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Virtualisation and Thin Client : A Survey of Virtual Desktop environments

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Virtualisation and Thin Client:

A Survey of Virtual Desktop Infrastructures

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Declaration

I certify that this dissertation which I now submit for examination for the award of MSc in Computing (Information Technology), is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

This dissertation was prepared according to the regulations for postgraduate study of the Dublin Institute of Technology and has not been submitted in whole or part for an award in any other Institute or University.

The work reported on in this dissertation conforms to the principles and requirements of the Institute's guidelines for ethics in research.

Signed:

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Tom Wall

Date: 01/09/2009

Abstract

As ICT and data processing systems have become ever more extensive and ubiquitous there has been widespread adoption of a distributed Client / Server topology to meet business and personal computing needs. The standard connectivity for a typical workstation is built around a Personal Computer linked to a nominated group of local nodes and Servers (Local Area Network), and via an external connection to myriad Internet resources worldwide. This model provides the knowledge worker and private ICT systems user with access to a comprehensive range of ICT services readily and efficiently, creating a global nexus of online computer users and their chosen ICT solutions and services. However, certain components of the ICT solution (including critical data and processing power) are exposed to fortuitous contact and risk of interference, misuse and theft due to poor security standards. In addition, the Client/Server units consume excessive energy, leading to poor ecological performance of up to one billion workstations worldwide.

A trusted synergy of newly available technologies - Virtualisation, Thin Client and an enhanced Remote Computing Protocol (RCP) interconnect - could now change this scenario significantly.

This survey examines some of the leading commercial Virtualisation and Thin Client technologies. Reference is made to a number of academic research sources and to prominent industry specialists and commentators. A basic virtualisation Laboratory model is assembled to demonstrate fundamental Thin Client operations and to clarify potential problem areas.

The objective is to examine these new developments from first principles, with reference to the underlying sciences. In addition to assessing the ecological and security benefits of the Virtualisation/ Thin Client technology, a number of themes emerge in the course of this survey and examination:

64-bit computing power and massive fast storage are now assumed as a given in the virtualised environment Data Centre (DC).

Adequate datacomms remains as a critical determinant of Thin Client computing.

Speed-of-light data transmission over fibre optic channel offers highest performance.

Further developments in fibre channel switching and WWAN datacomms may become increasingly relevant.

Acknowledgements

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1. Introduction

Computing as a science and as an industry must continuously regenerate in order to meet expanding human needs, to exploit ongoing research and development and to guard against hazardous and detrimental influences arising in the cyber environment. At a political level two serious concerns arise in recent years:

1. Energy Conservation: The developed world is implicated in proven environmental damage which is predicted to adversely affect the living conditions of the present and future generations. The Kyoto protocol (2005) and more recent proposals towards a Copenhagen Agreement in 2009 are political responses to the real concerns of people and calls to action by governments worldwide. The Data Processing industry is estimated to contain more than 1 billion workstations or PC's, with energy consumption in the range of 100 to 200 watts per unit. This energy consumption is roughly equivalent to that of total global air travel (Global Action Plan 2007), and is the source for 2% of global CO2 production (Fraunhofer Umsicht, Gloge *et al*. 2006).

2. Data Security: Recent high-profile examples of data loss and data theft, including loss of prison service staff information in the UK (*Home Office UK: loss of 5,000 prison service employees data – BBC July 2007)* contribute to growing concern about the volumes of personal data retained by various organisations, and the safety and confidentiality of this information. Again the ICT industry is implicated in that most data storage and data security disciplines are built around computing devices. Data Processing (DP) applications and associated data protection and security procedures are relied upon to govern and secure stored data. Failure, loss or theft of an ICT component can expose confidential information to unauthorised and malicious access.

Computing technology as an applied science is limited by the availability of suitable materials and processes to enhance the core technologies of Data Processing, Data Storage and Data Communication.

- *Processing*: Ongoing Developments in 64-bit Microprocessor architecture and Silicon switching will deliver an increasingly powerful CPU performance (Bass 2003), with an address space of up to 32 terabytes of RAM.

- *Storage*: Solid state hard disk technologies continue to enhance the performance of storage devices and Storage Area Networks (SAN). Recently available 250 GB USB memory devices are a measure of the ongoing progress in this area.

- *Communications:* Thin Client (TC) computing calls for a fast reliable link to deliver the hosted Virtual Machine (VM) from the Virtualisation Server to the remote client. Linking these devices is a component technology, Data Communications, which is limited by an absolute element of physics – the capacity of twisted copper strands, optical fibre or radio waves to transmit serial data reliably at increasing volumes and speeds. The intrinsic characteristics of the conducting medium will impose physical limits on the speed and capacity of data transmission.

Processing power is estimated to increase over time by a factor of up to 1.5 annually (Moore's Law). Kryder's Law States that storage density doubles annually (Adams et al. 2009).

Today this enables multiple virtual machines (VM) or platforms to be hosted on a single physical Server (Virtualisation), requiring only adequate Remote Computing Protocol (RCP) and datacomms technology to deliver the Virtual desktop service to remote users on any suitable Thin Client device.

It is proposed that the new Virtualisation and Thin Client technologies, mediated by broadband network links will have a very significant impact on our efforts to reduce energy consumption and to enhance data security throughout the ICT industry and for individual computer users. An examination of current Virtualisation models and features will be used to identify the practical advantages of the technology. Possible problem areas will also be identified, in the context of an examination of the relevant scientific principles and technical issues. A model of a virtualised learning lab environment is assembled to demonstrate the essential features of the technology.

1.1 The Technical Background to Virtualisation / Thin Client

To introduce the new ideas arising from Virtualisation and Thin Client (TC) technologies it is helpful to look again at the earliest models of computerised Data Processing (DP).

The first Mainframe computers were monolithic Computing Service providers, located within a strictly controlled environment, and connecting to the outside world through a Console or terminal (Often referred to as a Green Screen or Dumb terminal) and a Line printer.

A VT220 text terminal or Console

The RS-232 datacomms lines serving the Console and printer were essentially peripheral connections, in that the data line would not extend beyond approx. 100 metres due to RS232 Ground Loop limitations (Strangio 1997). Effectively the communication range and data access points were local. The Console was used for command and data input (Keyboard) and for the display of results (CRT Screen). All processing and data storage was confined to the central Mainframe unit. The Console provided a remote control panel, to keep the programmer / operator outside the protected DP area – the computer room. Typical data transmission rates achieved would be 19,600 Bits per second (baud) – quite adequate for the purely Ascii character-based input/output data streams occurring on these RS-232 lines.

Contrast this scenario with the standard ICT configuration in use today. The user's workstation (PC or other) is usually equipped with a powerful local processing unit and up to 250 GB of local data storage – far in excess of the resources available to the original Mainframe units. In addition, the PC is normally connected to a nominated group of local nodes and Servers (Local Area Network), and via an Internet connection to myriad Internet resources worldwide. Available data rates can be 10-100 Megabits per second (Mbps) on screened twisted (copper) pairs (STP) over Ethernet LAN (IEEE Standard 802.3), and typically 1 to 10 Mbps on Broadband WAN. It is clear that the current scenario provides a vastly more powerful and versatile Personal Computing environment. With this increased power and versatility comes a number of potential problems.

This dissertation examines two key disadvantages of the standard Client-Server architecture of Personal Computing - excessive energy consumption and inadequate security

A new upgraded architecture – Virtual Desktop Computing (VDC) – is proposed to address these disadvantages. The component technologies of VDC are:

Remote Computing Protocol (RCP) linking a *Thin Client device* (TC) to a central virtualised PC or *Virtual Machine* (VM).

The following chapters will attempt to clarify the potential of VDC and associated technologies to address these challenges, following a brief introduction below to the three component technologies.

The component technologies of Virtualised Desktop Computing (VDC):

(i) <u>*Remote Computing Protocol (RCP)*</u> in this dissertation refers to any one of a number of comparable remote desktop communication protocols currently in use, including Microsoft RDP, VNC, Citrix ICA, Sunray ALP and the open source ‘X’ protocol. These protocols define the data link between the Host Virtualisation Server and the Thin Client, and therefore are critical to the functioning of the VDC model. The RCP function is essentially “send clicks, get flicks”; that is the user’s keyboard and mouse input commands are sent to the remote host, which then returns the appropriate screen updates to the user’s screen. The RCP is also used for standard remote access to hosted systems and applications, not necessarily virtualised. Because VDC is based on centralising the complete PC or desktop environment, the data link between the remote user and the host is now more critical. Unlike the standard PC client/server model, with true Thin Client

there is no offline functionality. The RCP is therefore referred to as the ‘key enabling technology’ and also the ‘limiting factor’ in server-based computing performance (Nieh & Yang 2000).

(ii) *Thin Client.* Like the Console or ‘dumb terminal’ of old, the modern Thin Client requires only an input device (keyboard and mouse) and a Display unit (LCD screen), as shown for user ‘A’ in Figure 1 *VMWare © Virtualisation with Thin Client access using LAN/WAN*.

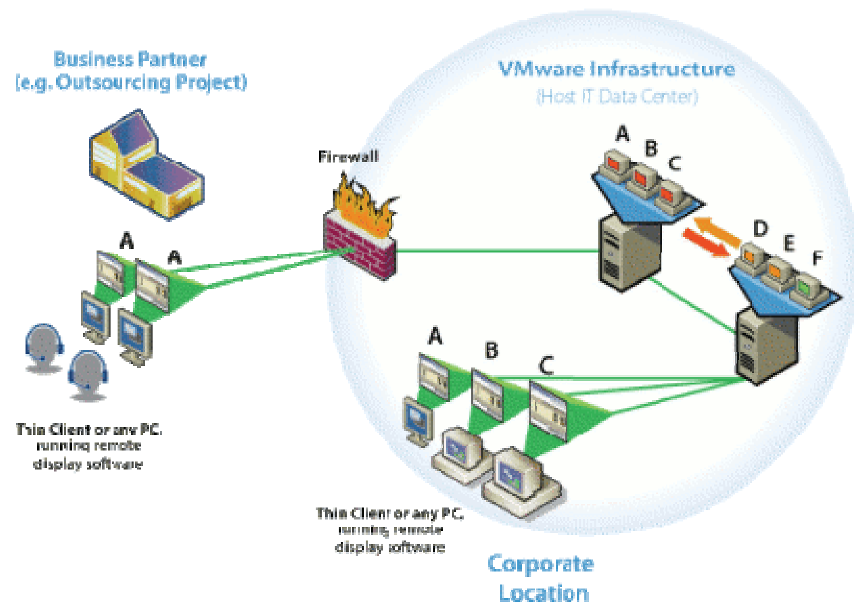


Figure 1: Sample VMWare LAN/WAN Infrastructure

VMware © virtualisation with Thin Client access using LAN/WAN.

The User’s customized computing environment (as per user profile) runs on the central Server/cluster (the *Host IT Data centre* in the diagram), which accepts data input to the PC session and displays outputs on the LCD Display via the Remote Computing Protocol (RCP) connection. A dedicated module or ‘portal’ at the client side provides the Thin Client network interface.

(iii) *Virtualisation* allows many typical PC sessions to run on a single physical device, here one or more secure Virtualisation Servers. The familiar PC desktop environment now runs on the central Virtualisation Server, with all data stored and protected within a high-specification purpose-built Data Centre (DC). The data lines that normally connect to the Display, the Keyboard and the Mouse (KVM lines) from the local PC are now running directly back to the Virtualisation

Server, encapsulated within RCP over TCP-IP and Ethernet (IEEE Standard 802.3) or other data transmission, for example Wireless IEEE 802.11*x* WLAN.

At the Server a user-specific desktop session is hosted as a Virtual Machine (VM), alongside many other similar virtual PC's serving other users.

In this new scenario the Thin Client device (thin because it does not require a full motherboard PCB or storage disks, therefore no beige box under or on the desk) is only required to forward keyboard and mouse input to the Server session, and return the screen update commands from the Server to the LCD screen.

This is the new Thin Client /Virtualisation version of the personal computing session, hosted on a secure Virtualisation Server and presented on a low-energy robust Thin Client device, similar in concept to the original console device used in the mainframe era.

A working model of this technology will be described in Chapter 4 together with a number of operational test procedures.

1.2 Energy Conservation and Data Security

Security of ICT systems is a concern to all ICT users and stakeholders worldwide.

In many cases total security of systems is being considered as unachievable, with advanced security applications (Anti-virus (AV), Intrusion Detection (ID), Firewall monitors, Service lockdown) acknowledged as maintaining a barely adequate level of protection. It is generally accepted that even protected networked systems host at least some illicit or rogue processes. Unless these processes are specifically intended to cause interference or serious damage, it is quite possible that they will go undetected. In less protected systems, the prevalence of unsecured software and data is such that the user environment is fundamentally unmanageable and untrustworthy (Baratto et al. 2004).

A proposition of this dissertation is that the standard ICT model for Personal Computing (Comprising of local or mobile CPU and data storage with broadband link to nominated Servers and Internet) is unreliable and hazardous, due to the unmanageability of distributed and multiple-instance data, unsecured clients, illicit and malicious software and unprotected data resources. It is also proposed that the model is excessively energy-reliant. The standard PC in use today may consume up to 200 watts for the basic CPU and peripherals excluding LCD screen. On an estimated 1 Billion personal computers worldwide this is similar to the energy consumption of approximately 20 million family cars (1Kw=1Horsepower or 100cc), or to commercial aviation (Global Action Plan 2007).

This dissertation will suggest that a trusted synergy of the newly available technologies - Virtualisation, Thin Client and an enhanced RCP interconnect - could now change this scenario fundamentally.

Current research and developments in the variants of the Remote Computing Protocol (RCP) are examined, with some emphasis on the potential effects of new developments including PC over IP (stateless TC device, lossless transmissions), Multimedia re-direction (to reduce volume on RCP links) and a proposed new Net2Display standard. The analysis is extended to describe a number of leading Virtualisation and Thin Client technologies, arriving at an outline description of a potentially secure, trustworthy and energy-efficient ICT architecture for Personal and Business computing.

1.3 The Evolution of the Networked Computer

There has been a recognisable evolution in computer system architectures and network topologies over the last 50 years. The original Mainframe structure was designed as a *single system for many users* (Weiser 1998). The computing service was normally provided from a single ICT resource or 'computer centre' to many organisational units. For example a program was coded on to punch cards and run in an available time slot, with hard copy results being delivered to the requesting department.

Networked computing and the Client–Server model were developed during the 1970's and eventually gave rise to the prominence of the Personal Computer (PC), normally provided with a network link to nominated local Servers, and more recently with an Internet connection to a worldwide network of systems (The Internet and World Wide Web of sites or URL's). The Home PC also became popular, again availing of the Internet connection to provide an enhanced experience of personal computing. This model can be described as the *One Computer per Person* model, and has been the familiar and prevalent model for the typical computer user in recent years.

A new paradigm or way of understanding IT ("The third paradigm") has now emerged which is based on a view of *many computers serving many people.*

Alan Kay, Apple (Kay 1995)

Associated with several innovations in this field including Grid computing, Cloud computing, Service Oriented Architecture, Software as a Service (SaaS) and ubiquitous computing (Ubicomp), the general underlying principle is that Computing Services should now be available on demand, to any client using any suitable networked device.

("Everything as a service -XaaS") (Woodward *et al*. 2008)

The analogy of a national electricity grid is used to suggest a ubiquitous standard universal Computing Service or utility. This level of Internet Service provision has already been achieved in many areas such as Airline Reservation systems, Stock Exchange monitors and many online retail sites such as E-bay.com and Amazon.com. The common user experience today is that these types of Internet services are available as basic utilities from any computer anywhere.

Only in recent years has the concept of providing the complete computing environment (or the Desktop PC session) as a service become a real possibility. A number of research efforts combined with the ongoing exponential rise in computational capacity, throughput and bandwidth have made these advances possible.

Server Virtualisation has already become a norm, providing several segregated Server operating systems on a single physical Server unit, thereby achieving vastly improved utilisation of resources and very significant energy savings (Gatke 2008). Savings achieved in many industries, including a 2000-ton per annum reduction in Carbon emissions by ESB Ireland, are documented in Section 2.4.

Application virtualisation has been in use for many years (e.g. Citrix XenApp) making the line-of-business (LOB) application available to clients throughout the enterprise, while the execution and associated file storage is managed and controlled at the central Server or Data Centre.

The possibility of virtualising the complete PC environment (including OS, applications, user profile and data storage) and delivering the standard PC session (XP, Linux or other similar Personal Computing environments) to a Thin Client device over wires (LAN or WAN) has even greater potential for energy savings and enhanced security.

Virtual Desktop Computing initiatives (VDC) are now being developed by a number of the most prominent Software enterprises, including the following typical examples;

- *Microsoft*: MS Server 2008 Hypervisor including dedicated VM Management centre.
- *VMWare Inc*: Virtual Machine technology is available on VMware VDC using the proprietary ESX OS now incorporated within the newly-released vSphere suite.
- *Citrix-Xen Desktop.* Citrix provides full VDC using their ICA protocol in parallel with Ardence image and provisioning manager and Desktop Server hypervisor. Having acquired Xen Technology Inc., the popular Xen hypervisor, formerly freeware has now been added to Citrix technology (Citrix 2009).
- *Oracle* having now acquired the Sun Ray technology is likely to become an even more prominent vendor.
- *Ubuntu Linux* bundles the KVM hypervisor, the software that provides virtualization on the Linux OS.
- *Desktone:* Desktop as a Cloud service - See example schematic outline in Figure 2. This example shows how the user's personal computing environment can be stored at a number of secure DC locations, and made available for access from any online client device.

  In the Desktone example the PC session is provisioned by the Desktone Server cluster as a Cloud service.

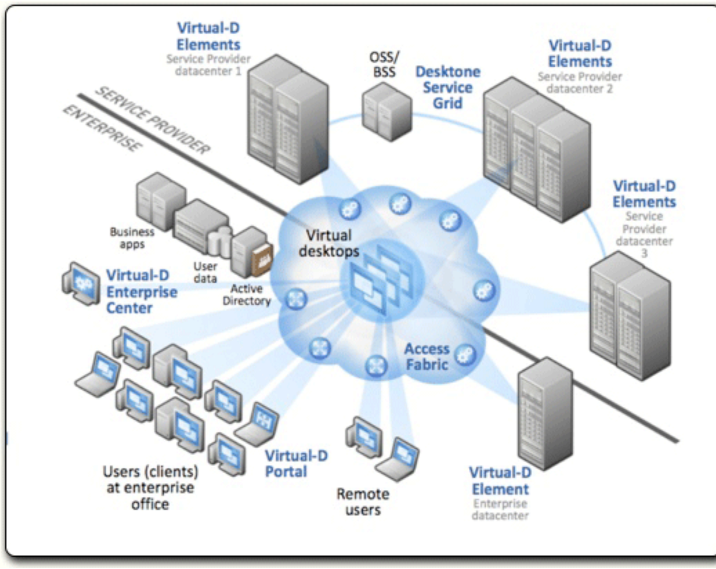


Figure 2: Desktone View of VDC as a Cloud Service

The Desktone © vision of VDC as a Service.

