Intel processor-based systems that brings the benefit of IBM's experience in enterprise computing and e-business to the industry-standard marketplace. They are available in a wide range of configurations that offer choices of CPU and disk subsystems, and innovative features such as IBM's Light-Path Diagnostics, FlashCopy, and enhanced RAID disk subsystems. Together, Windows 2000, MetaFrame and Netfinity servers provide a scalable and reliable multiuser Windows solution.

1.1 The Terminal Services component of Windows 2000

The Terminal Services component of Windows 2000, like its predecessor Microsoft Windows NT Server 4.0, Terminal Server Edition (TSE), is designed to distribute Windows 2000 desktops by using “thin client” technology. A thin client is a device that is easy to install and connects to a high-powered Windows Terminal Server (WTS) that provides the computing services the thin client needs. Windows Terminal Services communicates with a small client program installed on computers running Windows for Workgroups, Windows 95 and 98, Windows NT, Windows 2000, WinCE handheld PCs and Windows-based Terminals running WinCE or Windows NT Embedded.

The user starts the client program which then displays the name of the WTS. When the user double clicks on the WTS name, the user sees the server’s logon screen, an example of which is shown in Figure 1. Each user can log on to the WTS system and then the remote server provides a Windows 2000 desktop in the client window. Users can interact with this desktop just as if they have their own high-powered Windows 2000 workstation. However, the processing is being performed on the server, not the workstation, which merely provides input from the user and output to the display.
Windows 2000 Terminal Services operates in two distinct modes. The first is Remote Administration which allows remote administration for a maximum of two concurrent connections. The second, Application Server mode, allows many clients to connect and share the same WTS resources.

1.2 Microsoft Network Load Balancing

Network Load Balancing (NLB) is a function provided by Windows 2000 Advanced Server that distributes work between two or more Terminal Servers. NLB works by representing a group of Terminal Servers by a single IP address so that many servers can be effectively combined to support larger numbers of users.

If a client session is temporarily disconnected, IP affinity, used by NLB, enables a user, identified by IP address, to reconnect to the same server within the group. Without IP affinity, or other similar techniques, the user is not guaranteed to reconnect to the same server and thus may lose data.

1.3 Citrix MetaFrame

Citrix MetaFrame is an extension to Windows 2000 Terminal Services. This software is installed on a Windows Terminal Server to allow other clients, such as Windows 3.x, DOS, OS/2, UNIX, Linux, and Network Computers (NCs) to connect to the WTS. A diagram showing the relationship between the WTS and Citrix MetaFrame is given in Figure 2.

The standard WTS client can connect to the server using only the TCP/IP protocol. MetaFrame adds the ability for clients to connect using protocols not supported by WTS, such as IPX and NetBIOS, using the Independent Computing Architecture (ICA) protocol. MetaFrame provides essentially the same function set to clients as does WTS, but MetaFrame broadens the client base and the manageability of those clients.
MetaFrame also provides clients with services such as published applications. By publishing an application on the server, an administrator makes the application available to users as a resource. Users of client machines can select an application and launch it for use. Figure 3 on page 3 illustrates a user’s view of a set of published applications.

Users with a Windows 95/98/NT workstation can run these applications in seamless mode, which means the remote application looks as if it is running locally. The application window can be resized and moved around a user’s desktop alongside other, perhaps local, applications. The Citrix Independent Computing Architecture (ICA) client can be loaded on Windows 95/98/NT and Windows 2000 clients, making it a very quick process for companies to distribute new applications rapidly across an entire organization.

The benefit to administrators is that they can easily make applications available without having to visit users’ computers to install the application software. Managing the application is also simplified as upgrades and patches can be applied centrally.

You may hear this technology dubbed “thin client”. This is because the entire Windows desktop is provided by a central high-powered server, using a small
client program (usually 1 to 2 MB in size) to render the screen updates and transmit keyboard and mouse input.

### 1.4 Citrix Load Balancing Services

Load Balancing Services is an additional product available from Citrix which, as the name describes, balances the load of published applications. When you buy Load Balancing Services, you do not receive additional media. Instead, you receive license keys which, when activated, enable the function on your Citrix server.

Overall performance is improved in multiserver environments by the use of Load Balancing Services. Using the Windows Clock program (clock.exe) as a trivial example, if you have decided to publish Clock to your users, you could make it available on two or more servers. Then, when a user wants to use Clock, the user’s client asks a server called the ICA Master Browser to identify those servers that are running the application. The ICA Master Browser will then determine which server is the least busy, and notify the user’s client software with the name of the server to which it should connect to run the application.

The user’s workstation then executes Clock on the least busy server. Of course, this all occurs without the user being aware of it. With Load Balancing Services you can specify that parameters such as CPU load, available memory, and so on should be considered at various priority levels by the ICA Master Browser in determining which server is the least busy. We'll look at Load Balancing Services later in this paper when we look at a scalable Citrix solution in 3.3, “Large Terminal Server and MetaFrame environment” on page 20.

### 1.5 Citrix Resource Management Services

Citrix Resource Management Services provides an audit trail, system monitoring, and the ability to construct detailed billing reports for all MetaFrame, WinFrame, and Terminal Server systems. From organizations with a single Citrix server to enterprises with a large-scale deployment, Resource Management Services provides the tools necessary to effectively monitor and manage your Citrix server environment.

### 1.6 Citrix Installation Management Services

Citrix Installation Management Services automates the application installation process, so that applications may be quickly and easily replicated to a number of MetaFrame servers.

### 1.7 Terminal Services and MetaFrame Licensing

Windows 2000 Terminal Services and Citrix MetaFrame operate for a grace period of 90 and 35 days, respectively, before each product’s license must be activated. For more information on product licensing requirements, see:

http://www.citrix.com/support/solpractices/docs/licensing.htm
Chapter 2. Running a Terminal Server and MetaFrame pilot

Running a thorough WTS/MetaFrame pilot test will help to eliminate surprises after your system is installed in production. It will also provide information as to the stability of the system, how the system can be made fault tolerant, what other network requirements are necessary, and how the new solution will fit in with the existing infrastructure and user requirements.

You can use the methodology outlined below to determine application characteristics and server sizing requirements. The WTS resources evaluated during capacity planning testing are processor, memory, and network performance. We recommend that you perform your testing on the same hardware you will use for your final solution. The load measured on the system during the pilot can then be extrapolated to estimate overall capacity limits. If you don't have the time, resources or budget to perform a WTS pilot, we provide some very good sizing "rules of thumb". These rules of thumb have been obtained by combining industry experience with Microsoft and MetaFrame guidelines.

2.1 Terminal Server and MetaFrame pilot phases

A Terminal Server and MetaFrame pilot can be divided into the following phases:

- Install applications and test functionality in a multiuser environment.
- Define number of users and significant performance factors.
- Define acceptable performance.
- Establish baseline WTS performance.
- Run the pilot with your group of test users.
- Measure WTS performance during the test.
- Gather user feedback.
- Identify capacity limits.
- Resolve issues found during the pilot.

Using the information gained from the pilot will allow you to make sound judgements about the number of servers required and the overall system design.

2.1.1 Testing applications in a multiuser environment

This is one of the most important phases of your WTS pilot. You need to install all of the applications that you want to run on WTS to ensure that they operate as expected in a multiuser environment. As an illustration of the importance of testing we'll give you real-life example.

One of our customers wanted to run a telnet application on WTS. In principle, this is a simple exercise, but during testing it was found that user authentication was not working correctly. Analysis showed that the server was authenticating users based on each individual's IP address. However, in a WTS environment, all users share a single IP address. The resolution was to transmit the user's ICA client name to the server for use as a unique identifier.

This example illustrates that in a WTS environment you need to ensure that you test all functions of your application thoroughly, especially before a large WTS
Implementing Windows 2000 Terminal Services and Citrix MetaFrame on IBM Netfinity Servers

rollout. You will find installation and compatibility documentation for several common applications in 4.6, “Application installation and configuration examples” on page 40.

2.1.2 Securing the Terminal Server

Windows 2000 Terminal Server should be further secured using Group Policy Objects (or GPOs). Typical examples would be a GPO to hide the server’s drives from users, or one to remove a user’s ability to run administrative tools. These are just some of the areas that need to be controlled with GPOs. Use the pilot to test how you will implement GPOs and to ensure they meet your security needs.

In 4.4, “Group Policy Object and Profile configuration” on page 32, we provide a sample GPO and also explain how to customize your users’ Start menu under Windows 2000 in order to provide a simplified user desktop.

2.1.3 Choose a pilot group

Choose a number of users who will be willing to test your new Terminal Server. You will want sufficient users to place a moderate load on your server. The actual number will vary depending on your server configuration, the application mix and the sophistication of your users. How many use one application at a time? How many are power users? These are questions you must ask yourself when selecting a representative set of users.