"The hosted image can be delivered from a number of sources (Grid), and is available to all online clients.

- *You virtualise your desktops wherever they are, replacing them with Thin Clients and mobile "thinnish" clients.*
- *All your software remains in the data center under your control, whether its desktop applications (Office Apps, e Thin Client) or client/Server apps.*
- *The virtualization takes place in the* ***cloud****, which means at one or more data centers run by service providers. They house the Server hardware and support it accordingly"*

Copyright Desktone © 2008 (Woodward *et al*. 2008)

The above are suggested as a selection only of some of the major innovative players in the industry. The 'big 3' are considered to be Microsoft, VMWare and Xen-Citrix. There are many smaller companies also working in this area of research. Virtual Desktop Computing (VDC) is seen as one of the most exciting initiatives in the computer industry at present.

If it can be shown that these new research efforts will produce a viable replacement for the physical PC throughout Industry and home computing, the potential for improvements to the ICT environment and for cost savings will be immense.

This is the objective of frontline R&D teams in the above major IT companies. It is also the theme and subject matter of this dissertation.

A survey of these leading Virtualisation products and the component technologies will be used in the following Chapters to examine the potential of Virtualisation/TC to deliver true VDC and a secure ubiquitous personal computing service.

1.4 Project Aims and Objectives

The aim of this project is to research and describe the current status of Virtual Desktop Computing (VDC) initiatives and of their component technologies Virtualisation, Thin Client and the RCP interconnect protocols. The findings will indicate if virtualised desktops are capable of replacing the familiar standard PC units used in households, offices and factories worldwide. Further to identify those sectors where the VDC alternative would be most suitable and acceptable, and also particular configurations or environments for which VDC would be unsuitable (Examples include CAD, 3-D rendering and motion video applications) (Lai & J. Nieh 2002)

To enable a hands-on study of a typical VDC configuration, it is proposed to build a basic VDC model or simulation of an academic learning laboratory.

The model will be used to

a) Demonstrate fundamental virtualised desktop and Thin Client features and operations.

b) Compare standard Thin Client operations with PC performance, with particular reference to multi-media, video and graphics-intensive applications over RCP.

c) Demonstrate the use of an 802.11*x* WLAN wireless Thin Client as a 'ubiquitous' windows XP session

The user desktop machine or device will be a proprietary Thin Client low-energy device (maximum 100 watts on load, 10 watts quiescent). A total of 3 clients will be provisioned from the Virtualisation Server, which will host 3 instances of standard desktop OS and applications (1 MS XP, 1 MS Vista, 1 MS Win7). This is to demonstrate the main advantages of the Thin Client for learning lab configurations as outlined by Miller and Pegah:

"*The low utilization statistics indicate that workstation consolidation could achieve great savings in infrastructure, networking, power consumption, and maintenance costs. In addition, we would spend less time in deployment, security, and fault isolation without compromising performance*. ("Workstation Consolidation") (K. Miller & Pegah 2007)

The Lab model will allow an authorised user to access any one of the desktop environments from any one of the Thin Client devices. Standard computers running equivalent terminal emulator software can be used to simulate a Thin Client, in the event that TC devices are unavailable during test sessions.

A study of this model together with research into the performance of VDC in industry and business will lead to an evaluation of the potential advantages of VDC as compared to the current Client-Server architecture. Special attention is given to energy consumption, ICT security provision and the enhanced RCP protocols, being the 3 determining factors underlying the potential advantages of VDC (Baratto et al. 2005).

Exact performance comparison between existing software and protocols is not possible in most cases, being proprietary and closed-source (Lai & J. Nieh 2002).

Therefore a task-completion evaluation method as described in Yang (Yang et al. 2002) using a practical test of the systems responsiveness (file download and Google search engine) is used to test the basic performance of Thin Client against standard PC performance. In practice, as most TC's today are IP-based with resident or embedded OS, there is usually no discernible response difference except where special graphics features such as 3-D and motion video transfers (RCP overload) are involved. The test upload and search operations execute on the Virtual Machine and the results screens are copied over RCP in the normal way to the TC with minimal delay. These processes are almost identical to the comparison search and upload carried out directly from the host server or PC browser. The tests are included simply to demonstrate the similarity to standard PC operations, and any variations are attributable to normal network loads except where RCP overload occurs.

A further test of the VDC model will then involve the display of motion video and Live TV on a standard PC and over RCP on the Thin Client. Known problems of latency and RCP overload will be demonstrated and possible solutions identified (Ocheltree *et a*l. 2007). Task completion tests will be used to compile aggregate results for comparison over different platforms. Variations in performance will be identified by the aggregate results and by (QOS) subjective evaluation (Nieh & Yang 2000).

A mobile wireless (WLAN) Thin Client will be used to demonstrate the true 'ubiquitous' potential of the model, enabling access to a complete user's Windows XP environment from any part of the campus or WLAN precinct.

These basic tests are carried out in the PC desktop environment, with identical sequences performed on the TC. The results are recorded in Section 4.4 - Results tables.

1.5 The Scientific and Technological Perspectives

A new paradigm is defined as a new way of seeing and understanding a significant aspect of the world. In the ICT context, though much-heralded, an actual paradigm shift is extremely rare, and all the more worthy of study. If it can be shown and verified within reasonable probability that the VDC model can replace the ubiquitous PC box, the ICT landscape will have altered significantly (Kay 1995).

Proof that the complete PC environment can be hosted transparently and delivered over the wires on medium bandwidth (Ethernet 10 as a minimum) would fundamentally change the practice of ICT systems design. The consumer would be equally impacted, in terms of cost savings, sense of security and an SLA-type guarantee of reliable trustworthy computing at all times.

What may be more interesting in the long term is that the PC of old will become a metaphor, and the PC metaphor itself will gradually atrophy. The hosted Desktop will become a computer service alongside so many other services (Weinman 2007).

The familiar utilities bundled with today's desktop environment (Word Processing, Spreadsheet, Accounting, Database, E-mail, Contacts) may gradually be hived off to specialist Application Service Providers (ASP's) who will deliver applications to online Thin Client devices as standard online Services (Woodward *et al.* 2008). As the PC is migrated back to a central virtualisation Server, it may gradually lose its defining roles to the ASP specialists. Where local processing power and storage can offer a premium on performance and ease of use, the local PC box will be retained. If a virtual offering, either ASP or full VDC, can compete on these terms and offer the advantages of Virtualisation, the desktop utility suite may be at a competitive disadvantage, perhaps for the first time since its introduction.

The scientific challenges are summarized as follows :

Virtualisation of applications, Operating Systems and complete environments (Virtual Desktop Computing) are proven solutions scientifically and commercially. The challenge remains to host adequate numbers of PC sessions on a Server or Cluster, while protecting the application content and maintaining reliable responsiveness and performance levels as perceived by the user at the remote Thin Client location.

Thin Client devices are readily available either multi-purpose (Laptop, Tablet PC, PDA) or as dedicated units (including Igel, Sun Ray, HP, Wyse, Devon IT). Data Input is easily handled, requiring minimal bandwidth (a modem line at 56KBps is normally adequate for keyboard / mouse input). The screen display (VGA, XGA, DVI) presents a problem in that screen image must be continuously updated from the Server, requiring significant bandwidth, RCP processing and minimal latency. Presenting the visual image in real-time, as though the graphics processing were local, remains a challenge in terms of bandwidth utilisation. Research is ongoing as to how to reduce the data flow required to deliver the full Graphics display at the remote Thin Client, for example by building in local graphics processing components to the client -

"(d)transmitting the encoded video commands over the network to the Thin Client computer to be decoded by the client computer and processed using the video hardware capabilities of the client computer into one or more hardware calls for causing the client computer to display video associated with said video commands" (Baratto & Nieh 2005)

(See also Chapter 2.1.2: Thin Client becomes Thin OS)

For both Input and Display, assuming adequate bandwidth is available, there may still be the problem of latency. If the data round trip, from pressing the 'A' key on the keyboard, to its appearance onscreen at the Thin Client takes longer than approximately

100 milliseconds, this will be perceived as a problem to the operator (Dabrowski & Munson 2001).

<u>*Remote Computing Protocol*</u> (RCP) The process of interconnecting the PC session running on the Virtualisation Server to the user's Thin Client will be dependant on the efficiency of the RCP protocol and the underlying datacomms link. Work is continuing on new developments to enhance the RCP performance, particularly in compressing the Graphics content. (Baratto & J. Nieh 2005)

Assuming that processing time on the Virtualisation Server and presentation time at the Thin Client will continue to be reduced over time (given the advanced 64-bit CPU architecture and solid-state disk performance of current models), the success of Virtual Desktop Computing (VDC) will depend very much on how efficient the RCP can become. This in turn relies on the absolute speed and capacity of data transmissions achievable on typical network links, primarily screened twisted copper pairs (STP), fibre optic channel (FC), and UHF (300Mhz-4Ghz) radio signals.

The challenge is to achieve and maintain a "Lossless" transmission, essential for certain medical, security and CAD imaging applications, and desirable for high-quality motion video presentations. The RCP under load may compromise by dropping a percentage of video frames in order to retain voice and video synchronization at the expense of video quality (Qi & Dai 2006).

This compromise on the presentation of video or multimedia highlights the weakness of the RCP link and will be used in this study as the 'acid test' of RCP functionality. It will be seen that most normal screen content is presented without perceived loss to the user at the TC. However when video content is transmitted from the host over RCP to the TC device, the picture quality is seen to fail based on subjective assessments. This failure or 'overload' can also be demonstrated objectively by measuring the Frame drop or skip rate, giving an indication of how the RCP protocol is coded to omit non-essential content (adaptive updates) in order to stay in sync with the source (Nieh et al. 2000). This is an example of the essential trade-off or compromise in the RCP handling of motion video, driven by the need to refresh the complete set of pixels per video frame.

It should be noted that absolute fidelity to source is never achieved in graphics processing, from the camera lens through to the cinema screen. Good representation is achieved for example by the broadcast signal reaching the antennae of all TV consumers in near real-time (Live TV over wireless UHF broadcast). Acceptable 20 to 25 frame-per-second video reproduction can be delivered to the primary host over WAN broadband of 300 Kbps or better. Frame drops may also occur on this link, and it should be noted also that video lag, screen painting and similar overload can occur at the PC despite the presence of the local parallel bus and dedicated GPU.

When the video content is further relayed from the primary host to a Thin Client over a standard RCP link, the additional processing and data volumes will tend to overload the RCP session. The protocol fails to process and render the Video stream in real time, leading to losses and degradation of content. The protocol is designed to skip non-essential frames as much as possible, so that the viewer may not be aware of the loss in quality (QOS). This derogation from ‘lossless’ transmission is a measure of the intrinsic deficit of RCP processing and is used in several examples in this study.

(A practical test of the transfer of a Video presentation over RCP is described in Chapter 4.)

There are a number of phenomena (often referred to as Artifacts as viewed on the affected screen image) associated with these challenges and compromises which will be familiar to users of the technology. The performance of the video transmission is usually divided into temporal (Frames per Second) and Spatial (Image resolution, number of pixels, size of image, colour depth)

Colour depth: 24-bit Colour, allowing up to 256 levels for each of the 3 Red/Green/Blue (RGB) components yielding 16 million colour tones (3 bytes per pixel), is now a standard on PC LCD screens, driven from the local GPU card (Yang et al. 2002). On a Thin Client, 8-bit colour depth (1 byte per pixel) is normally permitted, to limit the file size over RCP (Nieh & Yang 2000). While 16- and 24-bit colour is available on high-performance devices (Sunray, Igel C300), the bytes-per-pixel payload will have implications for file size over RCP, requiring adequate bandwidth. For example, even at low resolution 800 X 600 24-bit colour, three bytes per pixel are needed to store 256 values for each of the primary Red, Green and Blue (RGB) colours, or 1.44 MB per frame. In practice, the RCP will adapt by reducing the colour depth where bandwidth will not support these file transfers, delivering the compromised graphics familiar to remote TC users.

The colour presentations on the TC are often recognized as below standard, although this may not be an issue for normal processing except in specialist art, CAD and reprographics tasks. Newer technologies such as multimedia redirection (transferring the graphics processing load for multi-media content to the TC) will help to alleviate this problem without a bandwidth penalty.

Screen Resolution: As for colour depth, the normal 1024 X 768 resolution may not be available on the TC, except with advanced units. If the higher resolution is selected, the RCP processing is increased and overload is more likely.

Frames per second: The normal transmission rate is estimated as 10 FPS while Video content is usually in the range of 20 to 30 FPS. (Madden, 2009).

Video lag, Video painting and Freeze frame: are seen to occur where the RCP processing lags the source signal. The onscreen image is seen by the user to be rendered in slow motion.

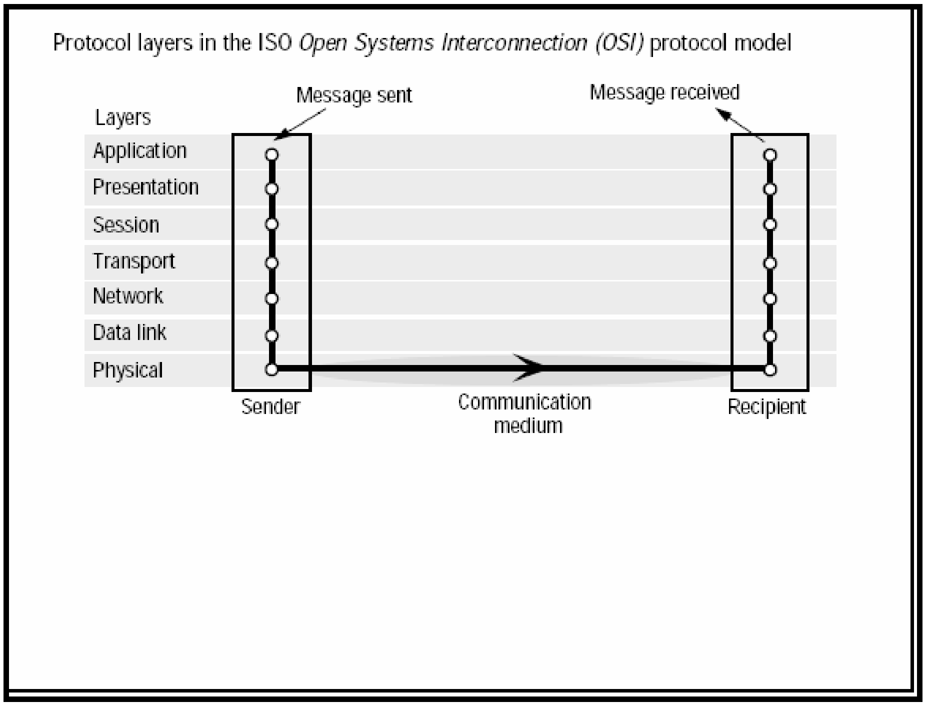
Resource Allocation: The RCP must be coded to achieve best possible reproduction using limited resources, "*dropping less important bits from the video stream, delivering lower quality but still recognisable images".* (Chaddha *et al*1995).

Given the difficulties and complexities of rendering graphics-intensive content, especially Video files, over the typical RCP remote connection there will be a good deal of focus on video performance throughout this survey and assessment. Many newer technologies are also mentioned as being a potential solution to the problems identified above. In the absence of a perfect datacomms channel (Infinite bandwidth and zero latency) these issues will also recur in the academic and scientific literature cited in the following Chapters.

A new RCP standard - Net2Display - is proposed by VESA to incorporate the facility for motion video, Audio, USB and keyboard/ mouse input (Ocheltree et al. 2007). This proposed standard may help in making VDC a universal option for the majority of Personal Computer users. Further improvements to Microsoft RDP V.6 and other standard RCP protocols may also have a significant impact in the near future.

Considered in the context of the ISO/OSI Network model, the typical RCP protocol runs at Presentation layer and avails of TCP/IP (or UDP for Sun Ray) protocol at the

Transport and Network layers. Ultimately, new scientific discovery at the Physical layer (STP cable, uhf wireless, Fibre channel) may be needed to deliver the complete fully-responsive RCP solution over WAN distances. Important new developments in Fibre channel will further enhance performance by building switching and routing into the optical layer, using tunable (colour coded) lasers. (John Dunne & Intune Networks Limited 2009).



Source: Pearson Education 2001(Pearson 2001)

Figure 3: 7 Layers of the ISO Open Systems Interconnect (OSI) Network Model

Figure 4: 7 Layers of the ISO Open Systems Interconnect (OSI) Network Model

RCP Protocols run at the Application level 7 but rely on the underlying Network and Physical layers to deliver adequate connectivity

(ISO - International Organization for Standardization 2009)

1.6 Summary of Deliverables

The initial tasks were to maintain contact with a number of major vendors and academic sources in this area of research, including visits to a number of local specialist suppliers. From an overview of available systems a selection of hardware and software was made to commence the assembly of a basic VDC system equivalent to a mini-Lab scenario as detailed in the project objectives in Section 1.4. Time was dedicated to maintaining communications with some of the main developers and vendors of the technology. Research was carried out on the most popular VDC options and a suitable technology and configuration for the model Lab system was chosen. As a practical issue, with some important exceptions Industry sources were generally unavailable for advice or comment on the scientific topics raised in this survey. Working mainly during early 2009, there were very serious economic and commercial issues to be contended with, and vendors were understandably averse to contributing time or resource to an academic survey of commercial technologies.

Time was also spent on experimenting with alternative software environments and equipment configurations to facilitate a number of tests and observations.

A wireless Thin Client model was configured and tested to work in parallel with the standard desktop Thin Client units. An assessment was then carried out to highlight:

a) The key enablers i.e. the features of the 3 technologies (Virtualisation, Thin Client, RCP) which function correctly and perform to specification within the VDC scenario

b) Any inhibitors identified in the process of testing the VDC model.

Special attention was given to technological features which appear to inhibit widespread adoption of VDC solutions. A survey of ongoing Research and Development in these areas of the technology was carried out. Liaison with R&D centres was continued to further clarify these topics. Some specialist advice and comments from leading enterprises (Igel, VMWare, Microsoft, Teradici, ESB, other) are included in the citations and Appendix A (Technical appendix) .

As a result of the ongoing research, model building and testing it was planned to arrive at final observations and an overall report on the project. On these findings is based the dissertation "*Virtualisation and Thin Clients: a survey of virtual desktop infrastructures*".

The combined observations from the implementation of a basic Virtualisation/TC Lab system were collated with feedback from recognized industry sources and academic research papers. These results are combined and presented in the following chapters. The overall performance of the model taken together with research and feedback from

Industry is used to inform the general assessment and summary contained in Chapter 5 *Evaluation* and Chapter *6 Conclusions*.

Throughout the research period, effort was focused on compiling the results of research into real-world VDC together with observations and results from tests carried out on the test systems. There is an attempt to maintain a balance between academic and scientific research findings and the voluminous promotional literature available from the manufacturers. Certain business and consultancy reports (IDC, Gartner, Ericom, McKinsey, ESB, Fraunhofer Institut Umsicht) were particularly valuable in pointing up the true gains associated with specific variants of the Virtualisation/TC model (e.g. Blade PC vs. virtual machine). Detailed findings by Igel/Fraunhofer also clarified the ecological arguments in favour of Virtualisation/TC.