As stated previously, it is important that your test is run on the same hardware that you will use for your final solution. A linear extrapolation to larger numbers of users will then be a reasonable way to approximate the size your server will need to be.

The table below shows a list of users that might be involved in a typical Windows Terminal Server and MetaFrame pilot test and also the job category and workstation types that will be tested. Note how we have chosen staff with a number of different job roles to get a good cross-section of user types.

<table>
<thead>
<tr>
<th>Current Job Role</th>
<th>Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secretary</td>
<td>John Smith, Mary Wilson</td>
</tr>
<tr>
<td>Administration</td>
<td>John Harris, Peter Jones</td>
</tr>
<tr>
<td>Sales or Management</td>
<td>Allen Jones, Stephen Candell</td>
</tr>
</tbody>
</table>

Each user should be told that their experience will be used to determine the outcome of the pilot test. You might find it useful to give users a prepared set of questions to answer at the end of the test. Some questions you might like to ask are:

- How easy to use was the Windows Terminal Server?
  (Very Easy/Easy/Average/Poor/Difficult)
- How fast, relative to your existing computer, was the Windows Terminal Server?
  (Very Fast/Fast/Average/Slow/Very Slow)
- Did you experience any problems? If yes, please give brief details.
• Did your computer have any errors, or stop working? If so, please give brief details.

• What is your overall impression of Windows Terminal Server?
  (Excellent/Good/Average/Poor/Very Poor)

Your goal is for the pilot group to find WTS easy to use, fast and convenient. The pilot feedback will give an indication of whether a broader rollout of WTS is feasible.

2.1.4 Perform the pilot

The Terminal Server pilot should run for at least four or five business days. The users in your test group should access a single Windows Terminal Server that you are monitoring with the Windows 2000 Performance tool (which is equivalent to the Windows NT Performance Monitor). Be sure to monitor the server at different times each day: during the morning logon load, at lunch-time when the server is usually less busy, and perhaps in the evening when batch-type jobs are run. These different sample times will give you a feel for how busy the server is and how the load varies over time. In the next section we discuss the performance counters you should track during your pilot.

At the end of the test period, you can gather the user feedback sheets to determine how well Windows Terminal Server was rated by your users, and check that all applications and network services such as printing worked as expected.

2.2 Sizing IBM Netfinity for Terminal Server and MetaFrame

Windows 2000 Terminal Services provides users with a desktop (operating system), applications, and network resources by way of remote network communications between the client and WTS. In the WTS computing environment, bottlenecks can quickly degrade performance and provide unacceptable response times for users. It is the dramatic user impact of system bottlenecks on a Windows 2000 Terminal Server that makes capacity planning a critical part of designing a WTS solution.

Server performance is affected by many interacting factors. The raw CPU performance and the number of processors, the amount of memory installed in the server, disk subsystem performance, and the network bandwidth available to the server all play their part.

The monitoring tool we recommend to record performance parameters is the Windows 2000 Performance tool. This is integrated in the operating system and does not require additional software components installed on the WTS system. The following sections provide information about important counters used to analyze Windows Terminal Server performance.

In most server applications, disk subsystem performance has a strong effect on overall system performance. We recommend that you purchase a high-performance disk subsystem to minimize this effect. Using RAID technology can also improve throughput.

Finally, we recommend that Performance counters are measured from a remote workstation to minimize the effects of taking measurements on the server.
2.2.1 Evaluating CPU performance

Detecting a processor bottleneck in Windows Terminal Server is similar to detecting processor bottlenecks in both Windows 2000 Server and Professional versions, but the baseline values for the counters may be different. The most significant counters for evaluating CPU performance are Processor Queue Length, % Processor Time, %Total Processor Time, Context Switches/Sec, and Total Interrupts/Sec.

Let us look closer at two counters of primary interest:

- Processor Queue Length (System) is the instantaneous length of the processor queue in units of threads. All processors use a single queue in which threads wait for processor cycles. Once a processor is available for a thread waiting in the processor queue, the thread can be switched onto a processor for execution. A processor can execute only a single thread at a time. It is important to note that the processor queue length is an instantaneous count, not an average over a time interval. The average processor queue length should be smaller than twice the number of processors for acceptable user response.

- % Processor Time (Processor) is the percentage of time the processor was busy executing a thread other than the Idle process thread. This counter has an instance for each system processor available to the operating system, and can be used to verify that each system processor is contributing equally to the processing of waiting threads. The average processor utilization should be less than 80%.

For CPU-bottlenecked systems, the most significant counters for identifying bottlenecks are % Total Processor Utilization and Processor Queue Length. As the system processors become busier, the number of threads in the processor queue waiting for execution increases.

2.2.2 Terminal Server testing tools and scripts

Microsoft provides tools such as Microsoft RoboServer, RoboClient and SMClient to assist you with Terminal Server capacity planning. These tools are included in the Windows 2000 Server Resource kit. Citrix provides an equivalent tool for MetaFrame, called the Citrix Server Test Kit, which can be downloaded from the Citrix Developer Network (http://www.citrix.com/cdn). Both tools use client drivers to send keystrokes, mouse movements, and clicks to a Terminal Server to simulate real users. You can use these tools to determine the maximum number of terminal server users that your environment will support. Many hardware vendors
are also supplying performance information using one or more of the commonly used scripts described in Table 2:

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Testing Script</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft</td>
<td>Knowledge worker</td>
<td>Based on the Gartner Group specification, this script simulates a user that keeps a number of applications open all of the time, switching between them to perform a number of tasks. The user’s typing rate is 35 words per minute (WPM).</td>
</tr>
<tr>
<td>Microsoft</td>
<td>Structured task worker</td>
<td>Based on the Gartner Group specification, the structured task worker script simulates a user who opens and closes applications while moving between different tasks. The user’s typing rate is 60 WPM. This script provides a more stressful test than the knowledge worker script.</td>
</tr>
<tr>
<td>Citrix</td>
<td>Normal user</td>
<td>The normal user script simulates a user running one application at a time. For example, the script may write and save a letter using Microsoft Word.</td>
</tr>
<tr>
<td>Citrix</td>
<td>Power user</td>
<td>This script simulates a user running two or more applications simultaneously. The power user typically uses more system resources than a normal user. For example, a power user script may open Microsoft Word and Microsoft Excel at the same time, and merge an address book in Excel with a letter in Word.</td>
</tr>
<tr>
<td>IBM</td>
<td>Light user</td>
<td>The light user script represents task-oriented users who normally use a single data entry type application. In most tests, light users are represented as Microsoft Outlook users who typically send/receive a text message every five minutes.</td>
</tr>
<tr>
<td>IBM</td>
<td>Medium user</td>
<td>This script represents normal users who typically have two or three non-computational applications open in the same session space, with light switching among them. In most tests, medium users are represented as using Microsoft Word to create small documents, Microsoft Excel for simple data entry, Microsoft Outlook for sending and receiving e-mail and Microsoft Internet Explorer for browsing an intranet site.</td>
</tr>
<tr>
<td>IBM</td>
<td>Heavy user</td>
<td>The heavy user script simulates power users who typically use multiple applications that require large amounts of memory space and processing power. In most tests, heavy users are represented as using Microsoft Word to create several documents, Microsoft Excel for extensive data manipulation and to create graphs and charts, Microsoft Outlook for reading and sending significant amounts of e-mail, and Microsoft Internet Explorer for extensive browsing of an intranet site.</td>
</tr>
</tbody>
</table>

The typing rate of your users, measured in words per minute (WPM), affects the capacity of your server. As the average typing rate increases, the number of users that can be supported by your server will decrease. Users who open and close applications rather than switching between them also place a greater load on a Terminal Server.

2.2.3 Using results to assess real-world requirements

Underestimates can occur due to the differences between the benchmark environment in which Terminal Server scripts are run and the real world. Scripts generate a synthetic workload that provides repeatability but that is not particularly representative of any specific real-world situation. Repeatability
allows comparison of the effects of changes to server and software configuration, which means the server may be finely tuned for this specific and stable workload. Production environments are more subject to variation than this.

Another very important factor is the rate at which the workload is placed on the server. In benchmarks, some effort is made at randomizing the work presented to the server, but real users’ work patterns can create significant peaks and valleys on a daily, weekly or even longer cyclical basis. For example, daily peaks can be expected when everyone logs on to the system as they arrive in the morning, while workload dips usually occur at lunchtimes and overnight.

In practice, test results provide appropriate “rules of thumb” for most users who run applications such as Office, Notes or Outlook. For more complicated or custom applications, you should be more conservative in your server sizing and use the results from the structured task workers, power users or heavy user scripts.