This information is included in the relevant sections of the overall report, with full citation references and attributions.

Project deliverables

1. A working model of a learning Laboratory set up on a Virtualisation Server, with provision for up to 3 standard environments (XP, Vista, Win7), available to any 1 of 3 Thin Client locations.

2. Thin Client devices (3 No.) with facility to log in to any 1 of the 3 PC desktop sessions on the Virtualisation Server.

3. A Wireless (WLAN) Thin Client device to demonstrate ‘ubiquitous’ TC.

4. Final test results and reports incorporated into the M.Sc dissertation entitled

“*Virtualisation and Thin Clients: a survey of virtual desktop infrastructures*”

Resources used for the project In order to build the basic Virtualisation lab model, it was decided to use a standard Dell Poweredge SBS Server running MS Virtual Server 2005. This configuration is adequate for basic demonstration purposes.

Recommendations for further study (Chapter 6) suggests a full 64-bit Quad core Server to run MS Server 2008 R2 including Hyper-V as a full - specification Virtualisation Server to meet the needs of a typical learning lab for 30 students.

1.7 Thesis Roadmap

Chapter 2 provides a survey of the technical and scientific literature and includes an examination of relevant articles, including material from academic, industry, commercial and regulatory sources. This examination is used to highlight the potentials of Virtualisation technologies to address known failings in existing commercial and academic ICT systems.

Chapter 3 provides an introduction and review of the current range of mobile 'personal computing' devices. A broad spectrum of Thin Client technologies is enumerated and described in a tabular format. Standard Ethernet LAN datacomms is reviewed and the implications of VDC for network design. Infrastructure management tools built on the Virtualisation Hypervisor layer which now exists between the operating system (OS) and the hardware are also introduced.

Chapter 4 describes the assembly of a basic Virtualisation/TC demonstration model, together with a number of operational tests. Using the demonstration lab model, critical issues of bandwidth and signal (ping) latency are described and demonstrated in the context of Live TV and Video presentation over basic RCP protocols and datacomms channels (RDP and Ethernet LAN/WLAN).

Chapter 5 *Evaluation* provides a summary of observations arising from the survey of current Virtualisation and Thin Client technologies in Chapters 2 and 3 and from the demonstration Lab system operations and tests described in Chapter 4, with an emphasis on the practical implications for a real-world VDC implementation.

From Chapters 2 to 4 is summarised the main potential advantages of Virtualisation/TC technology. These advantages derive from research and developments at the scientific level, engineered and customised by vendors to deliver enhanced performance and cost savings to the user. A number of limitations apply to even the most advanced Virtualisation/TC technology, particularly in the areas of graphics processing and signal latency over WAN connections. The test results from Section 4 support the general findings and clarify some potential shortcomings.

Chapter 6 *Conclusions and Future Work*

The dissertation concludes with a review of the aims and objectives of the research followed by a consideration of the findings. This is followed by an assessment of the implications for ongoing research and development towards more secure and energy-efficient computing. From the initial survey of Academic and ICT Industry research into the 3 component technologies (Virtualisation, Thin Client, RCP) it is clarified that there is now significant ongoing research and development which will continue to impact on Virtualisation/TC performance in the enterprise environment, with significant new developments already in the pipeline.

Also identified are a number of research opportunities arising from the findings in chapter 5. Included are proposals to optimize on server cluster and SAN technologies, and to avail of fibre channel links to overcome bandwidth and latency issues.

The full set of conclusions and recommendations arising from the research project are here categorized into Administration, Staff Access, Energy and Security issues.

The Bibliography listing is followed by Appendix A, a technical appendix providing further background to the main technical issues addressed in the dissertation.

2. Virtualisation and Thin Clients - A Literature Review

(*Including studies from academic and industry sources, business consultancies, relevant EIA and IEEE standards and a detailed ecological evaluation of Thin Client computing by Fraunhofer Institut*)

2.1 Introduction: Open and Restricted Access to Scientific Sources

Research and development work in commercial ICT systems is often carried out by the principal Vendors (e.g. VMWare, Microsoft, Xen-Citrix, Neodata, Sun Ray (Oracle), HP, Teradici and Dell). While the scientific bases for new developments may well be in the public or academic domain, the proprietary technologies developed by Vendors may remain confidential or permit only restricted access. For this reason, the selections in this section are chosen to highlight the typical everyday ICT issues confronting standard business and academic organisations, and how the Virtualisation/TC technology may help to resolve these issues. There is also some emphasis on scientific research into the component technologies.

Section 2.1 describes the ICT research background and the electrical and electronic sciences underlying data communications (datacomms) with reference to relevant EIA and IEEE standards. It is in this area that research will be concentrated to overcome some of the most important limitations to Thin Client computing and datacomms applications in general. Brief details of new directions in Thin Client computing are also included. Section 2.2 includes relevant academic sources followed by an overview in Section 2.3 of some advanced commercial Virtualisation/TC technologies currently available. This is followed in Section 2.4 by details of a comprehensive study of the ecological implications of Virtualisation and Thin Clients carried out on behalf of Igel GmbH by the Fraunhofer Institut Umsicht.

2.1.1 The ICT Scientific Research and Development Background

Virtualisation and associated technologies continue to emerge as a potential new architecture for the personal and business computing environment. Although becoming familiar over recent decades through a number of developments (application virtualisation, Server consolidation, VDC) and despite well advertised advantages, there is still some doubt as to the universal acceptance of

Virtualisation/TC as a new norm for the ICT industry. Ongoing scientific research and commercial developments (especially in Microprocessor design, storage technologies and datacomms) continue to enhance the potential for new and more powerful variants of the basic Virtualisation model.

The main questions and reservations revolve around the key technologies, Virtualisation, Thin Client and Remote Computing protocol (RCP). It will be seen that the RCP component will be the primary driver for enhanced responsive Thin Client and ubiquitous computing into the future. For this reason it is intended to give a detailed description of the issues surrounding RCP and the underlying data communications (datacomms) in this section (with additional material in *Appendix A, Technical Appendix*), followed by a description of the proposed new Net2Display protocol in Section 2.2

a) *Virtualisation.*

Virtualisation can be defined as the capacity to interpose a presentation level accessible to the user but at one remove from the actual source system or source data level. In ICT this is often referred as a Hardware Abstraction Layer (HAL). A simple example would be the mapping of a Network Share to a local disk drive (The familiar H: Drive). For all intents and purposes the H: drive resides on the local PC, immediately available to the user for data storage and retrieval. In actuality, the corresponding share may be a disk or folder on a Server in a local or remote Data Centre (DC).

The Hypervisor (and Virtualisation support provided at Microprocessor architecture level) in modern Servers makes available the complete physical layer of the host machine to one or more virtual machines (VM), each of which map their physical requirements to local hardware entities. The Hypervisor generates a new platform for every new VM. In doing so, the Hypervisor can track and monitor resource allocation per VM, providing an in-depth system audit in support of overall DC and ICT infrastructure management.

For example, each of 4 Virtual machines may connect to the Network via the single physical network interface card (NIC) device, mapping 4 network nodes with individual IP addresses, against a single actual hardware device. Similarly, a sector of the available disk storage will be dedicated for each Virtual Hard Disk (VHD), providing one 'C: Drive' for each virtual machine (VM). Significant savings are being achieved in this way by consolidating groups of Servers to a single physical machine (or to a Server cluster), economising on power and cooling costs as well as optimising utilisation of the actual DC resources.

Virtual Desktop Computing (VDC) now extends these potential savings to the standard desktop unit, where the local PC 'beige box' will increasingly represent a security exposure and a disproportionate energy cost. Multiple virtual PC's can now be hosted on a single Server and presented on low-energy robust Thin Client devices throughout the workplace, and further afield where bandwidth and latency permit.

Will ICT users learn to accept a reduced local autonomy and responsibility offered by VDC. The knowledge workers' key assets, their data and computational power, is transferred from known local devices or systems, to a Server in a central or remote Data Centre, subject to the governance and control of a corporate or 3rd party organisation.

b) Thin Client. Ongoing developments (Teradici, Igel *et al*) confirm that the thin low-power device will function as a full PC or Workstation environment, subject to adequate network connectivity. Mobile Thin Client devices (Devon IT Safebook *et al*) will further promote these advantages. Nonetheless there is a delay in acceptance of the 'Network Device' as the complete personal or business computing solution.

The role of the Thin Client has also varied depending on the Vendor's technology, from pure Thin Client device to a local client with minimal embedded Operating System (OS) including some local storage and computational functionality. Examples include Linux, Win CE and full XP, embedded on Thin Client devices manufactured by Igel, Wyse, HP, Sun Ray, Devon IT and others (See also section 2.1.2). The local embedded OS may in itself become a security exposure (attack surface) but is generally fully locked down with no permanent data storage (RAM disk).

c) Remote Computing Protocol (RCP). As outlined in Section 1.1, the performance of the datacomms (see full details in Section 2.1.3) and link protocol supporting the TC/Virtual Server connection is critical to the overall success of the model. Questions of latency and bandwidth dependency still remain in relation to WAN connections.

To highlight in some detail the potential problems of remote data communications (datacomms) which are fundamental to Thin Client technology, it is interesting to consider a theoretical perfect datacomms channel.

If the data signal path (be it Screened Twisted Pair (STP) cables, Fibre Optic, 802.11 radio WLAN, UHF Satellite signals or other) had zero propagation delay (zero latency) and unlimited bandwidth, the communication between Virtualisation Server and Thin Client would then be instantaneous and 'Lossless', and there would be no perceptible delay in responsiveness to the remote user, other than normal disk-access and processor queue delays. The standard PC can avail of near instantaneous responses using the internal parallel data bus and dedicated Graphics Processing Unit (GPU) logic. In practice, where serial data must be transmitted in significant volume over distance, delays are introduced between input and response over and above the normal CPU processing and disk access wait times, which can often be close to negligible in this context (Data Centre 64-bit processing racks, multi-terabyte RAM space and high-speed Disk access). These transmission delays or latencies will remain a key issue.

For example, even using near speed-of-light datacomms (Fibre optic), a propagation delay of greater than 100 Milliseconds will occur at WAN distances beyond approx 25,000 kilometers. This is a finite limit of the laws of physics. Under less than ideal network conditions, and allowing for broadband capacity, switching and routing delays, achieving reliable Thin Client performance over global networks will remain a scientific challenge. Table 1 gives an indication of typical limitations of the standard network types:

Table 1: Network Types: Bandwidth and Latency Limitations

	Range	*Bandwith (Mbps)*	*Latency (ms)*
LAN	1-2 kms	10-1000	1-10
WAN	Worldwide	0.010-600	100-500
MAN	2-50 kms	1-150	10
Wireless LAN	0.15-1.5 km	2-11	5-20
Wireless WAN	Worldwide	0.010-2	100-500
Internet	Worldwide	0.010-2	100-500

Source: Pearson Education 2001 (Pearson 2001)

For further details of the impact of serial data transmission and signal latency please see also Section 2.1.3 and ‘RCP Issues’ in Item 1 of Appendix A, the Technical Appendix.

A relevant pointer in terms of the ‘perfect’ datacomms links suggested above is that Fibre channel (FC) offers minimal latency (almost speed-of-light transmission) and maximum bandwidth (upwards of 1 Gbps over 10 Kms) in single channel mode. Further developments in FC switching technology promise improved cost-effective performance (John Dunne & Intune Networks Limited 2009). Of special significance in this study is that FC is completely noise-immune in terms of EMF radiations and is also invisible to EMF induction detectors. This means that FC cables can not be ‘sniffed’ or interrogated by induction probes which allow the data to be copied in transit, as is the case with copper conductors and wireless transmissions. In the context of RCP datacomms, the advantages of FC as a medium to guarantee responsive Thin Client computing will recur under a number of headings. This potential is also included as a topic for further study in Chapter 6.

2.1.2 New Directions – Image Management and the not-so-thin Thin Client

The business benefits of Server Virtualisation – improved resource utilisation, better manageability of Data Centres and 30-50% energy savings – and the enhanced security associated with Virtual applications have been well known and availed of for many years. (Citrix applications, VMWare, Microsoft (MS) Terminal Services *et al*)

Now that these benefits are being introduced to the Desktop PC scenario, further enhancements have been identified. Simply storing and running a Virtual Hard Disk (VHD) or dedicated PC Image per user at the Server, and making the corresponding session available at a remote Thin Client will certainly increase the security and efficiency of Desktop deployments. It soon becomes apparent that the overhead of maintaining a specific Image or VHD per user requires significant software maintenance (as with the discrete physical PC model) and consumes typically 2-10 GB Disk storage per user (IDC, O'Donnell, Neoware 2007).

A new set of initiatives, which may be referred to as an Image Management Environment (VMWare View, NeoWare, Microsoft System Centre Virtual Machine Manager, Ericom PowerTerm, Citrix Provisioning Server *et al*) allows for provisioning of Image-based systems, making available User-specific sessions based on a Corporate or Organisation-approved master image or Template. One advantage is that a single 'Pristine' copy of the OS (e.g. Windows XP, Linux) is maintained as a code source, and re-deployed into each users environment from that secure source. This is a type of re-entrant code on a system-wide scale. The same principle applies to select applications approved for use within the Corporate environment. A secure Master copy for each application (e.g. MS Office) is maintained, and is deployed or 'published' into User sessions on demand or as approved. It is helpful to think of this Provisioning of the user's environment as a 'Composite' Image, derived from:

a) A 'pristine' OS – maintained as a single source, fully protected and up to date (1 per Data Centre)

b) Selected applications – Source code also maintained as a 'pristine' master image and copied into Client images as required (1 per application per Data Centre).

c) User Profile – the user-specific settings for the Desktop session, derived from the personal selections and configuration parameters chosen by each user (1 file per User).

d) User Data – The User's store of data, normally saved on local C:\ drive or on nominated network shares, here secured in a Data Centre repository with restricted access and high-level security provision as part of the Data Centre management suite (saved on SAN or equivalent protected storage).

Intensive development is ongoing by the main players to develop the full Data Centre Management and PC/Image Provisioning environment. These powerful new tools are built on the security and manageability of the Virtualised desktop and the detailed resource-allocation data available at Hypervisor level. In more recent releases the Composite Image can be downloaded or 'streamed' to a Thin Client (having local processing and storage facilities). This gives true PC-like responsiveness (local execution) with most of the advantages of Virtualisation/TC. The Provisioned Composite Virtual Image, streamed down to a local workstation, delivers a Virtual Client. When the device is closed down, there is no resident OS, program or data remaining as a local security exposure.

Note from IDC Industry consultants:

"The combination of desktop image streaming solutions, such as Neoware Image Manager, and thin-client devices in conjunction with Server virtualization software and Connection brokers is opening up the possibility of creating an entirely new category of connected computing devices: virtual clients. By leveraging the trends in the Datacenter along with the growing interest in centralizing client activities, for both security and manageability benefits, virtual clients offer an intriguing new opportunity for medium-sized and large businesses. They feature the flexibility and compatibility of individual PCs but retain the centralized control of Server-based solutions, In essence giving IT managers the best of both worlds. Though the name "virtual" may imply that something doesn't really exist, all signs point to virtual clients as a very real force to be reckoned with in the years to come." (IDC, O'Donnell, Neoware 2007)

It is noticeable with these recent developments that functionality has already drifted back from the Data Centre to the local workstation, with possible implications for the energy and security gains of the original Thin Client model. The modern Thin Client generally runs at least a minimal or embedded OS, with some local processing and storage, and with a Graphics rendering capability that is becoming more like the standard GPU/CGI card used in the full PC. (See also Section 3: the TC-PC Continuum). The Thin Client envisaged in these developments is beginning to resemble a compact PC, at a time when the Compact PC is becoming more energy-efficient leading to a possible convergence of functionalities.

Further details of these new variants of Thin Client computing are outlined in Section 3.

2.1.3 Serial Data Communications: Data Link Media/Transmission Protocols

2.1.3.1 Data Communications – the Technical context

The datacomms link between the Virtualisation Server and the user's Thin Client is one of the defining features of the Virtualisation/TC technology.

It has also been observed that the computational power and reliability of the DC Virtualised Server configuration is increasing at a phenomenal rate (Bass 2003), to the extent that additional computational resources (e.g. CPU Cycles and RAM Memory) can be assigned on demand to specific VM sessions presented on TC. In this way the Virtualisation Server can respond to and assist exceptional work loads at the TC, thus exceeding the capability of the standard PC which has normally a fixed maximum CPU and memory capacity.

The Thin Client devices themselves exploit the most advanced VLSI Electronic circuitry to minimise weight and power consumption. The absolute compactness (and portability) of the Thin Client is limited only by the user requirement for a fully functional and clear LCD Display, equivalent to the 1024 X 768 VGA / XGA / DVI standard resolutions of the Desktop PC model. As designs evolve, it is becoming apparent (Devon Safebook *et al*) that the sub-components of the Thin Client (PSU, NIC, Graphics decoder, USB Ports, other special Interface cards) can be housed within the frame of a typical 15-inch LCD Display. This is probably as compact as a true business Thin Client can become, except insofar as miniature LCD Displays (GSM Phones, 3G phones, PDA's, Tablet PC's and similar devices) can be used to meet business needs.

As there is no theoretical limit to the further development of the Virtualisation and Thin Client technologies, the potentials for further development and universal implementation of the Virtualisation/TC model is very much dependant on the quality and reliability of the serial datacomms interconnect.

2.1.3.2 Serial Datacomms – Morse to Ethernet (IEEE Standard 802.3)

Perhaps the earliest example of Serial Datacomms is the Morse code which encoded alphabetic and numeric characters as a sequence of pulses per character, giving rise to such popular international signals as an SOS call (3 slow 3 fast 3 slow). A standardised set of signals enabled the development of international telegraphy in the 19th century. For the first time text messages could be transmitted almost instantaneously between cities and countries. The similarity to modern Internet datacomms goes beyond the Morse character coding, which is functionally equivalent to modern ASCII and EBCDIC codes used universally today over all media to transmit characters.

The sender and recipient must be interconnected by a standard ‘current loop’ Voltage/Current/Resistance electrical circuit, the typical telegraphic two-wire circuit familiar in all developed countries for over 150 years. Once this circuit or channel is in place it is simple to encode a text string as a sequence of switch strokes at the sender’s side, which can be readily decoded, or possibly decrypted using a pre-arranged cipher at the receiver side. Using basic telegraphy encoding, this apparatus can be regarded as the first Thin Client. The sequence of transmitted current pulses is decoded into valuable information, be that a personal message or an up to date stock index report, sent and received for the benefit of the recipient.