For this situation, IBM and other vendors have developed guidelines to map Terminal Server script results to recommended maximum values that customers can use for production servers for particular client workloads. The following rule determines the upper bound on the number of production Terminal Server clients actively connected at any one time to your Netfinity server.

---

**Rule of thumb - Terminal Server users**

80% of script result = maximum number of production Terminal Server users

---

For example, if a particular script, running on a particular server configuration, indicates that a maximum of 100 Terminal Server users are supported, you can expect to support up to about 80 users of the type represented by the test script in your production environment.

This rule of thumb provides some spare capacity for your production environment. These guidelines vary from vendor to vendor, but all aim to provide a reasonable safety margin in their calculations, so that you can feel confident your server can support the load that has been quoted and cope with reasonable peaks in demand.

---

**Tip**

Up to 70 concurrent knowledge workers or medium users can be supported on a dual Pentium III 450 MHz processor Terminal Server and receive acceptable response times. In practice, this relates to general application use of such products as Microsoft Office and Lotus Notes. Using our rule of thumb, this equates to 70 x 0.8 = 56 concurrent production users, or approximately 60 users.

---

### 2.2.4 Evaluating memory performance

To achieve the multiuser capabilities in Windows 2000, components, services, drivers, Virtual Memory Manager and Object Manager have been written to perform in a multiuser environment.
Analysis of WTS testing has shown that memory bottlenecks can have a significantly more severe impact on system performance than a CPU bottleneck. When a CPU bottleneck occurs, all client requests are processed, but at a slower rate. All clients on the CPU-bound machine will continue to operate, but with periodic pauses in processing, possibly lasting for many seconds.

In a memory-bound WTS implementation, as we would expect, after the amount of available system RAM has reached critical levels, the server immediately becomes overloaded with the task of paging information to and from the swap file. Memory utilization should be observed carefully because of the severity of the impact. The most significant performance counters are Available MBytes, Page Outputs/Sec, Page Inputs/Sec, and Pages/Sec (average). If an upward trend in Page Outputs/Sec and Page Inputs/Sec is observed, a memory bottleneck may exist in the system. To check for excessive paging due to programs that are running, stop the program with the highest working set value and see whether that significantly changes the paging rate.

The following is a graph of Available MBytes for different days of a WTS pilot. The number of people is the average from 7 a.m. to 6 p.m. for that day, and the WTS had 1 GB of RAM.

![Available MBytes for our example WTS pilot](image)

The graph shows that the amount of available bytes for users and applications is approximately 980 MB with no user load. The operating system is therefore using 44 MB for internal use.
If we plot the largest amount of RAM used during each day we find the following:

Table 3. Memory used per person

<table>
<thead>
<tr>
<th>Day</th>
<th>Lowest available MB</th>
<th>Number of people</th>
<th>Memory used</th>
<th>MB used per person</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>876</td>
<td>9</td>
<td>104</td>
<td>11.5</td>
</tr>
<tr>
<td>2</td>
<td>872</td>
<td>6</td>
<td>108</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>830</td>
<td>7</td>
<td>150</td>
<td>21.4</td>
</tr>
<tr>
<td>4</td>
<td>789</td>
<td>12</td>
<td>191</td>
<td>15.9</td>
</tr>
<tr>
<td>5</td>
<td>766</td>
<td>12</td>
<td>214</td>
<td>17.8</td>
</tr>
</tbody>
</table>

We have plotted the maximum RAM used for the each day of our pilot in the graph below:

![MB used per person](image)

Figure 5. Plot of maximum RAM per person

Microsoft’s memory guideline for a WTS is to provide a minimum of 10 MB per user. To verify the amount of RAM used per person, the Administrator can log on to the WTS and use the Windows NT task manager to view all running tasks per user. As a general rule of thumb, based on work in IBM’s performance laboratory, we recommend the following:

---

**Memory recommendation**

Servers should be configured so that average memory utilization does not exceed 70%. 30% usually is enough extra memory so that the server will not expand storage onto disk or page memory onto disk during periods of peak activity.

In addition, the following guideline is useful to estimate the amount of memory required:

---
Remember that this RAM requirement includes only the operating system and users. If you have any backup and recovery or anti-virus software running on your server, you will need to configure additional RAM for your server.

2.2.5 Evaluating network performance

Bottlenecks in network communications can occur in four different areas: the client's network interface, the physical network media, the server's client to server network interface, and the server's network interface for server to server/host communications. Bottlenecks in network communications directly impact the user at the client workstation. When network delays are encountered, the delay in response time on the client workstations is instantaneous. WTS performance can be considered unacceptable because of delays in network communications even though the CPU and memory are available. The counters that we monitor are the following:

- Bytes Total/Sec using the Terminal Services Session object, is the network bandwidth per user transmitted and received on the network for Independent Computing Architecture (ICA) communication between the client and server. This counter measures the bandwidth used by ICA only for each user and not any other traffic sent between your WTS and other servers such as file servers, AS/400s, and so on. You can record each user's bandwidth by selecting the appropriate user instances and exporting them to a spreadsheet where you can easily determine the total Bytes/Sec for all ICA traffic for the server.

- Bytes Total/Sec using the Server object is the total number of bytes received per second on the network interface.

A Windows 2000 Terminal Server communicates with its clients via the Remote Desktop Protocol (RDP) over TCP/IP. Citrix MetaFrame communicates with thin clients by another type of protocol called Independent Computing Architecture. This protocol can operate using transport protocols such as TCP/IP, NetBEUI or IPX/SPX. Both ICA and RDP Version 5 are on demand protocols. This means that when the screen is static, no keys are being depressed, and no mouse movements or clicks are occurring, no bandwidth is being consumed. This provides for much more efficient use of the network. 10 Kbps is commonly used as a bandwidth guideline for simple “green screen” applications running over ICA.

Citrix recommend the following bandwidth requirements:

**Useful formula**

The minimum amount of RAM you need in your Windows Terminal Server = 128 + 15 x (Concurrent number of Windows Terminal Server users) MB

**Bandwidth recommendation**

For optimal performance in an active ICA session, it is recommended to have 20 Kbps of bandwidth available for each session before the bandwidth becomes a constraint. Bandwidth usage can vary during a session depending on session activity. Latency of 1000 ms or more is likely to be unacceptable.
If you have people using MetaFrame at remote sites via Wide Area Network (WAN) links, then it is also very important to ensure that bandwidth is not a bottleneck. To determine bandwidth requirements, you can use the Performance tool to record the amount of ICA traffic sent and received on the network for each user during the pilot. You cannot simply record all traffic to and from the WTS server because, if your users access other servers for file and print, or e-mail, this would be measured as well.

We have also used a device from Packeteer (http://www.packeteer.com) called a Packetshaper which is installed between a site’s router and LAN. The Packetshaper provides a breakdown of the bandwidth and response times. It can provide additional information in sizing your Wide-Area Network (WAN) links for MetaFrame.

Below is a graph showing bandwidth measurements for eight users at a remote office. These users were connected to the MetaFrame server over a 128 Kbps Committed Information Rate (CIR) frame-relay link.

![ICA Network Bandwidth](image)

If we use the Citrix guideline to provide 20 Kbps of bandwidth per user, 10 users would require a 200 Kbps CIR frame-relay circuit. You can see from the above graph that the total bandwidth required for ICA traffic is “bursty” in nature, as users type on their keyboard, move their mouse and print to locally attached printers via Citrix. In practical environments, we have found that 20 Kbps per each Citrix user provides excellent performance.

However, you may not be able to afford the cost of providing 20 Kbps per Citrix user. In this case, you could reduce the WAN link speed by determining the average amount of time staff are actively sending and receiving ICA data on the network. To do this, plot the percentage of time your network is busy with ICA traffic on a spreadsheet. This will give you a graph similar to the one shown.
below, which is a graph of how often our eight users sent and received ICA traffic during our pilot.

![Graph of % Network Active](image)

Figure 7. % Network Active

We can see that the network was active with ICA traffic for about 50% of the time, on average. Using this information, we can modify the bandwidth guideline for ICA traffic over a WAN link as follows:

### WAN bandwidth guideline

Citrix recommends that 20 Kbps of bandwidth be allocated to each MetaFrame user connected remotely across a frame-relay network. Given that, on average, ICA data is active on the network only Y% of the time, a modified bandwidth requirement can be calculated using the following formula:

\[
\text{Link speed CIR} = 20 \times \left( \frac{Y}{100} \right) \times \text{number of remote users}
\]

The link CIR can be increased or decreased in the future depending on changing user patterns or network growth. This rule of thumb is only applicable for frame-relay networks which can burst to higher data rates if required. This rule of thumb would be 20 kbps per each user on DDS and ISDN circuits.

For more information on ICA bandwidth requirements, take a look at Citrix’s online forum at [http://ctxexl0.citrix.com/icaforum.nsf](http://ctxexl0.citrix.com/icaforum.nsf) and search on the keyword “bandwidth”.
Chapter 3. Terminal Server and MetaFrame design examples

We now discuss several Windows 2000 Terminal Services and Citrix MetaFrame design examples. Please note that these are examples only. You should consider the specifics of your own environment when sizing and implementing Terminal Servers, and when deciding whether or not you need to purchase the additional services of Citrix MetaFrame. Always consult with your colleagues and management before making server and configuration decisions.

3.1 Small Terminal Server and MetaFrame environment

A customer wants to install Windows 2000 Terminal Services and Citrix MetaFrame for 20 users at a single location. The customer has a mixture of older computers that do not have the capacity to run Windows NT or Windows 2000. The customer would like to re-use these computers by converting them to thin clients and using Windows 2000 Terminal Services. All users will run applications such as those in the Microsoft Office suite. The customer also wants the ability to take remote control of users’ desktops.

The solution is Windows Terminal Server and Citrix MetaFrame. TCP/IP will be used as the network protocol, and Novell's TCP/IP and ODI network drivers will be used for DOS clients. This will allow an easier setup of DOS clients with different Ethernet network cards.

Our choice for this customer was to run Windows 2000 Terminal Services and Citrix MetaFrame on an IBM Netfinity 5000 server. The customer did not expect significant growth in the short term and cost constraints prohibited choosing a more expensive server. The Netfinity 5000 has sufficient performance for this small Citrix network to provide Microsoft Office applications. Given that all users were connecting to MetaFrame via a fast 10/100 Mbps Ethernet network, no bandwidth sizing was necessary.

Using our memory formula, we calculated that we would need a minimum of 428 MB of RAM. The customer wants to run backup and restore and virus protection software, so another 32 MB of RAM was required, for a total of 460 MB of memory. Memory is typically packaged in multiples of 64 MB, 128 MB or 256 MB, so the nearest practical memory size that meets this requirement is 512 MB which allows about 10% additional headroom. The IBM Netfinity 5000 also has the ability to have an extra processor fitted if a greater workload is placed on the system in the future.

Looking at what software and data should be held on the server, we make the following recommendations:

- The Citrix server should not hold any user data, only the applications to be published to your users. In our example, the Citrix server will be installed with the customer’s applications, which include Office 2000, Lotus Notes and Client Access Express.
- 16-bit and DOS applications should not be installed on Windows Terminal Server due to their increased system requirements and the possible system instability that they may cause.
The Netfinity 5000 configuration included an IBM ServeRAID adapter to provide hardware RAID support. The disk requirements were met by two 9.1 GB, 10,000 RPM drives, configured as a RAID-1 logical drive. We also installed a third 9.1 GB drive as a hot-spare for additional redundancy. To protect against power problems, the server was also fitted with a redundant power supply.

![Netfinity 5000 Drive Configuration](image)

**Figure 8. Small Terminal Server and MetaFrame environment drive configuration**

The Windows Terminal Server, Citrix MetaFrame and applications were installed using the instructions provided with this paper. The Windows 2000 Terminal Server was installed as a stand-alone server rather than running the additional Domain controller tasks. The server was a member of the Active Directory Domain and the server object was placed in its own Organizational Unit (or OU for short). Placing the server object in its own OU allows it to be secured by Group Policy Objects. A sample Group Policy Object is provided in 4.4, “Group Policy Object and Profile configuration” on page 32. A license server is a domain controller on which Terminal Services Licensing is enabled. This server will track the number of licenses that have been purchased, and must be installed for the Terminal Server to operate.

The customer was running an existing file and print server with a number of different types of network printers. Our recommendation is to only use the multiuser printer drivers that are shipped with Windows 2000. Using third-party printer drivers in a multiuser environment has been known to result in system instability and the well-known blue screen trap in a Windows NT environment. For more information, consult the Citrix forum at:

http://ctxex10.citrix.com/icaforum.nsf

### 3.2 Medium Terminal Server and MetaFrame environment

Another customer wanted to use Windows 2000 Terminal Services and MetaFrame to support a total of 60 users for a single client/server application. Thirty of the users were located at the customer's headquarters, connected by a
switched 10/100 Mbps Ethernet network. The other 30 users were located at a remote overseas office via a 128 Kbps frame-relay WAN link. The application was to be accessed as a published application allowing users to easily connect to the new client/server application from their ICA clients. For Windows 32-bit clients, the application can be seamlessly accessed as if it were a local application. MetaFrame allowed the customer to rapidly roll out this application to all users in the company.

The customer wanted a 2-processor symmetrical multiprocessing (SMP) server that was capable of being upgraded to a 4-CPU configuration in the future. Using our guideline of 70 users per server with dual processors, and scaling this value by 80% we specified a maximum of 60 users per server. The IBM Netfinity 5500 M10 was chosen as the appropriate server. The customer did not expect that all 60 staff would access Citrix concurrently. However, if extra users were added to the system in the future, the customer would cope with the additional load by adding RAM and/or processors to the server or, perhaps, take a different approach by installing an additional MetaFrame server and implementing Citrix Load Balancing Services.

Four 9.1 GB, 10,000 RPM drives were connected to the on-board ServeRAID adapter and configured as a RAID-1 logical drive. This gives an effective disk space of 18 GB. Once again, an extra drive was installed as a hot-spare for added redundancy. If any of the four drives were to fail then the RAID controller would automatically rebuild information from the logical drive onto the hot-spare.

The customer was not able to perform a full-capacity planning pilot for their 60 users; however, from our guidelines we expected that two processors would be required for the 60 users. Using our memory formula we calculated that we would need 1028 MB of RAM. The customer also wanted to run backup/restore and virus protection software so another 32 MB of RAM was required. This gave us a total of 1060 MB of RAM as a minimum. Allowing for the granularity of memory
packaging, the customer decided to configure the server with 1.25 GB of SDRAM ECC memory. Finally, the server was fitted with two Pentium III Xeon processors.

The customer used our WAN guideline to size the frame-relay link as a CIR of 600 Kbps. However, the customer felt that it was unlikely that 30 concurrent users would access the application from the remote office overseas at the same time, so the link CIR was reduced. The customer would increase the frame-relay link speed in the future if their carrier reported high utilization. We informed the customer that users, particularly those working across a WAN, would obtain increased performance by having the application use only 16 colors, and also by activating bitmap caching on all ICA clients.

The Windows 2000 Terminal Server was installed as a stand-alone server and the server object was placed in its own Organizational Unit in the Active Directory. Placing the server object in its own OU allows it to be secured by Group Policy Objects. A sample Group Policy Object is provided in 4.4, “Group Policy Object and Profile configuration” on page 32. As discussed previously, a license server is a domain controller on which Terminal Services Licensing is enabled. This server will track the number of licenses that have been purchased, and must be installed for the Terminal Server to operate.

The customer configured the Windows Terminal Server using a drive partitioning scheme we have found useful. The operating system was placed on the C: drive, and data on the D: drive, both formatted using NTFS. A third, FAT, partition formed the E: drive. Using imaging software such as Symantec GHOST, images of the operating system and data drives can be created and stored on the E: drive. It is a good idea to make a new image after the initial installation and then prior to any major change to the server. Then, in the event of a system failure, the server can be brought rapidly back online by restoring the server from these backup images.

### 3.3 Large Terminal Server and MetaFrame environment

A large customer needed a reliable, expandable and centralized Citrix MetaFrame environment for 300 users. The customer had several existing servers at their headquarters, including IBM AS/400s running business applications and Lotus Domino, and file and print servers. The customer wanted to maintain this centralization, keeping major computing resources close to their support staff for better service and manageability, and increased security. The customer wanted Citrix MetaFrame to provide a full-screen desktop and a number of applications such as Office 2000 and Lotus Notes to their users. The desktop was to be secured and simplified for all users.

The customer’s headquarters was running a switched 10/100 Mbps Ethernet network, with frame-relay links to many remote offices. An implementation requirement was to have the Terminal Servers join the company’s existing Active Directory so that users could log on to any Terminal Server using the same account and password. A dedicated Active Directory Domain Controller was assigned to the MetaFrame server farm not only to authenticate users but also to store the users’ roaming profiles. The server will also have Terminal Server Licensing enabled, which will track the number of licenses the customer has purchased for all of their Terminal Servers. MetaFrame was also installed on this server so it could perform the role of an ICA Master Browser server. This is a
single server that provides ICA clients with information indicating to which MetaFrame server they should connect.

We recommend that at least two domain controllers are running to provide fault tolerance. Although we have not shown other domain controllers in our design, they are present and provide general authentication services for the company. The MetaFrame domain controller was installed on a Netfinity 5000 server because it can be rack mounted and has high availability options such as hot swap hard drives and redundant power supplies.