Table 2: Sample of Morse Codes Table

A	• ▬	U	• • ▬
B	▬ • • •	V	• • • ▬
C	▬ • ▬ •	W	• ▬ ▬
D	▬ • •	X	▬ • • ▬
E	•	Y	▬ • ▬ ▬
F	• • ▬ •	Z	▬ ▬ • •
G	▬ ▬ •		
H	• • • •		
I	• •		
J	• ▬ ▬ ▬		
K	▬ • ▬	1	• ▬ ▬ ▬ ▬
L	• ▬ • •	2	• • ▬ ▬ ▬
M	▬ ▬	3	• • • ▬ ▬
N	▬ •	4	• • • • ▬
O	▬ ▬ ▬	5	• • • • •
P	• ▬ ▬ •	6	▬ • • • •
Q	▬ ▬ • ▬	7	▬ ▬ • • •
R	• ▬ •	8	▬ ▬ ▬ • •
S	• • •	9	▬ ▬ ▬ ▬ •
T	▬	0	▬ ▬ ▬ ▬ ▬

(Note: Pulse duration as used in Morse is not normally a feature of modern digital transmissions, but can be used as an analogue metric in special current-loop modulations).

Table 3: Sample of Ascii Codes Table

065 101 041 01000001 A
066 102 042 01000010 B
067 103 043 01000011 C
068 104 044 01000100 D
069 105 045 01000101 E
070 106 046 01000110 F
071 107 047 01000111 G
072 110 048 01001000 H
073 111 049 01001001 I
074 112 04A 01001010 J
075 113 04B 01001011 K
076 114 04C 01001100 L
077 115 04D 01001101 M
078 116 04E 01001110 N
079 117 04F 01001111 O
080 120 050 01010000 P
081 121 051 01010001 Q
082 122 052 01010010 R
083 123 053 01010011 S
084 124 054 01010100 T
085 125 055 01010101 U

The situation has not changed fundamentally. Today the sequence of electrical pulses (Current pulses or more recently Voltage excursions above and below a defined baseline potential) can be decoded into myriad text formats and via Graphics command languages into Visual Displays including 3-Dimensional representations and motion video. In the simple example given in Figure 4 below it is clear that 8 discrete pulses define the character ‘K’ unambiguously. In today’s terms, where the ‘telegraphic’ link is usually specified in mega-bits per second (Mbps), a typical 5 Mbps broadband connection can theoretically send a 50,000 word article (5 Mbps = 500,000 characters = approx 50,000 words, allowing for Frame and CRC Control characters) from home to a remote host in 1 second.

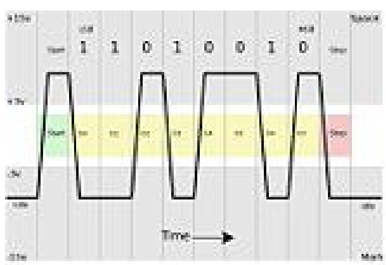


Figure 5: The Letter ‘K’ Represented in ASCII Binary Code and Electronic Pulse Value

Just how versatile the Datacomms can become in support of the Virtualisation/TC model is dependant on how rapidly and reliably these data transmissions can be conveyed between LAN/WAN nodes. This will in turn depend on the finite laws of physics applying to the interconnecting medium (Copper cable, Optical Fibre, UHF Radio frequency) and on how concise and powerful the data and command character strings can become. Compaction, Compression, Frame Merging and local client Caching can be used to minimise the number of pulses required per command or text string (Yang et al. 2001). Local caching can retain a common subset of the graphics screen content for frequent re-use but is found to be less valuable for multimedia or video content , where the complete image (every pixel) may change with every frame (‘the pattern is new in every moment’) (Eliot, 1940).

At one end of the spectrum, literal text messages (e.g. the stock exchange report above) must be conveyed normally as a full string of characters, although some compression algorithms e.g. the elimination of redundant space characters (data compaction) can be used to reduce the online content.

At the other extreme, using 'intelligent' transmission algorithms, a simple 'heartbeat' signal (a basic pulse sequence per second) indicating normal processing at the Host Server can be sufficient for a Thin Client to load and display the standard Start Up screen sequence from local ROM. The 'heartbeat' signal confirms that the Virtualisation Server is booting the Virtual session (VM), and that the actual Graphics Display commands will be in train within seconds or less. Meantime the local Thin Client user sees the standard start-up display and can assume that the session is commencing. By the time the Password prompt is responded to, the Thin Client will be on-line for actual authentication.

Having optimised the Ascii character payload, how fast and reliable can the interconnecting circuit and medium become.

2.1.3.3 Serial Datacomms – Electrical and Electronic Standards Underlying the Remote Computing Protocols (RCP)

Details of the relevant datacomms standards including Current loop PCM, RS-232, RS-422, RS-485, Ethernet (IEEE Standard 802.3), and IEEE Bus are outlined in Item 2 in the Technical Appendix.

It will be seen that datacomms rates of up to 10Gbps (ISO /IEEE 802.3ae) can be achieved over STP (Ethernet ISO/IEC 11801 Category 5) cabling and Fibre optic links (backbone, short hops). In practical real-world implementations, the standard Ethernet (802.3i) over STP cable will deliver 100Mbps at a maximum of 100 metres between nodes. These characteristics of the transmission media (Copper, Fibre, UHF wavelength) represent an absolute physical limitation on WAN Thin Client implementation, based on the physical structure of the cable medium (copper and fibre) and the physical environment, atmospherics and interference (UHF wireless). (PARASCHIV et al. 2008).

The Thin Client implementation is generally viable over LAN distances with Ethernet 10 or better (Nieh & Yang 2000). Individual Thin Client sessions call for anything from 20 Kbps (Citrix), to 350 Kbps (Sunray Alp) to greater than 1 Mbps for graphics intensive applications, usually quoted as an average figure. In practice it is acknowledged that if a high percentage of the Thin Clients are actually in use, the Display quality will be impaired as the bandwidth capacity is approached, especially noticeable on Video. For example the test video clip used in the lab demonstration in Chapter 4 calls for 6 Mbps bandwidth for a single unicast presentation. Despite the many advances in architectures and intelligent devices, the LAN connectivity is unlikely to meet peak demand for groups of users without some perceptible loss of quality and responsiveness.

It is estimated that Ethernet (IEEE Standard 802.3) provides the LAN solution for over 80% of ICT systems worldwide (Walrand & Varaiya 1999). In practice, the vast majority of existing LAN topologies will support Thin Client computing, subject to the bandwidth requirements noted above. The specific details of the networking system and known datacomms issues are described in more detail in Items 1 and 2 in Appendix A, Technical Appendix.

2.2 Recent Research: Technical and Academic Sources

The following section outlines a number of research papers covering the areas of Virtualisation/TC and serial datacomms as they apply to Remote Computing Protocol (RCP) connections. Sections 2.2.1 to 2.2.5 report on studies which describe the evolution of virtualisation/TC systems and explore new potentials including advanced (autonomic) systems management.

2.2.1 Remote Computing Protocol (RCP) Problem - Proposed New Standard

Net2Display (Ocheltree et al. 2007) is a proposed new *Video Electronics Standards Association* (VESA) standard RCP protocol which addresses the problem of delivering true PC-standard graphics at the Thin Client side within the constraints of available bandwidth and signal latency considerations. Net2Display is a proposed protocol which will run over TCP/IP on any suitable physical serial communications link, including the most popular :

a) Ethernet (ISO/IEEE 802.3*x*)

b) USB (USB Group Specification)

c) Firewire IEE1394,

d) Wireless 802.11*x* (300Mhz-4Ghz UHF)

The protocol will encapsulate the standard KVM (Keyboard, Video, Mouse) data streams. The intention is to make available additional Input/Output (I/O) facilities at the TC, including USB storage devices and Audio/Voice channels. A 'broker' Server or agent (also defined as a "Connection broker" in the Neoware and VMware examples in section 3) can be used to source Net2Display host services for groups of Thin Clients. Ethernet connections of 100Mb and 1 GB are provided for. A Net2Display terminal emulator program will be available to run on any existing PC. This will facilitate retro-fit of Virtualisation/TC technology, re-using obsolete units, pending their replacement with Thin Client devices. In this way the existing PC can gain access to Virtualised client sessions on any accessible Server. Latency problems on I/O can be overcome or minimised by 'mirroring' keyboard input and mouse cursor movements directly to the Thin Client screen.

The introduction of a universally accepted standard protocol would guarantee compatibility and interoperability between technologies and brands, and put an end to the expensive 'protocol war'.

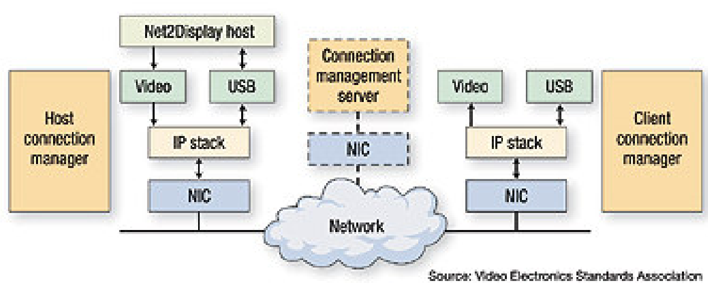


Figure 6: Net2Display Schematic Diagram

The proposed Net2Display ™ VESA standard is intended for remoting displays and USB I/O devices with responsiveness, performance and ***motion video*** *user experience comparable to a local PC. This proposed standard will enable client displays to connect over wired or wireless networks to host computers located centrally in businesses or homes or remotely at service facilities. (Source VESA).*

The problem of remote display will be managed by allowing the Thin Client receiver accept primitive graphics commands as delivered to a local Graphics Processing Unit (as for example the GPU within a standard PC) from the OS kernel (Baratto & J. Nieh 2005). This reduces transmissions via RCP from full bit-screen file updates to system commands, at the expense of retaining some local electronic or software VGA decoders at the Thin Client side. (Command sets are then transmitted over RCP, not full screen buffer files). In practice, the RCP often incorporates both system commands and Bitscreen files, and a growing tendency to provide a full working OS is tending towards local Graphics rendering at the Thin Client as is the norm for PC. (See also Multimedia Redirection in Section 2.1.1)

Further savings on Data Transmission packets can be achieved by relegating video file decoding (e.g. MPEG4) to dedicated local hardware. Dedicated ASIC decoders at the Server side will render typical formats e.g. MPEG4 (ISO/IEC Moving Picture Experts Group) compressed and encrypted for transmission over IP, further reducing the bandwidth demand. The Codecs for MPEG 4 files can reduce the File size by a factor of 10 using 'ISO/IEC 23003 video' compression tools (ISO/IEC 2007), but this will only apply to MPEG Video format, not to normal desktop content.

The Net2Display protocol will support the full spectrum of devices, from pure Thin Client through hybrid Streamed image to full PC. The Thin Client device can be Ethernet line powered up to 100 watts consumption.

The security benefits of thin stateless clients can be fully realised using Net2Display, with no local Data exposure at client side, and full Data Centre management of all ICT assets.

The VESA proposals for Net2display offer the advantages of an agreed interoperable RCP standard. However several of the major vendors are also in the process of refining and enhancing their proprietary RCP offerings. It remains to be seen if the commercial imperatives may result in the agreed industry-standard solution being left on the shelf in favour of a more heavily promoted commercial option.

The VESA specification in itself offers a useful summary of the desiderata and the limitations of RCP logic.

2.2.2 A Review of Desktop Virtualisation for Business

IDC Report : Virtualisation moves to the Front office (IDC, O'Donnell, Neoware 2007).

O'Donnell (2007) examines the new directions in Virtualisation/TC technologies with special reference to the potential implications for business and industry.

Beginning with an overview of the well-documented advantages of Server Virtualisation, his report examines the potential for Desktop Virtualisation and identifies a number of alternative technologies which can be used to deliver the benefits and savings of VDC. The savings achieved in deployment and maintenance leading to enhanced security and reduced Total Cost of Ownership (TCO) are explained against the background of real concerns to business computing: Virus attacks, Spy ware, Spam, Intrusion, data theft, device theft and regulatory compliance. Data security is identified as increasingly important to enterprise computing and corporate compliance issues e.g. data protection legislation (DPA 2002) and Sarbanes Oxley (SOX) regulations (ISO/IEC 17799 and 27001).

The potential for an enterprise architecture built around VDC, virtual machines (VM), Image provisioning suites and Connection Brokers is described as an outgrowth of the improved manageability and scalability of the Virtualised ICT environment. A number of alternative client options including true Thin Client and extending to Streamed Image and Virtual Client are identified as a growth potential arising from Virtualisation/TC. Single Master copies of the OS and of each application ('Single instance') are maintained rather than one complete image per User, further reducing client support costs and facilitating high-security code protection (unique source copy).

The improvements to manageability and security of the Data Centre and of all Virtualised systems within – comprising the critical ICT assets of the organisation – is cited as the most important long-term business advantage of Virtualised systems.

In addition, the reduced power consumption, ease of deployment, agility and adaptability to business demands are highlighted.

Potential sales of Thin Client devices are projected to increase to over 6 million units by 2010, with strong growth in the medical, pharma and financial sectors where security, confidentiality and compliance issues are foremost. The business growth will be supported by continuing exponential increases in computing power and storage capacities available at the Data Centre Server clusters. (Moore's Law estimates 100% increase in processing capacity of Microprocessors every 12 to 18 months. IC densities surpassing 200 million transistors on a 1-cm^2 die and corresponding increases in solid state disk storage will also have a significant impact) (Bass 2003).

With this powerful Server-based computing model, allocation of processing power can be varied by client workloads, delivering better than PC performance at the Client side whenever additional resources are required. While the network link remains critical to delivery of the centralised service, it is proposed that Wireless (WLAN) service will also be a viable option. In addition to 802.11*x* Wireless LAN, there is a significant potential for WWAN connections specifically availing of the 3G and 4G Mobile broadband (USB Dongle modem) now becoming widely available to mobile users. Used as Thin Client, the 3G connected device may provide the best example to date of secure 'Ubiquitous computing' service for business users. (See also working example of mobile Thin Client in Chapter 4)

The case is made for a variety of TC/Virtualisation configurations as against the more traditional Client/Server architectures, based on vastly improved security, energy efficiency and systems manageability and maintainability from a secure central Data Centre facility.

2.2.3 Synchronous and Asynchronous Database updates via remote client

Li, Stafford Fraser and Hopper (Li *et al.* 2000) describes how a complete specific environment – for example a software project management environment - is contributed to by a number of team members over the lifecycle of a project, with contributions being entered to the system from a number of LAN and WAN locations. Synchronous and asynchronous input is supported by independent sign-in to a single workstation environment. Data inputs and updates are recorded by source to a Transaction file, providing replay or roll-back reviews of all project updates.

In the Virtualisation/TC context, this research confirms multiple remote access from stateless clients to a single standard Operating System (OS) /application environment. The remote access from several locations is achieved using VNC. The task of transferring actual bitmaps (incremental updates) to sustain the images on remote displays is achieved over Ethernet LAN, allowing real-time collaboration from several sources (similar to a basic onscreen chat service). A cache or register of changes (frame buffer) is retained at the Server for download on request, allowing for incremental screen updates. The update file is retained at Server until the next request from the Thin Client (VNC pull protocol).

This example of true Thin Client means that all processing is centralised. The Thin Client itself is stateless – i.e. all system and application state vectors reside within the central Server. In this example, the screen image is identical for each user – the bit map is multicast (IP multicast) to each client location. One can expect reasonable responsiveness on LAN Ethernet using RDP or VNC over TCP/IP, with a nominal 10Mbps baud rate. The model can also be used over WAN links, however problems of bandwidth and latency may occur. A web browser as client is proposed, requiring at least a minimal OS and browser at the Thin Client side, equating Thin Client computing with Internet computing or 'Web PC'.

In this study a number of simple operations are carried out on a WAN configuration with up to 10 Mbps bandwidth channel, including a simple calculator operation and a Web search.

An important finding for the Thin Client model is a requirement for upwards of 4 Mbps bandwidth to ensure reasonable responsiveness, with 1Mbps as a minimum. There is also the clear exposition of a mobile, ubiquitous client session, available on a Thin Client network device from any Internet access point, dating from 2000.

2.2.4 Autonomic Systems and Systems Management using Hypervisors

Wakid and Sterrit (2007) explore a number of recent computing paradigms including Virtualisation and Grid computing. As outlined in section 1.3 above, the perspective and vision is that Computing Services will be available on demand, to any client using any suitable networked device. ("Everything as a service - XaaS").

Among the new technologies cited are:

a) Grid computing is the application of several computers to a single task or project at the same time, often distributed over many computing centres.

b) Data Centre Management suites: the Hypervisor offers the access point to enable intelligent management of all Virtualised systems supported by the Hypervisor. This is the key to providing comprehensive monitoring and management routines across all the DC systems to optimise allocation of system resources.

c) Service Oriented Architecture: the delivery of a pure computing service or utility as a linked module to the enterprise end user at the application layer (ISO/OSI protocol layer).

d) Software as a service (SaaS): the delivery of an application to the end user at the application layer (ISO/OSI protocol layer).

e) Ubiquitous computing (Ubicomp) is referred to as the presence in the environment of many linked intelligent devices (Weiser 1996). As well as the increasing number of sensors positioned throughout the modern environment, portable PC's or TC's having 3G or 4G connectivity will deliver a full computing service to any user in any location. A current example is the standard MS Outlook Web Access utility which provides an internet connection to personal E-mail Folders (and to the familiar MS Outlook menus) remotely from any online location.

To achieve this ubiquity, agility, and versatility, there is need for a managed core technology underlying and securing the transactional DP traffic. Virtualisation is the means to engineer and manage secure accessible platforms, and deliver the virtualised services to Thin Clients over very secure data links (typically VPN with SSL encryption).

The following examples are outlined as desirable features of virtualised Autonomic systems:

- Self Management using SMS, Tivoli or Open View to integrate DC Management where DC is the primary ICT repository for all ICT assets.
- Use Xen HyperVisor (or similar) to manage multiple disparate platforms on standard ‘commodity’ Server machines
- Service source is transparent to end user.
- Use to automate management of complete ICT Virtualisation infrastructures
- Spin up a new instantiation of a Server or PC User session on demand
- Move a Virtual Machine to a new physical host as required (or on system failure detection - autonomic provision). (MS Live Migration: VMWare VMotion: HP Sea of Sensors)
- Provisioning, migration and maintenance of all VM’s
- High Availability using VM migration and failover cluster (No single point of failure)
- The Virtualisation infrastructure allows disparate platforms from many vendors to be managed within a Virtualised environment (Prevent vendor lock-in).
- Visible and responsive supervisory services and agents to govern the ICT Infrastructures
- Autonomic Manager is self aware and infrastructure/network aware (HA & NSPF)
- Can provide binary segregation of sessions (software version of Rack/ Blade PC)

- Server energy costs (increased utilisation from 30% to 80%) are monitored to confirm savings.

- The <u>improved manageability, autonomics and self regulation</u> will be the true justification for Virtualisation environment with comprehensive Virtual and Physical platform management suite. (Examples include VMware View, Microsoft System Center Virtual Machine Manager VMC, Xen VDC, Ericom PowerTerm)

2.2.5 An Academic ICT Environment

Jonathan E.Geibel (Geibel 1999) conducted a survey of ICT and desktop requirements for the University of Pittsburgh. This study enumerates the main problems and challenges facing ICT Managers and Administrators with upwards of 2000 Desktop / Workstation machines and supporting infrastructures in an academic learning and administration environment. The scenario is similar to an equivalent scale of operations in business and industry, although certain aspects of the academic environment, especially the potential range of DP applications, present additional challenges to the system designers and managers. These challenges are quite similar to those faced by present-day ICT professionals. Newly available technologies and design models, particularly in the area of Virtualisation/TC will go some way to addressing the most serious of these problems.