We recommended that the customer implement a number of small MetaFrame servers rather than one or two very large ones. This allows the customer easily to scale the solution as user numbers increase. It also means that fewer users are affected in the event of a system failure. The other servers can support the slightly increased user load if one server is shut down for maintenance or repairs.

The customer chose the Netfinity 5600 for the server farm. Using our CPU and memory guidelines we judged that each Netfinity 5600 would support up to 60 concurrent users. This is a conservative estimate which should ensure excellent performance for all users. Our memory guideline determined that supporting 60 concurrent users would require 1028 MB of RAM which was rounded to 1GB. Each server was fitted with two Pentium III processors.

Five Netfinity 5600 servers configured in this way will support 300 concurrent MetaFrame users. A sixth server is recommended so that in the event of a server failure, the 300 users can be supported without a drop in quality of service.

An overview diagram of the final design is shown in Figure 10:
Each Netfinity 5600 server had four 9.1 GB, 10,000 RPM drives connected to a ServeRAID adapter and configured as a RAID-1 logical drive. This gave an effective disk space of about 18 GB per server. An extra drive was installed in each system, to act as a hot-spare for added redundancy. If any of the four active drives were to fail, the RAID controller would automatically rebuild information from the logical drive onto the hot-spare.

One of the Netfinity servers was installed with Windows 2000 Server, Terminal Services and the appropriate applications. While building the server, it is important not to join the domain, and to keep the local administrative password blank. We then used Microsoft’s Sysprep utility to prepare this server as our Master Terminal Server image. Using a disk imaging utility such as Symantec GHOST, the customer distributed this image to the other five Netfinity 5600 servers. After each server is imaged, it can join the domain. For more information on Sysprep, see:


You could also use the new unattended installation features of Windows 2000 to build a number of identical terminal servers.
The customer configured the servers using a drive partitioning scheme we have found useful. The operating system was placed on the C: drive, and data on the D: drive, both formatted using NTFS. A third, FAT, partition formed the E: drive. Using imaging software such as Symantec GHOST, images of the operating system and data drives can be created and stored on the E: drive. It is a good idea to make a new image after the initial installation and then prior to any major change to the server. Then, in the event of a system failure, the server can be brought rapidly back online by restoring the server from these backup images. GHOST partition images should only be used on the same server from which it was imaged.

A published application was then created using the Application Configuration program. However, instead of specifying an executable and working directory for a particular application we left these entries blank. Then, when users connect to this published application they are shown a full screen Windows Interface as shown in Figure 1 on page 2.

The final step was to specify the six Netfinity 5600 servers as hosts for the full-screen published application. Citrix load balancing was activated on each of the six Netfinity 5600 servers. Load balancing allowed the desktop published application to be available as a single selection for the user rather than the user having six desktop applications from which to choose. When the user connects to the Citrix servers, the Load Balancing Service makes the connection to the least busy server. From the user’s perspective, connecting to a “server farm” of six servers is just the same as connecting to a single MetaFrame server. If a server fails or is made unavailable for maintenance purposes, users will connect to one of the remaining servers.

It was desired to provide users with a consistent environment, regardless of which MetaFrame server they log on to. This included a user’s default printer, last documents accessed and Web favorites. This was achieved by using roaming profiles, stored on the Active Directory Domain Controller (DC). When a user logs on to one of the MetaFrame servers, the user’s profile is downloaded from the DC and saved back to the DC when the user logs off.

To secure the six Terminal Servers and to provide a list of application icons for each user, Group Policies were used. All six Terminal Servers were placed in their own Active Directory Organizational Unit (OU), to which a Group Policy was assigned. See 4.4, “Group Policy Object and Profile configuration” on page 32 for more details on Group Policies.

All user data was stored on separate file servers. Applications were installed identically on each of the MetaFrame servers. A single DLT tape drive was installed in the Domain Controller to back up all the MetaFrame servers nightly over the network.

The customer performed network bandwidth capacity planning and found that ICA traffic was present on the network 60% of the time for the pilot group. Using our bandwidth recommendations, 12 Kbps (0.6 x 20) was allocated for each remote user. So, for 50 users accessing Citrix from a remote location, the recommended CIR for the frame-relay network would be 600 Kbps. Under the ICA client’s MetaFrame Group configuration setting, the TCP/IP address of the ICA Master Browser was entered. All ICA clients configured in this way will contact the ICA Master Browser server for published application information rather than
broadcast to look for the ICA Master Browser. This enables the remote clients to work correctly in a WAN environment. Finally, we informed the customer that users, particularly those working across a WAN, would obtain increased performance by having the application use only 16 colors, and also by activating bitmap caching on all ICA clients.

3.3.1 Printing

Printing in a multiuser environment can be more troublesome than on most Windows NT networks. Although some printer drivers will apparently load correctly on your Terminal Server, system instability or blue screens may result because manufacturers’ drivers usually do not support a multiuser environment.

Through experience it has been found that you should only use the printer drivers that are shipped with Windows Terminal Server. We also recommend this for Windows 2000 Terminal Server. The drivers supplied with Windows 2000 are multiuser capable. Some vendors are now supplying multiuser compatible printer drivers.

3.3.2 UPS configuration

All Netfinity servers in our design for this customer were protected by American Power Conversion uninterruptible power supplies (UPSs). Netfinity UPSs are available as rack-mountable components and, because they are the heaviest components, these were placed in the bottom of each Netfinity rack.

Each Netfinity 5600 requires two power cords and has a power consumption of 500 Watts. The SU-3000RmiB UPS will typically keep a single Netfinity 5600 server operational for 40 minutes in the event of a power failure.

We can therefore calculate the run time for this UPS when it is providing power to four similar servers:

Run time = 40/ 4 = 10 minutes.

This provides sufficient time to keep four servers powered up long enough either for power to be restored or for the servers to be shut down properly.

The UPS can communicate with three servers, using APC’s PowerChute software to manage them. The UPS shut down time should therefore be set to about eight minutes or so, to allow enough time for the shut down processes to complete.

For more information about APC UPSs, see:

http://www.apc.com/

3.3.3 Rack configuration

IBM provides a tool called the Netfinity rack configurator which can be downloaded from:


This tool is used to help arrange the UPSs, servers, keyboard trays and flat panel monitors in the IBM 42U racks.
Chapter 4. Software installation and configuration instructions

Detailed installation and configuration instructions for Windows 2000 Terminal Services, Citrix MetaFrame and a number of common applications are provided below. You can use these installation and configuration instructions to help you install and configure your own servers.

4.1 Windows 2000 and Terminal Services installation

We recommend that you consult the IBM redbook Netfinity and Windows 2000 Integration Guide, SG24-5319, for assistance with installing Windows 2000 on IBM Netfinity Servers. The steps below provide our configuration suggestions in particular reference to Windows 2000 Terminal Services.

Follow each step below in sequential order:

1. Create a system partition of 2048 MB, and format the partition as NTFS.

   Note
   You must format the partition as NTFS so that important file security is applied to the system directory at the end of the installation. Do not format the drive as FAT and convert to NTFS at a later stage, as this will not apply the security required.

2. Enter the appropriate Regional Settings and Input Locales when prompted.

3. Set the partitions and drive letters as we suggest in Figure 11.

   You can create an E: FAT partition of size 2048 MB to begin with, and then create an NTFS D: drive from the remaining space. The E: drive is formatted with the FAT file system so it can be used to store images of the C: and D: drives. Images can be made to assist in disaster recovery situations by using software such as Symantec’s GHOST.

4. Click on Start > Programs > Administrative Tools and select Configure Your Server. You will be shown the window in Figure 12 on page 26. Select Application Server and click on Terminal Services.
5. On the Terminal Services page, select **Start the Windows Component Wizard**. This will then start this Wizard, which allows you to install the Terminal Services components as shown in Figure 13 on page 26.

6. Select **Terminal Services** for a member or stand-alone server which will provide multiuser services.
7. Select **Terminal Services Licensing** for a domain controller which will manage the Terminal Services licensing for your domain or enterprise. Terminal Services Licensing cannot operate on a member or stand-alone server. Click **Next** to continue.

8. Select one of the two modes that Terminal Services can operate in, as shown in Figure 14 on page 27. Click **Next** to continue.

![Figure 14. Terminal Services mode window](image)

9. Select the default permissions for application compatibility as shown in Figure 15 on page 28.

By selecting the second option **Permissions compatible with Terminal Server 4.0 Users**, additional rights to **Modify** and **Write** to the **Program Files** folder on your server, and access to the registry are granted to all Terminal Server users. We have found that most Windows 32-bit applications such as Office 97, Lotus Notes and Outlook work well using the higher security mode. We therefore recommend that you select **Permissions compatible with Windows 2000 Users**.

If an application requires higher level permissions to the file system, then you can increase this as required. We recommend the program FileMon for Windows NT from Sysinternals ([http://www.sysinternals.com](http://www.sysinternals.com)) to assist you in determining which files are accessed by each application. You can then grant higher permissions to specific files as required. This is a better approach than granting all users full control to server application directories, which may result in applications being modified or deleted.

Click **Next** to continue.
10. Click Finish when prompted and then click Yes to restart the server.

11. When the server has restarted, copy the I386 directory from the Windows 2000 Server CD-ROM to the D: drive of the server. This allows components to be added in the future without the need to insert the CD-ROM.

12. In Control Panel, double-click the System icon, then select the Advanced tab and click Performance Options...

13. Click the Change... button and set the initial and maximum paging file size to 1.5 times the total amount of physical RAM. For example, if the server has 1024 MB of RAM, then set the initial and maximum paging file size to 1536 MB. We have found that if the paging file is too small, even with large amounts of physical RAM in your Terminal Server, you can still get virtual memory errors. Click OK to save the Virtual Memory settings.

14. Select the Startup and Shutdown tab and set the System Startup and Recovery options as shown in Figure 16:
15. Click **OK** to save the System Properties settings.

16. Click **No** so that server shutdown does not occur.

17. In Control Panel, double-click the **Network and Dial-up Connections** icon.

18. Right-click the appropriate Local Area Connection and select **Properties** on the pop-up menu.

19. Select **File and Printer Sharing for Microsoft Networks** and click **Properties**. Change the settings to those shown in Figure 17:
20. Click **OK** to save the Server Optimization settings.

21. Click **OK** to close the Local Area Network Properties.

22. In Control Panel, double-click the **Display** icon

23. Select the **Settings** tab, then click **Advanced...**

24. Select the **Adapter** tab, then click **Properties**.

25. Select the **Driver** tab, then click **Update** to start the Update Device Driver Wizard.

26. Click **Next**, then **Next** again to start a search for a suitable driver for the video adapter.

27. Insert the appropriate IBM Netfinity video drivers for Windows 2000 and click **Next**.

28. Click **Next** again to install the driver.

29. Click **Finish** when complete.

30. Restart the server when prompted.

31. Set a system screen saver such as the **Default Screen Saver** which does not consume much CPU and which sends negligible screen updates to remote Terminal Server users.

### 4.2 Windows Terminal Server configuration

1. Log on as Administrator and start the registry editor: regedt32.exe. Locate the following registry key:
   HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\Winlogon
   and set
   Don't Display Last Username to the value 1.
   This registry entry prevents the display of the name of the last remote user who logged on to the Windows 2000 Terminal Server. We recommend this setting for increased user account security.

2. Create a directory called \SPOOL on the D: drive.

3. From the Start menu, go to Settings > Printers > File > Server Properties and select the Advanced tab.

4. Set the following spool configuration for WTS to spool all printing to the D: drive.

   ![Print Server Properties](image)
   Figure 18. Changing the server's spool folder to D:\SPOOL

5. By default the Windows 2000 directory permissions are set to secure each directory from unauthorized user access. Browse the root directories on each drive and inspect the security settings. Ensure that users do not have Full Control, Write or Modify rights where they are not required.

### 4.3 MetaFrame installation and configuration

Installation of MetaFrame is straightforward and requires little user input. The following list describes the steps of the installation process:

1. Log on to the Windows 2000 Terminal Server as an Administrator.
2. Insert the MetaFrame 1.8 CD-ROM into the server.
3. Allow the installation menu for MetaFrame to automatically start.

4. Click **MetaFrame Setup**.

5. Install MetaFrame license information if available. Otherwise this can be entered at a later stage.

6. Enable the protocols required for your environment.

7. We recommend that you do not remap the Terminal Server drives when given the option to do so.
   
   Remapping the server’s drives to M:, N:, and so on (for example) allows users to access their own system’s drives through the server’s Windows Explorer, as letters C:, D: and so on, which is convenient. However, we recommend hiding the server’s important drives from the users (see 4.4.2, “Group Policy Objects” on page 35) and the client’s own drives are clearly labelled as such, which minimizes the inconvenience of them being at the “wrong” drive letter when accessed through the Terminal Server.

8. Restart the WTS when prompted.

### 4.4 Group Policy Object and Profile configuration

Follow each step below to configure and secure the Windows Terminal Server installed in 4.1, “Windows 2000 and Terminal Services installation” on page 25.

#### 4.4.1 Windows 2000 Profiles

The Start Menu in Windows 2000 provides the user with a number of applications and system configuration tools as seen in Figure 19:
We recommend that users be supplied with a simplified Start menu that provides access only to those applications required to perform their work. You should remove access to applications which are used to configure the server or perform administrative functions, such as Command Prompt and Administrative Tools.

Under Windows 2000, all users profiles are stored in the C:\Documents and Settings folder. Using Windows Explorer:

1. Go to Tools > Folder Options...
2. Select the View tab and click the radio button to Show hidden files and folders.
3. Click OK to close the Folder Options... window.

You will now be able to see the hidden folder called Default User. When a new user logs on to the server, the Default User profile is used as a template to create a new profile for the user. Editing the Default profile to remove items in the Start menu will ensure that new users are set up without access to the removed items. Before deleting items from this folder you may want to make sure you have a backup copy available in case you later decide to restore some features.

To edit the default user profile, browse the Default User folder using Windows Explorer and remove those folders and program icons which you do not want your users to access with Terminal Server. In Figure 20 we are removing four...
programs from the Default User profile, so that new Terminal Server users will not have access to these programs.

Another approach is to customize a template user account and copy the settings to the Default User. Here are the steps we suggest:

1. Create a special user account called Templateuser, for example.
2. Log on to the server using the Templateuser account.
3. Customize the Start menu, application settings, screen saver, and desktop color to suit your preferences.
4. Log off the terminal server and log on using the Administrator account.
5. In Control Panel, double-click the System icon and select the User Profiles tab of the resulting window.
6. Select the Templateuser profile from the list and copy it to the C: \Documents and Settings\Default User folder. Now all new users who log on to the Terminal Server will get the same settings as those set up for Templateuser.

After making changes such as those described above to the Default User profile, you will notice that Terminal Server users still have access to a number of important folders, such as Administrative Tools. These folders are provided to the user from the All Users profile. Application shortcuts placed in the All Users profile are available to all Terminal Server users. We show you how to use a Group Policy Object to hide icons in the All Users profile from users in 4.4.2, “Group Policy Objects” on page 35. In this way you will provide a simplified set of applications for your Terminal Server users to access.

Roaming user profiles allow users to move between different Terminal Servers and maintain the same environment and preference settings. To enable a Roaming Profile for a user, first click Properties for the user object in the Active
Directory. Then select the **Terminal Services Profile** tab. Finally, enter the profile name, as shown in Figure 21, and click **OK**:

![Figure 21. Domain Users Terminal Services Profile location](image)

### 4.4.2 Group Policy Objects

In Windows 2000, Group Policy Objects (GPOs) allow administrators to control users’ desktops and to secure Terminal Servers. GPOs are linked to selected Active Directory containers such as sites, domains and organizational units (OUs). Looking at the screen captures in Figure 22 on page 36, you can see the Active Directory configuration for the fictional company acme.com.
A GPO is defined for the domain acme.com by selecting the Properties of the acme.com object. This will display the GPOs for acme.com as shown in Figure 23 on page 37. Policies are applied in the order: Local Group, Site Group, Domain Group, and, finally, Organizational Unit. Using the example above, users Bob Smith, Ted Jones and Michelle Sargent will have the acme.com policy applied unless group policies are defined for lower OUs such as accounts or sales. The policy applied will be the same regardless of which computer or Terminal Server they log on to in the company.

In many cases, you will want to have a more secure policy for your Terminal Server. The solution is to apply an alternative policy when a user logs on to a particular computer. To do this, create an organizational unit for your Terminal Servers as shown in Figure 22. Our example shows our Terminal Server is located in the organizational unit acme.com/resources/terminal servers. For this OU, also create another Group Policy with the settings you want applied for all Terminal Server users.
Ensuring that users have sufficient freedom on their own PC, while providing adequate protection to the Terminal Server is achieved through use of the loopback processing mode.

In Figure 24 on page 38, you can see the Group Policy for the acme.com/resources/terminal servers OU. Set the User Group Policy loopback processing mode to Enabled with a mode setting of Replace. Now when users log on to a Terminal Server whose computer object is in the acme.com/resources/terminal servers OU, they will receive user policy settings based on the computer object location, rather than the user object location. You must shut down and restart your Terminal Server for the loopback processing mode to take effect.
Table 4 below lists some suggested Group Policy Object settings to control the user’s desktop and secure your Terminal Server. Review the online help in the Microsoft Management Console for detailed explanations of these settings.