According to Geibel the challenges are:

1) *To deliver applications and software fixes to a defined group of workstations.*

   The range and complexity of applications offered within the academic environment continues to increase, resulting in faculty desktops having upwards of 100 applications installed for a desktop image specific to a course of study or school. The maintenance and support overhead on distributed units is considerable, even when using central management systems such as MS SMS (now MS Configuration Manager) or HP Openview

2) *To provide users with the facility to choose which applications to install to their local workstation from a central software distribution Server.*

   Provisioning and publishing of a choice of OS and applications as described in the managed Virtualisation / Thin Client architecture will be convenient for users and more efficient for systems management.

3) *To uninstall or refresh broken software. The installation of over one hundred applications on the same machine can sometimes produce unpredictable results.*

   Failures of software at OS level and within or between applications often require a fix and re-image of a computing group or sector. The image management solution will assist the efficient repair and upgrade of affected departments. A key advantage would be the availability during this down-time of alternative images and platforms, delivered as a service to the client desktop (TC). This is the ideal upgrade scenario where a user may select e.g. Microsoft XP *or* Vista from the Setup menu. Crucial to this option is that either selection provides a full personalised environment, including nominated applications, all user profile settings and user data. Deploying Upgrades to OS is then a switch-on option, with time for the user to gradually learn in to the new environment.

   New features within application provisioning also allow for an Appliance to be downloaded and run directly at Hyper-Visor level. The application is delivered encapsulated within a minimal OS package which allows for local execution without any potential incompatibilities with the local OS (Wakid & Sterritt 2007).

4) *Asset management for both hardware and software.*

   Keeping tabs on the full complement of workstations, Servers and peripherals over many departments and campuses is critical to the management, maintenance and security of all ICT devices and software assets. The Virtualisation/TC model will enhance the effectiveness of systems security using the high-security Data Centre to protect all key computing assets, particularly confidential data storage and processing resources.

5) *Ability to track user, application, and usage statistics.*

As part of user authentication and the recording of resource usage, Colleges and Universities are obliged to maintain a 'Lab Supervision' procedure to ensure that their often very powerful computing resources are not being abused (Ref: DIT Computer Security Policy). In addition, to continue to provide a good service to the student community and to staff it is helpful to maintain metrics as to usage of each application or utility. With the introduction of Virtualisation/TC solutions, all processing is retained within the monitored Data Centre environment, thus facilitating a precise audit of usage and resource consumption per User and per Department.

A newly available security feature of virtualised kernels will allow the 'white listing' of approved applications at domain level, helping to ensure that illegal, objectionable or offensive material can not be displayed on any equipment connected to the Institution's domain (Trend / Faronics).

2.2.6 Summary

The above selections from the academic literature are chosen to highlight the significant benefits in terms of energy saving, security and overall systems manageability conferred by Virtualisation and Thin Client computing. In addition, a number of known limitations are high-lighted, reflecting ongoing scientific research and development work dedicated to enhancing the key technologies. The main recommendations arising from these articles are incorporated in the overall Chapter 5 'Findings' section. It will be seen that the research work cited above continues to have critical value to decision makers and CIO's faced with the security and general management challenges of modern ICT systems.

2.3 Recent Research: The Main Players in the ICT Industry

In parallel with academic and scientific research into ICT technologies including Virtualisation and TC, most of the important ICT software and hardware vendors have availed of the scientific developments to provide for and promote the ever-increasing demands of their customer, the universal computer user. The following sections outline new virtualisation/TC technologies by 3 of the main developers (Microsoft, VMWare, and Xen-Citrix) and a number of specialist developments including Teradici and Intune Networks.

Virtualisation/TC has made available several key features and technologies, as well as new disciplines and procedures which are being promoted by the primary vendors as solutions to critical issues in the ICT world. Most important among these are the ongoing concern with system security, data theft, general desktop management and energy costs associated with workstation and Server electronics. The issues of Server security and energy consumption are being addressed very effectively within the Data Centre (DC) using Virtual Server technology. These benefits are now being migrated to the virtualised desktop. With the growth in VDC options, vendors are tailoring their offerings to meet the differing requirements of small, medium and large-scale enterprises and also to compete at the level of ease of implementation and reduced Total Cost of Ownership (TCO).

One very noticeable common factor between all the main vendors is an emphasis on the complete Virtualisation and ICT Infrastructure management. As Virtualisation is introduced initially to the DC Servers, the opportunity is identified to standardise on a set of monitoring and control routines which can be applied in parallel to all VM's via the hypervisor. This in turn enables full systems auditing from a Management Control Centre or Console. This opportunity has given rise to specialist developments by each of the main players which enable not just the delivery of a Virtualised infrastructure, but also the automatic monitoring and control of the complete ICT environment (See also Virtualisation and Autonomic systems Section 2.2.4). Over time the powerful management procedures enabled by Virtualisation and the Hypervisor may prove to be the most significant advantage of the technology. This in turn will contribute indirectly to improved energy management and data security.

As outlined in section 3.2 and table 3.2(a) there is a continuum of Virtualisation/TC configurations ranging from standard PC to pure Thin Client:

1) Virtual applications. The standard 'fat' Client PC is used to access a Server-based application (Citrix Apps and Microsoft Terminal Server applications).

2) Blade PC's which are identical to the desktop PC except that the hardware 'box' is stored in a 3u rack in the data centre. The transmission of graphics to the desktop can be handled by dedicated graphics accelerators (Pixels only) e.g Teradici. While originally regarded as prohibitively expensive (Nieh & Yang 2000), a number of companies are now using dedicated logic to deliver the pixels-only files to pure stateless TC devices over Ethernet. Advantages include zero data exposure and 'Lossless' graphics rendering.

3) Web PC. The PC desktop environment is presented as a web service usually from a 3rd party DC server (e.g. Amazon, WebPC). The session is available to any device with browser. WAN latencies will affect responsiveness.

4) Virtual clients (Streamed Image) which download and run the full OS and application programs locally, but retain zero data on switch off.

5) VDC (VDI). Virtual Desktop Computing (VDC) (referred to commercially as Virtual Desktop Infrastructure) enables the standard desktop PC session to run as a virtual machine on the central DC Server. Remote users login at a Thin Client unit, using a standard RCP link.

6) VDC (VDI) Image management. The Thin Client operates as for VDI. At the DC side, a composite image per user is assembled from pristine OS and Application code, user profile and user Data. Image management enables fast new user set-up and fast virtual desktop provisioning while economising on storage.

7) oVDC (oVDI). This innovation from VMWare includes for Offline VDC (oVDC), which allows the complete image to be retained and updated on the local TC/PC device, pending next save back to the Virtual hard disk (VHD) in the Virtualisation Server

8) Pure Thin Client : For text displays only (e.g. the Console or Dec VT220 green screen), a remote login via Dial-up can permit Console or administrator access to a Unix (HP-UX V11) or other mainframe host.

Each of the main Manufacturers position their Virtualisation product range competitively. As a result the prospective implementer is presented with a wide range of very advanced computing solutions. This competition will be of benefit to the ICT community of users in ensuring best quality solutions across all computing sectors. For example standard VDC may be suitable for most standard applications over LAN, whereas a Blade PC with accelerated Graphics (Teradici *et al*) may be required for CAD, video editing and similar graphics-intensive applications. Ideally this will lead to a situation where any TC may be used to access any virtual session.

2.3.1 Microsoft

Microsoft made available MS Terminal Services (TS) service in the early 1990's to allow any client to access a Server using the original RDP protocol (based on the International Telecommunications Union standard T.120). The Server may run a Line of Business (LOB) application which many business users will access and update. The application program and associated databases are secured on the TS host Server, usually within a dedicated Data Centre. From the user's workstation, the LOB application appears to be fully available as with local applications. However some of the key advantages of Virtualisation - security, central storage and ease of administration - are already evident in this early example of Virtual applications.

A recent release of Microsoft Windows Server 2008 with Hypervisor includes some significant new Virtualisation features. In general the Microsoft technology demonstrates how Virtualisation enables enhanced monitoring and control within the Data Centre (DC) and across the complete ICT systems infrastructure.

- Hypervisor runs at kernel level -1, with the host and subsequent Virtual Machines (VM) running at level 0 to optimise resource allocation. (Intel VT and AMD's Pacifica enable chip-level support for MS Hyper-visor Virtualisation)

- Differential Virtual Machine (VM) option to include unique source OS and application code referenced by all images. This means a full OS is not saved to every Image, and that the 'pristine' source code is more easily secured.

- Failover Cluster providing a high availability (HA) option. When the Cluster is configured (using 2, 4 or more physical units and a Clustered Shared Volumes storage resource), all or selected VM's can be joined to the

HA Cluster. The VM will then continue to function even if one physical Server fails (No single point of Failure), although an interruption equivalent to a Restart will normally occur. Similar true HA options are being made available by the leading vendors.

- Live Migration or Quick Migration allows for a VM to be moved to an alternate physical host while remaining online. Estimates of the outage (Ping timeout) during transfer range from 1 to 20 Milliseconds. In practice this will not affect normal DP applications. However there remains the concern that complete context saving is not as yet fully guaranteed during migration.

- Core Parking: Allows for one or more Processors on the Virtualisation server to be shut down during low-activity periods, to reduce energy consumption.

- VHD Image Format which is the saved version of a MS VM environment is being recognised as a new default Image or backup format. Options to boot from VHD file and to retain a 'syprepped' or source version for general deployment will help to promote VHD as an agreed universal standard. The VHD file also serves as a perfect Disaster Recovery and Business Continuity (BC) resource, as it can be run immediately at any alternate DC or fallback operations centre.(IDC,Egge,Martinez 2009)

- RDP enhancements in Windows Server 2008 and in recent MS client Operating Systems will also address some of the problems identified in relation to video and other graphics-intensive applications over RDP.

Note: (3rd party enhancements to RDP are now also permitted using free available Logical RDP channels)

The test model described in Chapter 4 will use a basic Beta-version Microsoft VDC solution approved for demonstration purposes only. The more advanced MS Server 2008 R2 with Hypervisor is now on release and will introduce further enhancements at the level of RDP and Client OS features (See also *Opportunities for further Research* Section 6).

2.3.2 Citrix

Citrix are considered as leading specialists in Virtual applications. The primary configuration is to run the Line of Business (LOB) application on a dedicated Server, with specialist dedicated ICT support to maintain and secure the application environment. The remote access protocol (ICA and RDP are both available with Citrix) permits the local PC user to access the Server and run the application.

Citrix having acquired Xen is now actively promoting their Xen-Desktop VDC solution and Virtualisation management suite with HDX protocol.

A Citrix Application Delivery Infrastructure including Xen Desktop VDC. Applications are centralised to lower management costs and to increase data security. Citrix "decouples users, networks and applications and then dynamically re-couples them on demand, delivering applications cost-effectively and securely at the point of need".

The Data centre is now a "Dynamic Delivery centre", comprising:

a) Workflow Studio – to orchestrate build and delivery of Applications

b) XenApp (formerly Citrix Presentation Server) offers streaming of applications to client and publishing of Server-based applications.

c) XenDesktop, (Desktop Virtualisation) to deliver the security and reduced TCO associated with virtual desktop for remote users. Recommended for "office, branch, outsourced and home workers and to facilitate expansion, mergers, business continuity and regulatory compliance"

d) XenServer delivers the Virtual Server savings for a dynamic and responsive DC via a management Console

e) Citrix Provisioning Server is used to stream desktop images to selected clients

f) Citrix WanScaler applies intelligence algorithms to accelerate performance for remote users, approximating to LAN-level performance on WAN connections

g) Net Scaler. Enables secure access to Citrix - hosted web applications, providing the Internet computing solution to centralised applications. Includes SSL acceleration, data compression and network optimisation

Copyright Citrix
(http://www.citrix.com/english/ps2/products/product.asp.contentID).

(Citrix,2009)

2.3.3 VMWare

VMWare has been generally considered the most successful Virtualisation developer worldwide. From an initial success with application virtualisation, VMWare have developed their range of systems to provide for DC Server Virtualisation and a full Virtual Desktop Infrastructure (VDI). The competitive advantage is a proprietary VMWare Infrastructure, a Server and Datacentre Virtualisation suite which incorporates a total ICT management solution (VMWare View) based on the provision of Servers, desktops and applications from a pool of infrastructure resources.

A VMWare Enterprise overview

A number of ESX3i Servers are configured to run individual VM sessions, as determined by a built-in Network Load Balancing (NLB) utility.

A Connection Broker is installed on a separate 'Virtual Centre' Control Server with NFS folder and SCSI or ISCSI parallel bus interconnects. The Control unit manages the Image creation and management utilities, from a Template created from the Master OS and including all common utilities and features (a corporate image). To this template is added the requisite applications (from the application master images) together with the profile data per User.

Additional VM's can be provisioned simply and quickly by a Snapshot process of the existing Template plus user-specific data and settings (Delta values). The new Image contains only the Delta values, with referencing out to the Template master image for common content.

The final image is available to login client users, allocated on the basis of Active Directory group membership or similar authentication.

A key advantage is that there is only one master copy each per application and per OS. The unique content for each image (Profile data per user or group, and user data or pointers to SAN repository) is actually written to the image file. The storage cost per Image is the differential or delta subset of code which is not included in the Master OS or application code, realising significant savings in image copying and storage. In practice, a new user Image can be deployed at the Controller in minutes.

For High Availability (using Cluster VM Site Manager), the Controller NLB feature maintains a bit-identical lockstep copy of the VM environment, allowing a second host to assume the VM processing load - with full context saving - in the event of a failure on the original hardware host. This High Availability (HA) feature, as with other Vendors is intended to provide for No Single Point of Failure (NSPF), here guaranteed by the sustained bit-identical mirror copy. In practice there is always some delay in transferring a VM to a new host, which can be verified by a Ping record to the VM which will identify a no-response period.

The guarantee of a flawless migration of the VM to a new host 'on the fly', that is while continuing to field online transactions and with full context saving appears to be something of a 'holy grail' for the main manufacturers. The potential for a Virtual Server or Client to hover above a cluster of physical Servers, immune to any single failure in the underlying cluster, will have significant implications for 24/7 online transaction processing applications, especially in the E-Commerce environment. It is clear that a great deal of research is being dedicated by the major developers to deliver a true cost-effective High Availability option with zero disruption and negligible delay to online data processing.

2.3.4 Special Purpose Developments Including Teradici, oVDC and Intune Networks

As Thin Client devices have evolved there is a question as to exactly what form factor and functionality will be applied at the client side. Section 3 includes an outline of the spectrum of TC-type devices now available, (See Table) from which it will be seen that more functionality is being transferred back to the Thin Client end, with a view to providing PC-like performance whilst retaining the main advantages of Virtualisation and TC. An exception to this trend is the pure 'zero state' device (Teradici *et al*).

Teradici uses the existing standard IP network connection to link a Blade PC to a true stateless Thin Client device, having zero security exposure. The PC over IP technology connects 2 dedicated hardware modules (proprietary chip-pair) which incorporate high-efficiency encryption, compression and compaction at the Blade PC side with decoding at the receiver side. Prioritization of the most latency-sensitive data is built in to the logic. The efficiency of these algorithms and the speed of the dedicated hardware reduces the data transmission load to the extent that true workstation-like performance can be achieved at the remote Thin Client with significantly reduced bandwidth requirement. Intelligent prioritization of latency-sensitive data will support Teradici Thin Client operation over higher-latency LAN and WAN connections where latency issues would normally prevent adequate responsiveness.

As the inherent limitations of the channel link (latency and broadband capacity) are well understood the development of 'intelligent' compression technologies and dedicated hardware accelerators offers increasing potential for the delivery of true 'Lossless' workstation performance to the remote client. In the Teradici example as shown in Diagram 2.3.4(a) the viability of the link protocol is confirmed by support for standard peripheral devices including VGA and DVI LCD screens, printers, USB and Audio devices.

Overall the Teradici solution (hardware accelerators, intelligent algorithms and high-security encryption) is at the forefront in providing remote PC access at close to zero performance cost, subject only to link capacity. When Teradici can make available a transceiver at the host for each individual hosted VM, with a corresponding portal module at the Thin Client end, the advantages currently available for Blade PC's only can be delivered for VM's across the complete range of VDC architectures. This may be a new and powerful commercial option for LAN Thin Client implementations (A new release is due October 2009).

The advantages cited by Teradici (see Technical Appendix, Item 3) for their Zero State client PC-over-IP technology give an indication of many benefits common to Virtualisation technologies in general, and of some specific to the Zero State option. A number of potential disadvantages are identified, centering on the familiar connectivity issues.

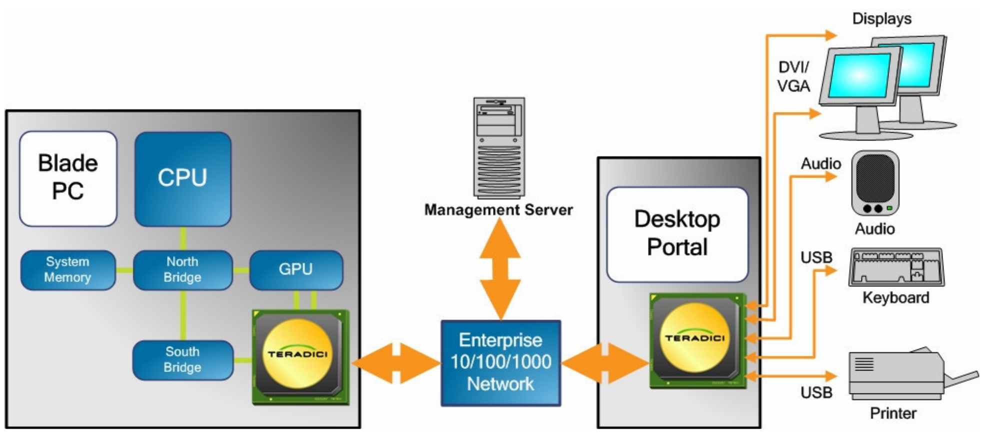


Figure 7: Schematic of Typical Teradici PC-over-IP Solution

Note : "Teradici's solution is designed to improve PC asset management by centralizing the operating system, applications and PC components, providing enhanced security, power savings and simplified maintenance, while maintaining the power and user experience of a traditional desktop PC" (IDC,Collins,Teradici 2008).

oVDC - A recent release by **VMWare**

Offline VDC (oVDC) will address Thin Client performance issues by providing a Thin Client with full local processing and storage capabilities. The user Image is streamed to the local PC/TC and can be edited locally pending periodic resync with the VHD image at the Virtualisation Server side. This option is a full hybrid of PC and Thin Client and may compromise the security and energy advantages of TC.