### Table 4. Terminal Server Group Policy Object settings

<table>
<thead>
<tr>
<th>Policy</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Group Policy loopback processing mode</td>
<td>Enabled, mode setting of Replace</td>
</tr>
<tr>
<td>Delete cached copies of roaming profiles</td>
<td>Enabled</td>
</tr>
<tr>
<td>Remove Run menu from Start Menu</td>
<td>Enabled</td>
</tr>
<tr>
<td>Do not detect slow network connections</td>
<td>Enabled</td>
</tr>
<tr>
<td>Disable and remove links to Windows Update</td>
<td>Enabled</td>
</tr>
<tr>
<td>Remove common program groups from Start Menu</td>
<td>Enabled</td>
</tr>
<tr>
<td>Disable and remove Shutdown command</td>
<td>Enabled</td>
</tr>
<tr>
<td>Disable changes to Taskbar and Start Menu Settings</td>
<td>Enabled</td>
</tr>
<tr>
<td>Add Logoff to the Start Menu</td>
<td>Enabled</td>
</tr>
<tr>
<td>Disable Active Desktop</td>
<td>Enabled</td>
</tr>
<tr>
<td>Disable Deletion of Printers</td>
<td>Enabled</td>
</tr>
<tr>
<td>Disable Addition of Printers</td>
<td>Enabled</td>
</tr>
<tr>
<td>Hide these specified drives in My Computer</td>
<td>Enabled, Restrict A, B, C and D only</td>
</tr>
</tbody>
</table>
Explaining all of the features of Group Policies is beyond the scope of this document. For more details on how to create a Group Policy Object refer to the Microsoft document *Step-by-Step Guide to Understanding the Group Policy Feature Set*. This can be found at:


Useful information can also be found on this Web page:


4.5 Application installation and configuration

It is a requirement of Windows 2000 that all applications are installed using the Add/Remove Programs function in the Control Panel. This ensures that application settings are configured for a multiuser environment. When applications are installed using this tool, the server is put into Install Mode automatically. In the Install Mode, WTS monitors how the application is installed, so that the application can be used in Windows Terminal Server’s multiuser environment. If you run the installation program without using the Add/Remove Programs function, the application you are installing may operate inconsistently for your users.

After an application has completed its installation, you will see the following screen:

![Figure 25. WTS After Installation window](image)

Click the **Next** button and you will see the final screen (Figure 26 on page 40). It is imperative that you follow the instruction to click the **Finish** button, regardless of whether the installation completed successfully or not, as this turns off Install Mode and returns the Terminal Server to Execute Mode.
Some applications must also have compatibility scripts executed after they are installed. These “compatibility scripts” are provided by Microsoft to make some final changes to applications so they run in multiuser mode more efficiently. For example, the compatibility script for Microsoft Office 97 is called C:\WINNT\Application Compatibility Scripts\Install\MSOFF97.BAT. This script is provided with WTS and performs some final registry changes for Office 97 in a WTS environment.

All applications must be installed from an Administrator account. Also ensure no users are currently accessing the server. You can prevent users from logging on to the server by using the MetaFrame Administrator program, or by simply disconnecting the server from the network.

4.6 Application installation and configuration examples

In this section, we provide sample installation and configuration steps for a number of common Windows applications.

4.6.1 ServeRAID administration

This program is used to monitor the RAID disk sub-system of the local Netfinity server.

1. In Control Panel, double-click the Add/Remove Programs icon.
2. Click Add New Programs.
3. Click CD or Floppy.
4. Click Next.
5. Click Finish to accept the A:setup.exe program.
6. After the program has been installed, click Close on the Add/Remove Programs window.
4.6.2  Advanced system management adapter device driver

This program is a device driver that allows the adapter to communicate with Windows NT. When started this will allow Netfinity Services to display temperature alerts, BIOS events etc. This device driver comes in different versions for the Netfinity 7000 and Netfinity 5500 models.

1. In Control Panel, double-click the **Add/Remove Programs** icon.
2. Click **Add New Programs**.
3. Click **CD or Floppy**.
4. Click **Next**.
5. Click **Finish** to accept the A:setup.exe program.
6. You will be prompted with a screen showing you that the device drivers have been installed and started.
7. After the program has been installed, click **Close** on the Add/Remove Programs window.

4.6.3  Microsoft Office 97 SR2

This suite of programs is Microsoft Office 97 SR2, which provides word processing (Word), spreadsheet (Excel), a presentation program (Powerpoint) and database functions (Access).

1. Stop the WTS Licensing Service. If you do not stop this service you will see the following error “Setup cannot register MSJET35.dll in the system registry because an older version is in use. Close all applications and try again”. For more details, refer to Microsoft Knowledgebase article number Q193386.
2. In Control Panel, double-click the **Add/Remove Programs** icon.
3. Click **Add New Programs**.
4. Click **Next**.
5. Click **Finish** to accept the T:setup.exe program (assuming T: is the drive letter of your CD-ROM drive.
7. After the program has been installed, click **Close** on the Add/Remove Programs window.
8. To complete the installation for use with WTS, run the following program:
   
   C:\WINNT\Application Compatibility Scripts\Install\MSOFF97.BAT
   
   During execution of this file, you will be asked to set the drive letter to which the user’s home directory will be mapped. This is set in the compatibility file C:\WINNT\Application Compatibility Scripts\ROOTDRV2.CMD, which is opened in Notepad for you by the compatibility batch file.

4.6.4  Microsoft Office 2000

This suite of programs is the latest release from Microsoft to provide word processing (Word), spreadsheet (Excel), presentation graphics (Powerpoint) and database functions (Access). Microsoft has
determined that Office 2000 performs better on Windows 2000 Terminal Services, than it did on the older Windows NT 4.0, Terminal Services Edition.

1. Visit the Microsoft 2000 Resource Kit site at:


3. Customize the Windows 2000 transform file (TermSrvr.mst) to meet your needs.

4. In Control Panel, double-click the Add/Remove Programs icon.

5. Click Add New Programs.

6. Click CD or Floppy.

7. Click Next.

8. Click Browse.

9. In the root folder of the Office Disc 1, select setup.exe and click Open to insert setup.exe in the command line of the installation dialog.

10. On the command line, add the following two parameters after setup.exe, separated by spaces:
    
    TRANSFORMS="path\TermSrvr.mst"

    This command identifies the Terminal Server transform for Setup to use during installation. Specify the correct path to the MST file:

    /l* "%WINDIR%\Office 2000 Setup(0001).txt"

    This optional command places the Setup log file in the Windows folder, rather than in the %TEMP% folder, so that it is not deleted automatically by Windows.

11. Click Finish to start the installation program.

12. After the program has been installed, click Close on the Add/Remove Programs window.

13. By default, the Terminal Server transform (TermSrvr.mst) does not install any Office Assistants. After running Office Setup you can install the Motionless Office Assistant (Stiilogo.acs) included in the Office Resource Kit. This Office Assistant uses no animation, so there is minimal network traffic between the Terminal Server computer and the Terminal Client computer. For information about installing the Motionless Office Assistant, see Terminal Server Tools in the Office 2000 Resource Kit Toolbox.

### 4.6.5 Client Access Express

![Client Access Express](image)

This program is used to provide a terminal emulator for clients connecting to an IBM AS/400 server.

1. In Control Panel, double-click the Add/Remove Programs icon.

2. Click Add New Programs.
3. Click **CD or Floppy**.

4. Click **Next**.

5. Type the name of the installation program into the command line of the installation wizard:

   ```
   x:\CWIN95NT\EXV4R4M0\BASIC\SETUP.EXE
   ```

   where `x:` is the drive containing the installation files.

6. Click **Finish** to accept the A:setup.exe program.

7. When the window in Figure 27 appears, click **Typical**.

![Type of Installation](image)

**Figure 27. Client access installation window**

8. Disable the creation of a desktop icon and the display of the README file by clearing the relevant boxes.

9. After the program has been installed, click **Close** on the Add/Remove Programs window.

10. In Control Panel, double-click the **Client Access** icon.

11. Select the **Services** tab and, in the Service Level area, set When to check, to Never.

12. Any applicable Client Access Express service packs should be installed at this point.

13. After the installation, click **OK** on the Finish window to acknowledge that the application has finished installing.

### 4.6.6 Notes R5

Notes R5 provides e-mail and groupware services to users.