A review from an Industry analyst:

"At this point oVDC is just a basic technology preview, and it's rough around the edges, but it solves some interesting problems for VMware:

- *oVDC fixes the* (RCP) *protocol capabilities problem. What protocol is better than ICA, RDP, Spice, or PC-over-IP?* ***VGA!***
- *oVDC fixes the peripheral problem, in that all local USB camera, mics, phones, scanners, devices, etc. work as planned.*
- *And of course, by definition, oVDC fixes the offline problem". Ref:BrianMaddenVNConsultant).http://www.brianmadden.com/blogs/brian madden (Madden, 2009)*

Wyse multimedia 2.0 Thin Client (Wyse 2008) is an example of the " Multimedia Redirection" method of handling Graphics processing in a Thin Client architecture (see also Section 3.4). By dedicating multimedia recognition software at the Server side these commands are re-directed to a dedicated software layer at the Thin Client side for local decoding and rendering. As with other local GPU facilities, there is an implicit requirement for a minimum 800 Mhz processor and 128MB RAM at the Thin Client – clearly a migration away from the basic Thin Client model and an intelligent solution to the problem of sending full video frames over typical RCP interconnects. This leads to significant gains including reduced computational load at the DC server and the elimination of poor video quality – frame skips, visible painting, low 8- or 16-bit colour depth and audio synchronization problems – at the TC (Chaddha *et al*. 1995).

The feature list for this range of Wyse Thin Clients also identifies a number of industry aspirations:

"Wyse X Class Mobile Thin Clients:-

The first mobile thin clients to offer multimedia video playback, integrated Bluetooth™ 2.0 and built-in smart card support.

- *12.1" or 15.4" widescreen displays.*

• *Thin fan-less design.*

• *Built-in WiFi™;* ***3G wireless-ready.***

• *Smart card and Bluetooth option.*

• *Integrated Citrix Password Manager™.*

• *Express Card slot™, 3 USB 2.0 ports*

• *External monitor output*.

(Wyse 2008)

As this process continues it is clear that there is very little difference now between a high-end Thin Client device (e.g. Igel Universal PC, Wyse TCX Multimedia 2.7 model) and a standard-specification low-cost Netbook laptop e.g. Lenovo 3G enabled S10 NetBook. The latter can be effectively locked down and enabled for secure image streaming only. As these developments continue, it is possible we will see an enlightened convergence of technology and function, delivering a 'Network Device ' which will combine the most important advantages of PC, Laptop and Thin Client .

Intune Networks are developing a technology which will further enhance the datacomms capability of fibre channel (FC) optical transmission. Already identified as an optimal real-time interactive medium in terms of bandwidth and latency, FC is liable to the typical switching and routing delays (switch latencies) which affect all TCP/IP traffic. To reduce the queuing of packets at centralised switches, Intune will use tunable lasers to colour code the optical transmissions based on destination. Local filters will then draw down the traffic appropriate to each destination. This means that the switching is intrinsic to the medium, and is distributed around the network avoiding the switch queues that accrue at centralised switching stations. An 'exemplar' tunable laser network is currently being trialed in Dublin and results may have a profound impact on LAN, MAN and WAN designs. In the context of VDC, the enhanced FC may provide a near-perfect platform for real-time interactive responsive Thin Client computing.

2.3.5 Summary

The above examples of new and specialist innovations in VDC technologies indicate the amount of interest and perceived potential within the industry for a 'lossless' Thin Client solution, that is a Thin Client solution which will deliver the security and energy-saving benefits without compromising the standard PC-levels of responsiveness, display quality and resource accessibility. The continuing efforts in this sector help to clarify the known limitations of even the most up-to-date Virtualisation/TC solutions. Specialist technologies such as Teradici and Intune Networks suggest more radical departures, with dedicated accelerators to deliver fully interactive data interconnect, and near - PC performance levels.

2.4 The Ecological Dimension

2.4.1 Introduction

This section includes a summary of findings from a number of prominent researchers into the Ecological aspects of ICT systems, including ESB Ireland, Gartner, McKinsey, Ericom, Microsoft and IDC. Also included is a detailed Ecological comparison between PC and Thin Client computing carried out over a two-year period by Fraunhofer Umsicht Institut on behalf of Igel GmbH, a leading European manufacturer of Thin Client technologies. The energy calculations and general results are supported by standard observations of the virtualisation process as applied to DC reorganisation throughout the industry, for example in the ESB Ireland project cited in Section 2.4.2

Energy savings result from both Virtualisation and Thin Client computing:

a) A Single Server with Hypervisor will run multiple Instances of Server OS, offering a range of alternative platforms from a single physical unit. This will reduce the number of physical Servers and energy demand per DC, as shown in Microsoft diagram 2.4.1(a) below.

b) The power consumption of a typical Thin Client device (excluding LCD screen which is usually common to PC and TC) will be approximately 20%-40% of a comparable PC. (Fraunhofer Umsicht,Gloge et al. 2006)

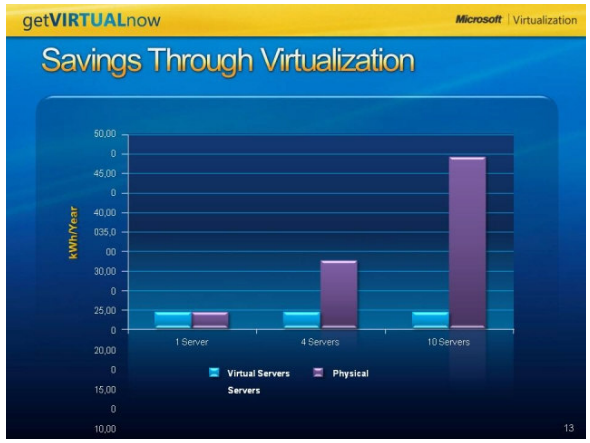


Figure 8: Comparison of Annual Energy Savings Using Virtual Server

2.4.2 Industry Sources

ESB Ireland. A recent presentation by ESB claimed a 30% per annum saving in energy costs following virtualisation programs applied to their two main Data Centre (DC) locations. This saving corresponds to a 2,000 ton reduction per annum in carbon emissions. Other savings and benefits are included in the summary below by ESB.

Summary of the ESB report**:** (Brien & ESB 2009)

Savings ESB has achieved by virtualizing Servers

- *Lower Upfront Hardware Cost - Up to a 50% savings in up front Server hardware*
- *Decreased Datacentre Space Requirements - Up to a 75% savings in rack space*
- *Decreased Datacentre Power Requirements - Up to a 75% reduction in power consumption*
- *Decreased Licensing Costs - As many vendors such as Oracle and IBM license software on a per CPU basis savings can be achieved by hosting multiple virtual machines on the same physical hardware - Successful Outcomes*
- *Virtual machines are now the accepted default option for all new Server builds in ESB underlining their advantages*

- *Consolidating 25 stand alone Oracle Servers onto a 4 node ESX 3.5 cluster resulted in significant license reductions (reduced number of required licenses from 50 down to 16)* (See also VMware Section 2.3.3).

- *The existing virtual infrastructure in ESB will reduce carbon emissions by over 2000 tonnes this year alone*

Benefits of virtualization to ICT customers

- *Faster Server Deployment*

- *Provisioning time of servers down from 6-8 weeks to 2-3 days (However the same planning policies are still enforced)*

- *High Availability as standard: All 500+ virtual machines are hosted on clusters that have VMware High Availability configured (*See also VMWare Section 2.3.3)

- *Simplified Disaster Recovery*

- *Virtual machines (VM) are decoupled from the physical hardware and are encapsulated in a small number of files. By hosting the virtual machine on replicated SAN storage and provisioning VMware ESX hosts in each Datacentre we are able to power on the virtual machine in either Datacentre*

Copyright (Brien & ESB, 2009)

Following the success of the Server Virtualisation programme, ESB are now carrying out a follow up Pilot VDC project using VMWare ESX infrastructure. (See section 2.3.3)

Gartner, Ericom and IDC. Research indicates potential savings of between 30 and 60% using DC Server Virtualisation, resulting from increased utilisation of resources per Server and reductions in energy and cooling costs for fewer Server units. These findings are borne out in many practical applications from small-scale consolidation of Servers to complete corporate DC re-design. The calculations include for provision of dedicated local electricity substations, often required when scaling up of the ICT infrastructure is proposed. Server consolidation using Virtualisation can provide for upwards of a 100% increase in Server numbers for minimal increase in energy consumption. At present the total DC energy consumption accounts for upwards of 0.3% of global energy consumption (Tucker 2008).

At the Desktop, it is possible that the potential savings arising from VDC could be even more significant. If a standard desktop PC consuming in the range 100-200 watts can be substituted by a Thin Client device rated at 35 to 100 watts, energy costs would be reduced by at least 50%. The potential energy savings can be applied in time to approximately 1 billion personal workstations worldwide.

Of more direct relevance to business users may be the reduction in Total Cost of Ownership (TCO) arising from improved manageability and system security to be derived from the ultra-secure DC-hosted desktop environment, as outlined in sections 2.2 and 2.3 above. While not of direct ecological concern, a well managed and secure ICT Infrastructure will prevent the abuse of resources and proliferation of wasteful and hazardous online content, as well as reducing the difficulties and time costs associated with emergency response, and facilitating business continuity (BC) and Disaster Recovery (IDC,Egge,Martinez 2009).

A report from **Gartner** (Gartner,ICT & Co2 2007) includes estimates for IT's contribution to CO2 and energy

- *Commercial IT contributes to 2% of global CO2*
  - *PCs, Servers, network, printers, mobile phones etc*
  - *More than commercial aviation*

- *PCs contribute to 0.5% of global C02*
  - *Or 25% of commercial IT's CO2*

- *Energy represents 10% of the IT budget but this could grow to 50% in the next few years.*

Table 4: Total Cost of Ownership Comparison - Ericom

Annual TCO per User – Comparison with Traditional Desktops

	Traditional Desktops[5]	Windows Terminal Server (SBC) Only[6]	Virtual Desktops (VDI) Only[7]	Blade PCs Only[8]	Combination of Virtualization Options Managed by Ericom's Hybrid Solution
Desktop Capital Expenditures (PCs for traditional desktop scenario, thin clients for other options)	$490	$70	$70	$70	$70
Desktop Operating Expenses (Includes management and overhead costs)	$534	$202	$259	$320	$225
Desktop Energy Costs (Power & cooling)	$94	$69	$69	$69	$69
Environment Investment (Servers & software)	$0	$125	$263	$471	$187
Total Annual TCO Per User	$1,118	$466	$661	$930	$551
Total Annual TCO Savings vs. **Traditional Desktops** (**500 users**)		**$326,000**	**$228,500**	**$94,000**	**$283,500**

Refs

[5] ***VMware Calculator***

[6] ***Gartner, Citrix***

[7] ***VMware Calculator***

[8] ***IDC***

An analysis by **Ericom Ltd ©** as shown in Table 4 identifies savings at DC and Desktop, together with reduced overall TCO items by comparing Standard PC and a range of Thin Client options including application Virtualisation, Blade, VDC, and Hybrid.

Additional source material identifying the gains from Virtualisation and Advanced (managed infrastructure) Virtualisation is included in the following three tables 5,6 and 7 from an IDC / HP Labs report “The business value of Virtualisation : Realising the benefits of integrated solutions”

Table 5: Business Value of Virtualized Deployment: Users per Server

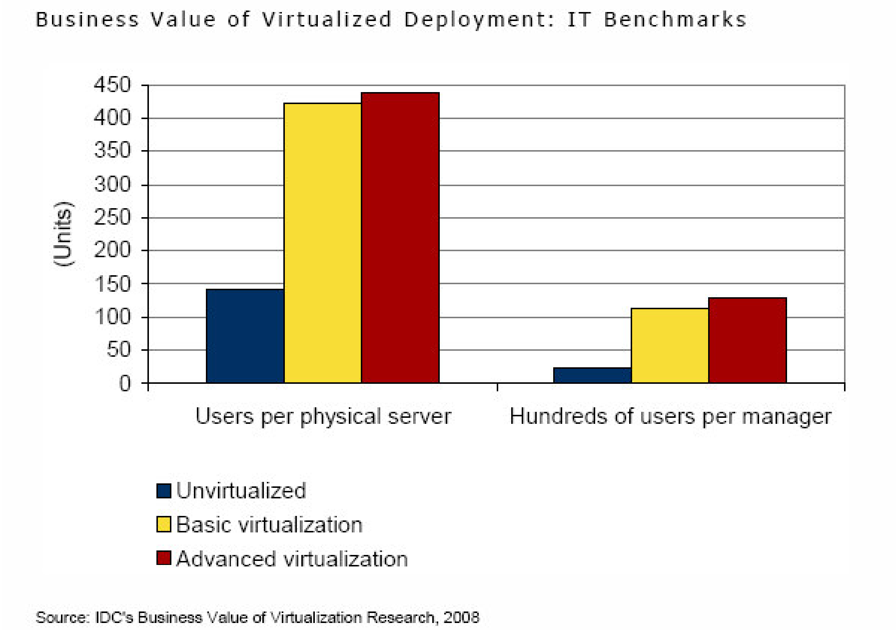


Table 6: Servers per Manager, Time and Downtime Costs

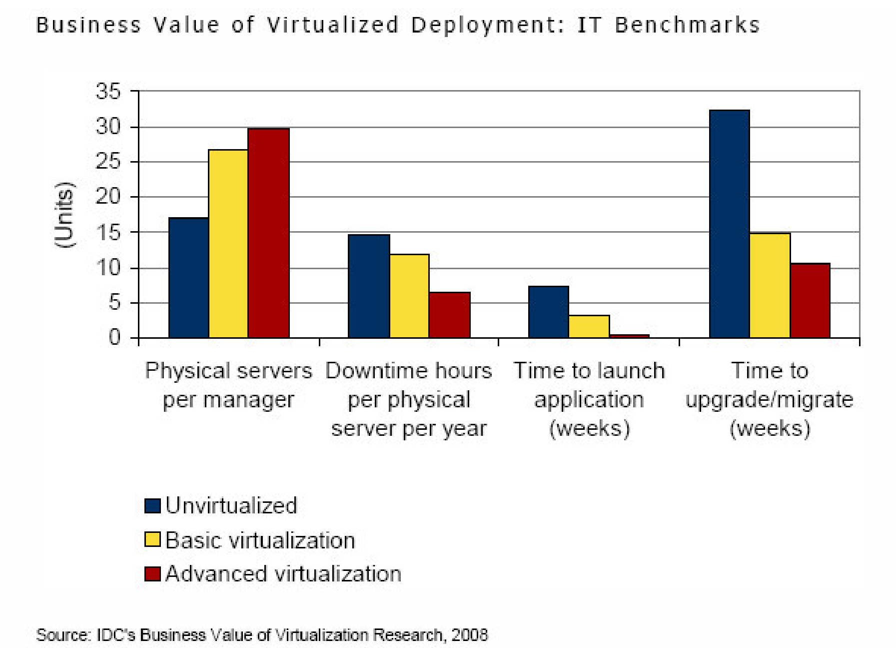
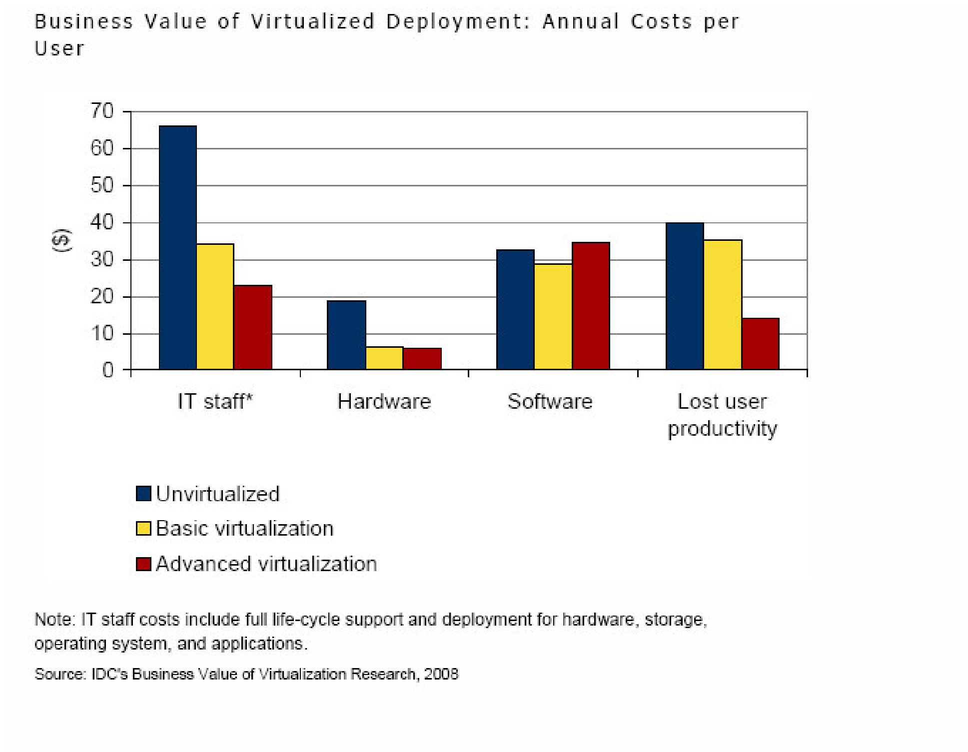


Table 7: Business Value of Virtualized Deployment: Annual Costs per User



(ID C,HP labs,Gillen,Grieser,Perry 2008)

2.4.3 Special Report on behalf of IGEL GmbH by Fraunhofer Umsicht Institut

A detailed study on behalf of **Igel Technology GmbH** was carried out by **Fraunhofer Institut** over a 2-year period to compare the environmental impact of moving from PC to Thin Client computing. Igel Technology GmbH is a leading manufacturer in Europe of intelligent Thin Client devices ranging from basic MS CE-embedded client units to the more recent 'Universal PC' range of systems. The following excerpts from the study summarise the key findings.

About the Fraunhofer Umsicht Institut

- One of the world's largest private research organizations
- 12400 employees
- 58 institutes across Germany
- 9th largest patent producer in Germany
- 22nd largest patent producer in the world

- Fraunhofer UMSICHT
    - Specialises in energy and environmental technology
    - Hosts the Citrix SBC farm for the whole of Fraunhofer

Summary of Ecological comparison of PCs and TCs - Fraunhofer Institut

Cost and energy savings are identified during 3 Phases

a) Manufacturing costs: The Thin Client is smaller and lighter than PC giving reduced transportation costs, and consumes lower amounts of energy and raw materials in production. ***Result: Significantly Better***

b) In-service costs. Energy consumption savings up to a factor of 4, (typically 2 to 3) are identified. ***Result: Significantly Better***

c) Recycling/Disposal costs. Lower costs to dispose of and/or recycle the reduced material content of TC. New EU directives will promote the collection and recycling of obsolete equipment.

   The EU requirements will include dismantling and recycling of returned units. A full environmental performance evaluation from production through to disposal is not available due to absence of a life cycle inventory per product. Sample key data was used to give a reasonably accurate assessment. ***Result: Better***

The overall Ecological concern is comprehensively addressed in this study, from exploiting finite raw materials in manufacture, through normal consumption of energy resources during productive use to the clean and responsible recycling and disposal of end-of-life units. The underlying technology can be seen as a first step on the road to ecological ICT, by eliminating surplus computing and storage devices from the workspace.

Notes on the Study

Real users were classified into light, medium and heavy groups and suitable Thin Client devices assigned to each group as shown in table 8.

- Users did their daily jobs with their PCs or Thin Clients

- Energy used was measured in-situ over a period **of 2 years**

- Server and data centre (DC) energy was also measured
- Infrastructure shared by both PCs and Thin Clients was not considered.

Table 8: Comparison of Fraunhofer Umsicht Institut Thin Client Groups

Thin Client s	compared with	PC work station system
Light User IGEL-2100 CE Smart	compared with	equivalent PC system
Medium User IGEL-3200 LX Compact	compared with	equivalent PC system
Heavy User IGEL-5600 XP Premium	compared with	equivalent PC system
Proportional offset of expenses for a Server for each Thin Client	compared with	With the PC systems there are no Server costs

Additional Notes:

Note 1: The generally acknowledged problem of graphics-intensive presentation over RCP is identified. The study excluded customisation of the Thin Client by using special Graphics controllers to overcome these problems.(e.g. special purpose Graphics accelerators) as being beyond the standard Thin Client definition.

Note 2: Ergonomic advantages including reductions in size, noise and Electro Magnetic Frequency (emf) emissions are considered as part of this study.

Note 3: Estimates of Server sizing (all components) are included in the calculation of additional demands and costs using Virtualisation/TC as against PC with local processing.

Note 4: A total of 35 Medium users (considered as equivalent to 20 heavy Users or 50 Light Users) per Server was identified as an optimal resource utilisation target, rather than theoretical limits of 200+ users. This was borne out during **2 years** observation of productive operation**,** where utilisation was optimal and available physical main memory appeared to be the most important limiting factor.

(Recent developments in 64-bit computing and multi-terabyte memory address space will help to overcome this type of limitation)

To summarise the results, the following tables are copied from the Fraunhofer 2006 report, full source details of which are shown in the Technical Appendix. The brief details given below highlight the potential savings in Ecological terms to be derived from Thin Client computing as compared to the standard PC model.

The results… a 51% energy and CO2 saving!

CO_2 wastage with server share

	Thin Client	Thin Client with server pro rata + server cooling[3]	PC
Power consumption[1]	16 W	41 W	85 W
x 8 hours per day	128 Wh	328 Wh	680 Wh
x 220 working days per year	28 kWh	72 kWh	149 kWh
Costs for 1 working station per year[2]	17,64 kg	45,36 kg	93,87 kg
- 10 working stations	176,4 kg	453,6 kg	938,7 kg
- 100 working stations	1,76 t	4,54 t	9,39 t
- 1.000 working stations	17,6 t	45,4 t	93,9 t

[1] Average active power
[2] The production of one kWh with the German electricity network gives rise to 0,63 kg CO_2
Source: Fraunhofer UMSICHT / IGEL Technology: Environmental comparison of PC and thin client desktop equipment

IGEL Technology | Stephen Yeo, Marketing | 21

A Sample output from the Energy/CO2 measurement of Thin Client /PC usage by Fraunhofer ©

The results are very conservative

- **As more applications become web or Java based, thin clients don't need a server infrastructure for GUI generation, further increasing their CO2 advantage**
- **The research used 32 bit Citrix but 64 bit computing will dramatically reduce CO2 production further**
- **The research assumes that PCs do NOT require air conditioning, but in many cases they do and this can double or triple their effective energy use**
- **Manufacturing and disposal not included**
  - Thin clients are only 35-40 % of the weight of a PC
  - Thin clients are only 19-30% of the volume of a PC

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Conclusions

- **All organisations will be forced to reduce carbon emissions**
- **Commercial IT is a major contributor to CO_2 emissions**
- **Citrix users are in an ideal position to make major savings in CO_2 emissions**
- **It is an unusual CO_2 reducing measure**
  - It doesn't involve a change of user experience or lifestyle
  - It has many additional financial and security benefits

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<u>Note:</u>

<u>Additional tables and a link to the complete results of the Fraunhofer Institut study are given in the Technical Appendix Item 4</u>

2.5 Summary

Many of the scientific and technological developments in computing are not fully in the public domain but we do see the evidence of the intensive R & D effort and their impact on systems innovation.

New technologies give rise to a revision upwards of systems analysis, design and management procedures, leading to very advanced audit and security features. Rationalisation and consolidation of the ICT 'estate' leads to cost savings and energy conservation. As yet certain connectivity issues restrict the universal availability of TC computing, but new developments are announced almost daily claiming further advances in these areas.

Constant improvements in the existing technologies lead to intrinsic self-regulatory sub-systems which underpin the 24/7 requirements of commercial computing.

Industry and academic research over many years has highlighted the recurring issues for large-scale corporate and campus computing. Touch points, systems maintenance and Total Cost of Ownership (TCO) are important concerns for CIO's everywhere.

In addition, recent findings in support of environmentally friendly processes and systems help to identify other kinds of efficiency , not always so evident on the balance sheet. The detailed study by Fraunhofer Institut provides comprehensive evidence of the 'green' direction for future computing.

3. Variants of Virtualisation and Thin Clients

3.1 Introduction

With intensive ongoing Research and Development into enhanced Virtualisation and Thin Client devices, it is not surprising that there are new variants and flavours of the core technologies being announced regularly by the main development groups. Pivotal to the scientific and commercial efforts is the ultimate goal of providing true secure ubiquitous computing. The 'network device' Thin Client will be the Passport for every cyber citizen, giving access to the increasing range of online social and commercial facilities.

An indication of how close this possibility has now become can be seen from the gradual convergence of a number of key technologies. Amongst the personal handheld devices currently available are a range of portable Thin Client devices, 3G Phone, Tablet PC, GPS, Sat-Nav, and a wide range of PDA's equipped with 3G/4G Mobile broadband. There is considerable overlap between the functionality of many of these portable devices. The eventual portable Personal Computer may be a foldaway or scroll-type LCD screen attached to a pocket device. The functions available could include:

- Access from any location to the user's Personal Computer or Desktop environment.
- Video - Phone contact with similarly-equipped users.
- Digital TV and radio service
- Personal location tracking via GPS.
- Satellite Navigation service based on GPS.
- Individualised communications based on personal profile and location.

Home broadband is now commercially available via the TV cable network, while TV broadcasts can be viewed over WAN on standard PC's. (A working model of Live TV over IP is described and tested as part of the demonstration unit in Section 4). Satellite GPS signaling can locate an individual or vehicle on the globe to within 15 metres.

This convergence of UHF radio, Fibre channel (FC) and cable network communications has the potential to deliver ubiquitous personal computing in parallel with many personal services and utilities not presently regarded as part of the ICT domain.

The following sections 3.2 and 3.3 identify a range of commercially available Virtualisation/TC models and outline the implications for LAN/Ethernet network design. This is followed in section 3.4 by a brief description of relevant associated technologies including failover clusters, ubiquitous computing, and multimedia redirection.

3.2 The TC-PC Continuum

Table 9 outlines some examples of the range of Virtualisation/TC models which are currently being promoted. The number of alternatives does indicate that Vendors are positioning their Virtualisation/TC offering at some remove from the pure Thin Client option and with an increasing tendency to return significant CPU, GPU and storage capacities to the client device, while also attempting to retain the key advantages of Virtualisation.

The manufacturers are confronted by fundamental laws of physics (Capacitance, Resistance, Inductance, Electro Magnetic frequency (EMF) radiations) which will set a limit to the absolute data transmission capacities of physical media. Therefore despite the many new developments such as compression algorithms, multi-media redirection and redistribution of processing tasks as between Thin Client and host, remote interaction with the host session will always present some intrinsic loss of responsiveness. The range of Thin Client options reflects the different approaches to overcoming these problems and meeting the needs of the many different industry segments and user categories.

Ranging from the Blade PC unit (a full PC configuration distributed over a dedicated network circuit) to the pure text-only Thin Client, there is a group of designs which seek to localise function at Thin Client (including Graphics processing, Cache memory, Minimal or full embedded OS, RAM disk storage) insofar as this will enhance the communications function. As we have seen in section 2.1.3, any features such as graphics processing and rendering which can be relegated to a hardware function at the client node will reduce the data load and bandwidth requirement, thus optimising the

RCP serial datacomms while also transferring non-critical graphics processing from the host CPU to an auxiliary (TC) processor .

In all cases (except actual PC) the key advantages of centralised management and security and to a lesser extent reduced local power consumption are retained.

A sample of the range of devices and protocols used to provide remote access to the PC Desktop session is given in Table 9.

Table 9 : PC-TC Continuum

Table 10 : PC-TC Continuum

Model	**PC**	**Blade**	**Web PC**	**VDI-segregated session**	**Virtual Client-Streamed image**	**VDI-Image Mgt**	**oVDI**	**VDI**	**PureThin Client**
Operation	The standard PC unit and LCD screen with local direct (hard-wired) connections to peripherals and LAN connections to nominated Server/shares. Usually incorporates an Internet connection either via Lan/Proxy server or dedicated line	The physical PC is installed as a Rack unit (normally 3U dimensions) within the DC with dedicated accelerated serial comms (KVM) connection to a small Desktop module at the Client side . The Keyboard , Mouse and LCD connect directly to desktop module	Similar to Web Applications. The PC desktop environment is provided as a Web Service from a 3rd party DC Server. (Amazon, WebPC). The session is accessible from any device with browser. WAN latencies will affect responsiveness.	The VDI session is provided by a VM running on the central Server . In this case , each session is segregated at binary level , to provide for very high data security between sessions, without requiring a seperate physical PC Blade unit for each user	The user-specific Desktop Image is compiled as for VDI-Image Mgt. The TC is provided with local processing power. The Image is streamed to the TC and runs locally , with all the advantages of the standard PC (local execution, zero latency)	The client TC operates as for VDI. At the DC side , a composite image per user is assembled from pristine OS and Application code , user profile and user Data. Enables New user set-up and fast virtual desktop provisioning while economising on storage.	As for VDI. The TC can store the image and work offline , becoming a full PC pending resync with the Vn server	The VDI session (VM) runs on the central DC Server. Remote users login to the session from TC units , using a standard RCP session.	ASCII character stream between TC (Console) and Server. No Graphics rendering. See Dec Vt220 'dumb' terminal (green screen)
Vn Type	Appln Vn or RCP	Presentation Vn	Web Appln/Web PC	Composite Image on Vn server	Composite Image on Vn server	Composite Image on Vn server		Composite Image on Vn server	Remote Access, Control
LAN/WAN	Local Hardwired	LAN: dedicated Xmit/Rcv Chip pair over ethernet.(<10Msec latency)	HTML over WAN	TCP-IP over Ethernet	TCP-IP over Ethernet + Streamed Image	TCP-IP over Ethernet	TCP-IP over Ethernet	TCP-IP over Ethernet	Dial-up Modem. 56Kbps is adequate

3.3 Network and Infrastructure Designs

As already identified in section 2.1.3, Ethernet communications (10, 100 or 1000 Mbps) has become a default network communications standard for more than 80% of LAN systems worldwide. An important advantage for migration is that TC/Virtualisation architecture is compatible with and will map directly to existing Ethernet network topologies (Ethernet wired STP ISO/IEC 11801 Category 5 cabling, Fibre optic and WLAN 802.11x). As shown in the Teradici example in Section 2.3.4 a very advanced encrypted protocol can be transmitted over the existing IP network, delivering near-workstation performance including additional peripheral devices (2 No. DVI LCD's, USB connectivity and Audio). This level of performance is close to the leading edge of true Thin Client performance, having no OS or data exposure at the Thin Client side. Only the dedicated Portal or ASIC is present within the TC, and carries encrypted data while the unit has an authenticated connection. This advanced solution can be super-imposed on the standard office Ethernet LAN (Ethernet 10 or better). At present the Teradici device is used only with Blade PC's but may become available to link to VM's in the near future.

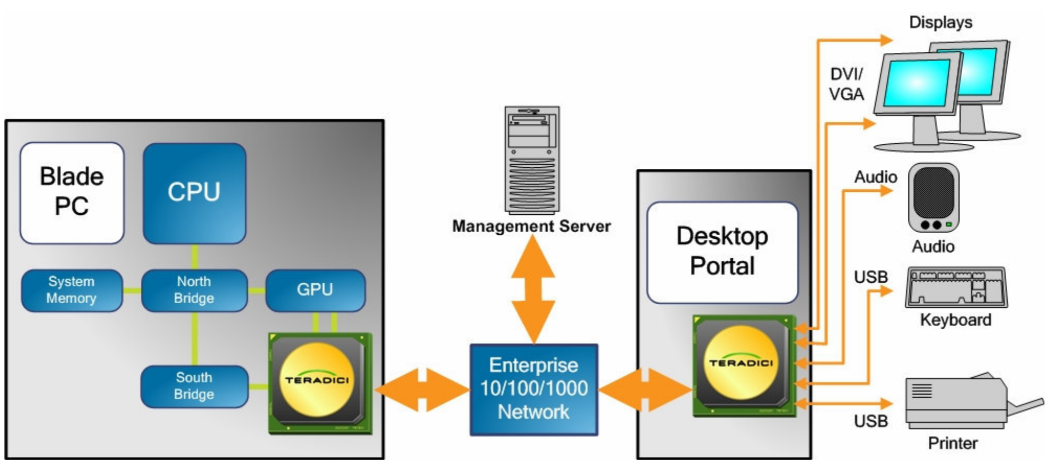

Figure 9: Teradici zero-state Thin Client system

Standard RCP connections also avail of existing IP networks. However as has been shown in Sections 1 and 2, these protocols have not so far evolved to provide the actual workstation level of performance, particularly in the area of graphics-intensive applications, motion video and USB peripheral support. Nonetheless many standard line-of-business applications (LOB) can be delivered over Ethernet LAN on Thin Client devices without any significant degradation of performance.

Further developments of special-purpose proprietary protocols such as the Teradici accelerator chip pair, and enhancements to the existing RCP protocols to overcome these recognised limitations are constantly under review. The TCP/IP over Ethernet networks are standardising on 100 Mbps on STP (Ethernet wired STP ISO/IEC 11801 Category 5) cabling or equivalents. Increases to 1Gbps and beyond will generally call for Fibre optic or specially developed cable links. A combination of research into the two technologies will continue to provide faster transmission of more concise data streams, tending towards and in certain respects exceeding actual PC workstation standard of performance. (See also Dynamic allocation of CPU resources in Chapter 5). Further developments in Fibre Channel switching may also become very relevant to delivering ‘Lossless’ presentations as a feature of MAN and WAN designs (Dunne & Intune Networks Dublin 2009).

DC Infrastructure management tools (Ref: VMWare View, Xen Citrix VDC, Microsoft VC-VMM, Ericom PowerTerm WebConnect) are becoming more important as part of the Virtualisation migration policy. The migration project will offer the opportunity to review and update Infrastructures Management policy and procedures. Many Hypervisor and Virtualisation products are now being delivered as part of a Systems and DC Management suite, offering long-term management and security utilities as an extension of the core Virtualisation technology. This area of systems Management is an offshoot of Virtualisation and Hypervisor technologies and may become one of the key facilitators for intelligent autonomic system and network management, delivered as a built-in feature of Virtualised systems.

3.4 Associated Technologies

3.4.1 Failover Server Cluster

Server Virtualisation is a well established DC technology which is delivering energy savings across the ICT industry. A single physical machine can support several Virtual Server environments, thereby achieving improvements in machine utilisation. However a single hardware failure (Single Point of Failure) on the physical unit may result in the loss of the complete set of Virtual environments, with serious implications for business continuity.

Server Clustering has been developed by several of the major vendors (VMWare, Microsoft *et al*) to provide a group of linked physical machines supporting the complete Virtualisation infrastructure. The Cluster Configuration (and defined file and memory sharing protocols) allows for continued operation of the Virtual devices in the event of hardware failure on a single machine. Moving of VM's to a new Server is also enabled, including the transfer from physical to virtual. The move may be triggered automatically by Autonomic sensors in the event of anticipated failure on a specific host.

Guaranteed continuity in the event of hardware failure is still something of a 'holy grail' for many developers. It is demonstrable that the VM can be transferred to a new Virtual or Physical Server by Administrator intervention. This transfer can occur during normal service, with minimal interruption to online processes. However there is no SLA-type guarantee that the Cluster will automatically transfer and support all live transactions (context saving) in the event that a single physical host is disabled by a hardware fault during normal Server operations.

A full sustained 'mirror' copy is required to run in lockstep with the host system to provide for full context saving, as in the High Availability (HA) option in VMware.

3.4.2 Ubiquitous Computing

Section 2.2.4 includes a definition of Ubiquitous Computing, and the examples cited above in 3.1 of the Virtualisation/TC models highlight just how achievable the ubiquitous PC service has become. As these developments continue, it is possible we will see a radical convergence of Communications, ICT, Geostationary Satellite Positioning (GPS) and uhf broadcasting technologies, delivering a 'Network Device' which will combine the most important advantages of PC, Laptop, Netbook and TC.

The Thin Client of the future may then become a foldaway or scroll-type LCD screen with onscreen i/o, connected to a pocket device. This Thin Client will connect the mobile user to the complete set of ICT functions and services using the most accessible and powerful network connection available. At present the Tablet Thin Client or Safebook (Devon IT) using 3G or better wireless network provides possibly the best example of a ubiquitous secure personal computing service for the standard PC user. In the context of Virtualisation, the user and his 'Network Device' or Thin Client may be anywhere on the globe, whereas the user's full computing environment and critical data are safely stored on one or more secured DC Servers.

(See example of demonstration WLAN Thin Client in the lab model of Chapter 4 and recommendations for further study in Chapter 6)

3.4.3 Multi Media Redirection

An example of transferring much of the graphics processing and rendering workload to the Thin Client side, the Wyse TCX Multimedia Thin Client shows significant gains in terms of freeing up CPU cycles at the Host Server. (See Figure 9: and Figure 10: the blue graph shows % processing time and the yellow graph shows Bandwidth in Mbps) The reduction in processing time is due to the transfer of graphics processing tasks to the processor at the TC. There is also a corresponding critical reduction in bandwidth consumed (Mbps) by sending the multimedia graphics file as a command sequence rather than sending the full screen buffer per frame.