1. Log on to the server as Administrator and ensure no users are currently accessing the server.
2. In Control Panel, double-click the **Add/Remove Programs** icon.
3. Click **Add New Programs**.
4. Click **CD or Floppy**.
5. Click **Next**.
6. Run the Lotus Notes 5 install program setup.exe from the CD-ROM.
7. Click **Next** to continue on the first Notes install screen.
8. Click **Yes** to accept the Notes licensing agreement.
9. Enter the company name in the appropriate fields. Do not enter a user’s name in either field as data entered here will be seen by all users.
10. Click the check box **Shared install**.
11. Enter the destination folder as D:\APPS\Lotus\Notes.
12. Notes installation will now copy files to the hard drive.
13. Click **Finish** when completed.
14. Create a folder on the server called r5clienttemplate. Share the folder using the same name for the share and set Permissions to give Read access to everyone.
15. Connect the standard user’s home letter to this share. Enter the command: 
   ```
   NET USE U: \AUTS03\R5CLIENTTEMPLATE
   ```
   for example.
16. Run the D:\APPS\Lotus\Notes\setup.exe Notes installation program.
17. Click **Next** to continue on the first Notes install screen.
18. Click **Yes** to accept licensing of Notes.
19. Click **Next** to accept the existing Company name field.
20. Change the destination folder from C:\Lotus\Notes\Data to H:\Lotus\Notes\Data and click **Next**, where H: is the letter of all users’ home drive.
21. Click **Finish** when completed. Do not launch Notes now.
22. After the program has been installed, click **Finish** on the Add/Remove Programs window.
23. Using Windows Explorer, cut and paste C:\WTSRV\NOTES.INI (equivalent to moving the file) to the directory H:\Lotus\Notes.
24. Create a common desktop icon for all users to run Notes:
   a. From the Windows Explorer menu, select **File > New > Shortcut**.
   b. Enter D:\APPS\Lotus\Notes\Notes.exe in the location field and click **Next**.
   c. Enter Lotus Notes in the name field and click **Finish**.
25. Still in Windows Explorer, right-click on the newly created Lotus Notes shortcut.
26. Select Properties and then select the **Shortcut** tab.
27. Set the Start in: field to H:\Lotus\Notes.
28. Copy the contents of the r5clienttemplate directory (including the Notes folder within that folder) to each user's home directory (or H: drive). This is a standard Lotus Notes administration task.
Special Notices

This publication is intended to help technical staff and administrators to implement Citrix MetaFrame on IBM Netfinity servers running the Windows 2000 operating system. The information in this publication is not intended as the specification of any programming interfaces that are provided.

References in this publication to IBM products, programs or services do not imply that IBM intends to make these available in all countries in which IBM operates. Any reference to an IBM product, program, or service is not intended to state or imply that only IBM's product, program, or service may be used. Any functionally equivalent program that does not infringe any of IBM's intellectual property rights may be used instead of the IBM product, program or service.

Information in this book was developed in conjunction with use of the equipment specified, and is limited in application to those specific hardware and software products and levels.

IBM may have patents or pending patent applications covering subject matter in this document. The furnishing of this document does not give you any license to these patents. You can send license inquiries, in writing, to the IBM Director of Licensing, IBM Corporation, 500 Columbus Avenue, Thornwood, NY 10594 USA.

Licensees of this program who wish to have information about it for the purpose of enabling: (i) the exchange of information between independently created programs and other programs (including this one) and (ii) the mutual use of the information which has been exchanged, should contact IBM Corporation, Dept. 600A, Mail Drop 1329, Somers, NY 10589 USA. Such information may be available, subject to appropriate terms and conditions, including in some cases, payment of a fee.

The information contained in this document has not been submitted to any formal IBM test and is distributed AS IS. The information about non-IBM (“vendor”) products in this manual has been supplied by the vendor and IBM assumes no responsibility for its accuracy or completeness. The use of this information or the implementation of any of these techniques is a customer responsibility and depends on the customer's ability to evaluate and integrate them into the customer's operational environment. While each item may have been reviewed by IBM for accuracy in a specific situation, there is no guarantee that the same or similar results will be obtained elsewhere. Customers attempting to adapt these techniques to their own environments do so at their own risk.

Any pointers in this publication to external Web sites are provided for convenience only and do not in any manner serve as an endorsement of these Web sites.

Any performance data contained in this document was determined in a controlled environment, and therefore, the results that may be obtained in other operating environments may vary significantly. Users of this document should verify the applicable data for their specific environment.

Reference to PTF numbers that have not been released through the normal distribution process does not imply general availability. The purpose of including
these reference numbers is to alert IBM customers to specific information relative to the implementation of the PTF when it becomes available to each customer according to the normal IBM PTF distribution process.

The following terms are trademarks of the International Business Machines Corporation in the United States and/or other countries:

IBM ®
AS/400
BookManager
Netfinity
Network Station

OS/2
RS/6000
ServeRAID
System/390

The following terms are trademarks of other companies:

Tivoli, Manage. Anything. Anywhere., The Power To Manage., Anything. Anywhere., TME, NetView, Cross-Site, Tivoli Ready, Tivoli Certified, Planet Tivoli, and Tivoli Enterprise are trademarks or registered trademarks of Tivoli Systems Inc., an IBM company, in the United States, other countries, or both. In Denmark, Tivoli is a trademark licensed from Kjøbenhavns Sommer - Tivoli A/S.

C-bus is a trademark of Corollary, Inc. in the United States and/or other countries.

Java and all Java-based trademarks and logos are trademarks or registered trademarks of Sun Microsystems, Inc. in the United States and/or other countries.

Microsoft, Windows, Windows NT, and the Windows logo are trademarks of Microsoft Corporation in the United States and/or other countries.

PC Direct is a trademark of Ziff Communications Company in the United States and/or other countries and is used by IBM Corporation under license.

ActionMedia, LANDesk, MMX, Pentium and ProShare are trademarks of Intel Corporation in the United States and/or other countries.

UNIX is a registered trademark in the United States and other countries licensed exclusively through The Open Group.

SET and the SET logo are trademarks owned by SET Secure Electronic Transaction LLC.

Other company, product, and service names may be trademarks or service marks of others.
Related publications

The publications listed in this section are considered particularly suitable for a more detailed discussion of the topics covered in this redbook.

International Technical Support Organization publications

The following publications are available and offer information on topics related to the subject of this Redpaper. For information on obtaining these ITSO publications, visit our Web site at:

http://www.redbooks.ibm.com/

- *Migrating IBM Netfinity Servers to Microsoft Windows 2000*, SG24-5854

Redbooks on CD-ROMs

Redbooks are also available on CD-ROMs. Order a subscription and receive updates 2-4 times a year at significant savings.

<table>
<thead>
<tr>
<th>CD-ROM Title</th>
<th>Subscription Number</th>
<th>Collection Kit Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>System/390 Redbooks Collection</td>
<td>SBOF-7201</td>
<td>SK2T-2177</td>
</tr>
<tr>
<td>Networking and Systems Management Redbooks Collection</td>
<td>SBOF-7370</td>
<td>SK2T-6022</td>
</tr>
<tr>
<td>Transaction Processing and Data Management Redbook</td>
<td>SBOF-7240</td>
<td>SK2T-8038</td>
</tr>
<tr>
<td>Lotus Redbooks Collection</td>
<td>SBOF-6899</td>
<td>SK2T-8039</td>
</tr>
<tr>
<td>Tivoli Redbooks Collection</td>
<td>SBOF-6898</td>
<td>SK2T-8044</td>
</tr>
<tr>
<td>AS/400 Redbooks Collection</td>
<td>SBOF-7270</td>
<td>SK2T-2849</td>
</tr>
<tr>
<td>RS/6000 Redbooks Collection (HTML, BkMgr)</td>
<td>SBOF-7230</td>
<td>SK2T-8040</td>
</tr>
<tr>
<td>RS/6000 Redbooks Collection (PostScript)</td>
<td>SBOF-7205</td>
<td>SK2T-8041</td>
</tr>
<tr>
<td>RS/6000 Redbooks Collection (PDF Format)</td>
<td>SBOF-8700</td>
<td>SK2T-8043</td>
</tr>
<tr>
<td>Application Development Redbooks Collection</td>
<td>SBOF-7290</td>
<td>SK2T-8037</td>
</tr>
</tbody>
</table>

Other resources

These publications and Web sites are useful sources of further information:

- *IBM Network Station Manager V2R1*, SG24-5844 (Redpiece)
Referenced Web sites

These Web sites are also relevant as further information sources:

- Citrix Systems: http://www.citrix.com
- Citrix Developer Network: http://www.citrix.com/cdn
- Microsoft Terminal Server: http://www.microsoft.com/ntserver/terminalserver
- Microsoft Terminal Services
- Product licensing:
  http://www.citrix.com/support/solpractices/docs/licensing.htm
- Group Policies in Windows 2000
- Sysprep
- The ThinNet: http://thethin.net
- Thin Planet: http://thinplanet.com
- IBM Network Station Web site: http://www.ibm.com/nc
- APC Web site: http://www.apcc.com/