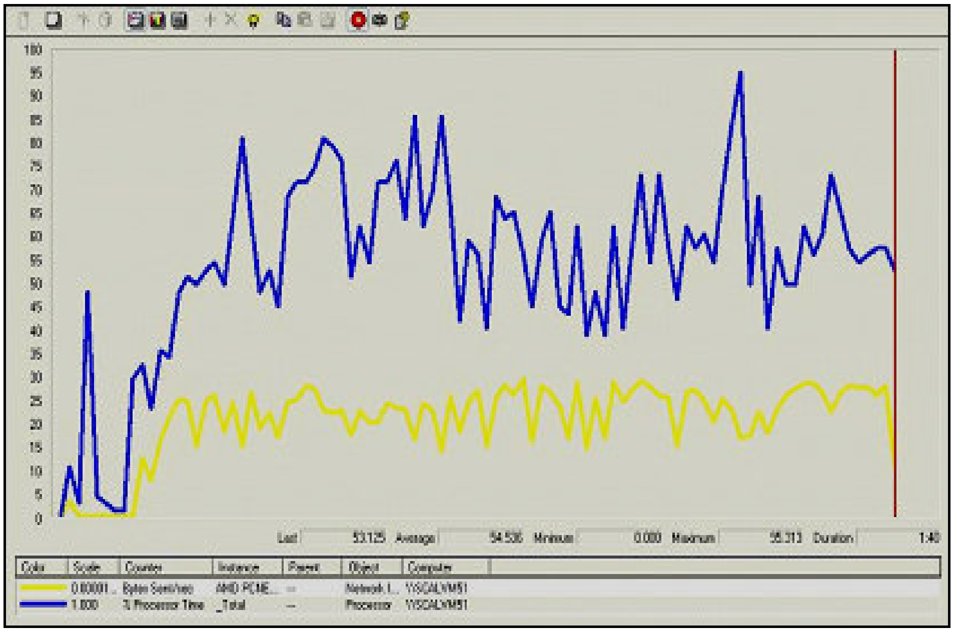

Figure 10: CPU and RDP Remote Video Load - Typical Situation

Figure 11: CPU and RDP Remote Video Load - Typical Situation

Typical Situation – Heavy and constant use of both the server CPU and the network bandwidth as RDP tries to communicate the multimedia information to the client

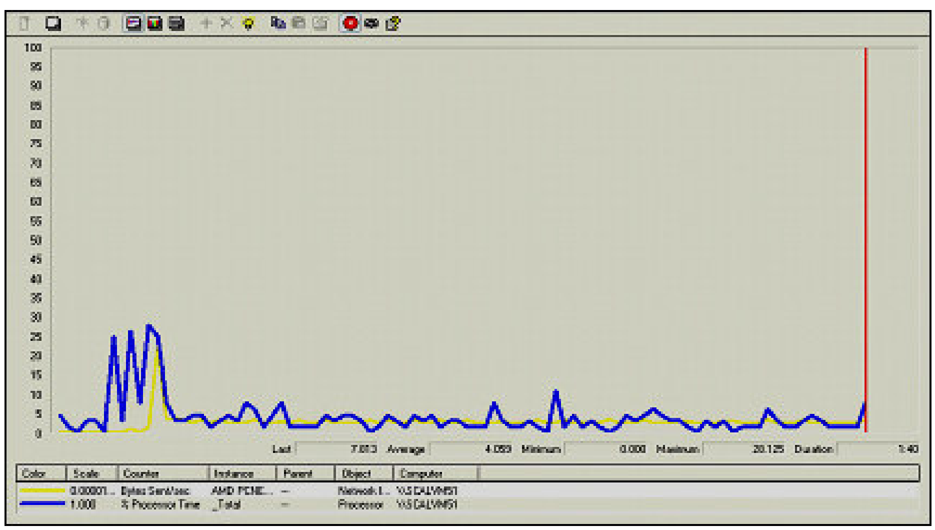

Figure 12: CPU and RDP Remote Video Load - Wyse TCX Multimedia Enabled
Figure 13: CPU and RDP Remote Video Load - Wyse TCX Multimedia Enabled

With Wyse TCX Multimedia enabled – Server CPU and network activity for the same user action is reduced significantly

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As outlined in Section 2.3 a number of manufacturers (Wyse, Igel, HP) are building in graphics rendering functionality, hardware and software, at the remote TC side. This example of Wyse TCX technology gives an indication of the reduced bandwidth requirement using this configuration, and also highlights the compromise of transferring workload to the remote TC side to optimise on RCP bandwidth.

3.5 Summary

A wide range of variants based on the essential TC concept are being made available commercially. Designs can be categorized in terms of the amount of functionality devolved to the TC side, and there is evidence of a drift back to local computing and storage whilst retaining central management and data protection at the DC side. Convergence of technologies is also leading to synergies in design and production of personal hand-held devices. Special 'Lossless' display devices using dedicated electronics and standard TCP-IP links are supplied as an ultra-thin stateless client option, where only screen pixel data is sent from the host machine to the TC. Further specialist technologies associated with TC provide for high-availability ubiquitous PC service, with near PC graphics quality

Common to all the new developments is that network devices will map to existing Ethernet LAN 803.3 topologies , enabling slot-in replacement units (Server and TC) as a low-cost feature of the migration to VDC project.

4. The Teaching Lab Model

4.1 Introduction

Sections 1 to 4 explain the design and purpose of the demonstration Virtual lab model as a central feature of the overall survey and examination of VDC and the component technologies. It is intended to demonstrate the fundamental features on a micro scale, to validate the findings as outlined in the Literature and Industry survey and to provide a hands-on experience of a range of physical units including a Virtualisation server environment, LAN Thin Client and WLAN Thin Client.

Section 4.2 provides details of individual device configuration, followed in Sections 4.3 and 4.4 by a description of the basic lab test procedures and their results.

In section 4.5 details from an Interview conducted with Dr John Dunne of Intune Networks Ltd. are included to further illustrate QOS issues and the challenges of delivering aggregated TC computing and similar Internet and Web services over MAN/WAN connections. Advanced developments in tunable fibre optical lasers are proposed as the solution to MAN/WAN latencies and capacity, making available bandwidth-on-demand over existing FC circuits. These developments at the physical and transport layer will underpin the ongoing refinements of RCP protocols, by effectively integrating the transport layer into the underlying FC medium.

In order to demonstrate and assess a typical Virtualisation/TC LAN configuration the basic model was built in accordance with the project deliverables set out in section 1.4. The basic components are a Dell /Windows SBS Server 2003, 3 Thin Client devices from Vendors HP, Igel and Devon IT and interconnecting Ethernet 100 LAN switch and Zyxel NBG 334L wireless router.

The Laboratory model was used to simulate a number of standard tasks, and results were compared against an equivalent PC performance. The results of these tests are recorded in Section 4.4., tables 10-14.

The Laboratory model is also used to demonstrate a mobile, wireless, Thin Client device on a WLAN. The model used is a Devon IT Safebook running the original DETOS Operating System. This model is used to deliver full Microsoft (MS) XP SP2 and Windows 7 (Beta Test copy only: Build 7100) desktop sessions at any location within the WLAN radius. As part of a further study it is planned to connect this model to a host device using WWAN connection.

(The options considered are O2 and Vodaphone 3G/4G modem broadband. See also Chapter 6, *Opportunities for Further Research*).

The purpose is to demonstrate the fundamental operations of the component technologies,Virtualisation, Thin Client and the RCP interconnect and to extend these functions to the WLAN mobile 'ubiquitous' Devon IT device. Using basic tests it is intended to prove that the model will function as a near equivalent to the standard PC device in a test environment and also to demonstrate that in certain key aspects, the model will fall short of PC performance.

The results are intended to be indicative only. Overall performance measurements (task completion) are used to clarify the case for and against Virtualisation/TC in standard commercial and academic environments. Where degradations in performance or failures are noted, the cause is identified and attributed to the functionality which is at fault.

The general results will reflect the experience of typical users confronted with completing standard computing tasks from a Thin Client device. The results suggest no significant perceived deviation in terms of Thin Client performance as compared to standard PC, except where indicated in relation to graphics and multi-media presentations. The user can log in and access all applications 'as though' logging in at the PC. It is important to consider that the end-user does not require any special training to avail of the new technology. The benefits in terms of data security, energy conservation and general systems management are transparent to the end-user.

4.2 Device Configurations

The test devices to be used are set out below:

a) Host Server running MS Virtual Server 2005:

Microsoft(R) Windows(R) Server 2003 for Small Business Server

Version 5.2.3790 Service Pack 2 Build 3790

System Model Dell Power Edge SC440

Total Physical Memory 4,029.81 MB

b) Thin Client HP Compaq t5520

800 MHz processor

64 MB Flash memory

128 MB DDR SDRAM

Microsoft® Windows® CE 5.0 operating system

(NOTE: 16 MB of system RAM is reserved for video graphics usage)

c) lgel UD3 Thin Client

Linux OS

Microsoft® Windows® Embedded CE 6.0

Processor VIA Eden 800 MHz

Memory RAM IGEL Linux: 512 MB

Windows CE: 512 MB

Video Memory 16-64 MB shared memory

Ports 1x DVI-I (DVI-to-VGA adapter included)

d) Safebook (Thin Laptop) DeTOS V6

CPU Intel Celeron 550

Memory 2GB Flash 1GB RAM

Display up to 1280x800 at 32bit colour depth

Internal 802.11x wireless

All devices are interconnected over Ethernet 100 on a Dell DC mini-hub. A Zyxel NBG 334L wireless router is used to connect the Devon IT Safebook on a 802.11x WLAN wireless link.

4.3 Summary of Lab Tests

Tests 1, 2 and 3 show normal tasks being performed from the Thin Client, but with actual results being processed at the VM and relayed as screen image to the Thin Client over RCP.

Test 1: Google applications File Upload. A 250 Kbyte Word document is uploaded to Google applications from the host Server

Test 2: Google search for terms "nyse,ftp,owner,nyxdata,euronext.tokyo".

Test 3: Ping to known www.NYSE.com host: confirm round-trip latency.

Test 4: vVideo playback statistics. A test Video File Amazon_720.wmv (1.42 minutes duration) is played on 5 different configurations.

Test 5: Live TV Display 2 minutes duration. Compare viewer experience on Thin Client and PC. Record actual Frames Per Second (fps) and frame drops.

Test 6: Demonstrate Devon IT SafeBook Thin Client using WLAN connection to access MS XP and Windows 7 from any point within WLAN radius.

The critical traffic for this survey is the Remote Computing Protocol (RCP) session which is negotiated between the TC and the Virtualisation server, and which renders the Virtual Machine (the secure PC as distinct from the embedded OS) on the local Thin Client device. In practice, the best test of this rendering over RCP (Tests 4,5 and 6) is to load the protocol with graphics–intensive content (in this case Live TV and Video transmissions) and observe the failures introduced at the application layer. The best metric available for Live TV presentation was found to be the Frame drop or Frame skip rate which is recorded by the RCP and viewable at the Thin Client, indicating the failure of the protocol and datacomms medium to render full synchronous 25 fps motion video as compared to the reception at the PC (Qi & Dai 2006).

For Video playback quality, the subjective QOS evaluation by 5 typical users , taken together with the data transfer volumes per platform are used as an aggregate indicator of presentation quality. Although frames are evidently dropped in video playback as part of the RCP processing, there is no audit log to confirm the actual skip rate as used in the Live TV example. As in earlier tests of multimedia over RCP , the available statistics can be used as a general indicator of what is evident to the user – a much reduced video replay quality when viewed over most typical RCP connections (Nieh & Yang 2000).

It should be noted that TV and video presentation at the standard PC is also imperfect, subject to the available bandwidth between the PC and signal source (Here the RTE TV network). The only hypothesis to be verified in this video test is that the RCP-mediated PC session will further attenuate and distort the video image files due to the intrinsic limitations of the RCP protocols running on standard datacomms media (STP cable and UHF wireless).

It is noted also in the results that the Fibre Channel medium is less prone to this failure, due to superior bandwidth capacity, minimal latency and immunity to EMF interference.

4.4 Lab Test Results

Tables 10 to 14 show sample results for the test units.

A number of basic tests are included to indicate the normal functioning of the Thin Client devices connected to XP VM on the server as compared to standard PC.

TEST 1:

Task Completion: Google applications File Upload. A 250 Kbyte Word document is uploaded to Google applications from the XP VM. Variations occur depending on the external network load but are not attributable to RCP or the TC.

Result Table 10: No significant variations in File Upload times. Source and destination is identical for each test file transfer.

Table 11: Virtualisation - Google Apps File Upload

Virtualisation - Google Apps File Upload								
		LAN	LAN	WLAN	LAN	LAN	WLAN	
Model	results	Igel - UPC	HP	Devon	Igel3/4	PC	Laptop	IP
XP		25	33	50	33	35	35	
Tests on Thin Client comms- 250Kb Word File upload to Google Apps **Upload times variable on DSL connection** User = user : Password = Password								

TEST 2:

Google search for terms "nyse,ftp,owner,nyxdata,euronext.tokyo". Total of 1 query, 5 constraints in approx 50 Msecs. No significant variation between PC and TC Search times and results virtually identical.

Table 12: Google Search over RCP

Virtualisation - Google Search Test							
		LAN	LAN	WLAN	LAN	LAN	WLAN
Model	results	Igel - UPC	HP	Devon	Igel3/4	PC	Laptop
XP	Time , Msecs	400	200	220	270	150	220.00
Windows 7	Time , Msecs	NA	270	240	NA	NA	440.00
Google search on 'nyse,ftp,owner,nyxdata,euronext.tokyo' **Response times for avg. 2-4 results from 150-500 Msecs** User = user : Password = Password							

*Note: Values recorded for Devon IT device may be affected by home WLAN limitations

TEST 3:

Task Completion : Ping to known www.NYSE.com host: confirm round-trip latency. Presentation and results identical for PC and TC task

Table 13: Virtualisation - Ping NYSE.com from TC Test

Virtualisation-Ping NYSE.com from TC Test							
		LAN	LAN	WLAN	LAN	LAN	WLAN
Model	results	Igel - UPC	HP	Devon	Igel 3/4	PC	Laptop
XP	Time , Msecs	14	16	15	16	21	18
Windows 7	Time , Msecs	16	18	18	NA	NA	18
NB Ping latency is the measure of TC reach . Limit = 100MSec							

TEST 4:

Video playback statistics. A test Video File Amazon_720.wmv (1.42 minutes duration) is played on 5 different configurations. Compare viewer experience on Thin Client and PC.

Values A) Subjective evaluation (QOS) compared to PC (Range 1 to 10).

B) Total duration.

C) Total data transfer (Mbytes) per playback per platform using a network traffic analyzer (Etherpeek). Includes display data , control data and packet overhead, which can account for some variations. However the protocol coding will in time be seen to manage the transmission and the dropping of specific frames to optimise available bandwidth. Win 7 values suggest improvements in compression , possibly allowing for RDP 7 compressors.

(see also RDP7 in Technical Appendix)

Comparison of results indicates variations in quality and throughput depending on protocol and device used (Nieh & Yang 2000). 'Lossless' video presentation is seen as achievable, but parameter settings will have a significant impact in terms of the data transfers per session, for example Colour depth set to 8-bit up to 32-bit .

The frame skip log is not given in the Media player for Video playback over RCP. However the QOS value is obviously very poor compared to the PC presentation. There is evident skipping of content to maintain realtime display on XP . Screen 'Artifacts' are visible during *all* presentations over RCP in these tests.

(Note: The original video clip used in the 200 Yang and Nieh experiment (2002) called for 3 Mbps while the Amazon_720 24-bit colour clip is set to 6.4 Mbps)

Result table 13 test Video displays – Frame drop count not available on Media Player for Video playback

Table 14: Virtualisation - Video Presentation over RCP and on Thin Client

Virtualisation - Video presentation over RCP and on Thin Client

	Link	QOS (5 samples)	Duration	total data xfr (MB)	Protocol	Rates	Notes
	Laptop - Server	10,10,10,10,10	(1min 42 secs)	88,91,92,93,93	SMB		Map drive
	XP VM - HP TC	7,6,5,8,6	(1min 42 secs)	135,139,140,138,140	RDP	6416 Kbps	
	W7 VM - HP TC	7,7,6,5,6	(1min 42 secs)	31,32,35,32,35	RDP		MS*
	XP VM - Laptop	6,7,6,8,7	(1min 42 secs)	129,140,141,141,150	RDP	6416 Kbps	MS*
	W7 VM - Laptop	7,6,7,7,6	(1min 42 secs)	66,62,68,68,67	RDP		version 7
70% 10Mbps	**PC-Server**	**6,7,6,6,7**		88,88,x,x,x	SMB		10MB link

Tests on Thin Client comms - Video playback

Notes: View 1 Minute 42 Seconds Video

Default RCP settings inc '*allow frame drops*' on Server , TC, VMs and allow *5 seconds buffering*

Show subjective **QOS** value (1 -10) X 5 users per playback per platform

Show time/duration (norm **1 Min 42 Sec**) of playback per platform

Show data xfr (in **MBytes**) per playback per platform

All values refer to test Video Amazon_720.wmv : 74MB

*Note MS Chapter 8 Item 1(e) - Microsoft table of data transfer reduction on RDP V 5.2 and V 6.1
Includes screen data , control data and packet overhead. W7 inc RDP 7 c/w compressors - see RDP in Apendix P 123

<u>TEST 5</u>:

Live TV Display 2 minutes duration. Compare viewer experience on Thin Client and PC. Record actual Frames Per Second (fps) and frame drops. Proof of loss is indicated in perceived Video quality. The metric used is Frames per second(fps)/ Frame Drop rate which is seen to be negligible at the primary receiver (Host PC or server), and to average 75 drops per minute on TC with up to 200 drops per minute on WLAN Mobile TC (Note : domestic WLAN router limitation) Result – Significant signal loss. See table 14.

Table 15: Virtualisation - Live RTE TV on Thin Client

Virtualisation - Live RTE TV on Thin Client							
		LAN	LAN	WLAN	LAN	LAN	WLAN
Model	results	Igel - UPC	HP	Devon	Igel3/4	PC	Laptop
XP	frame drops, actual/fps	61, 20/19	60, 20/18.3	100, 20/9.3	200, 25/19.1	10, 25/24.8	130, 20/12.9
Windows 7	frame drops, actual/fps	0, 24/18.5	0, 24/13	0 , 20/23	NA	NA	200, 20/13
Tests on Thin Client comms- Frame drops							
View 2 Mins Live RTE PC & TC							

<u>TEST 6</u>:

Demonstrate Devon IT SafeBook Thin Client using WLAN connection to access MS XP and Windows 7 from any point within WLAN radius. The Safebook mobile Thin Client is used in carrying out Tests 1 to 5 as a comparison against Standard Thin Client and PC over Ethernet LAN. The results correspond to performance on wired Thin Client, with some fluctuations attributable to domestic WLAN coverage.

Result – The WLAN mobile TC device is seen to perform broadly similar in response to the standard wired TC units. Further research is proposed to carry out equivalent tests on WWAN connection using O2 or 3G national WWAN network. This test is to prove the viability of the true ubiquitous mobile PC service on TC device.

Results Table included as WLAN/Devon IT column in Tables 10 to 14.

Each of the tests 1 to 5 includes the response/ performance when carried out using the Devon IT Safebook as a mobile Thin Client over WLAN Ethernet 802.11(b).

4.5 Details of Interview with Dr John Dunne of Intune Networks

The above tests in section 4.4 have shown that:

a) Thin Client and similar SBC services can be delivered over quality LAN connectivity with certain known limitations

b) Delivery of TC computing across Internet and Web introduces new challenges in terms of bandwidth, latency and Quality of Service (QOS) over variegated switched WAN services. Guaranteed QOS on free Internet will not be delivered to SLA standards using existing telecommunications networks.

The new technologies proposed by Intune Networks Ltd are designed to bypass the latency and cost/complexity of traditional IP routing by encoding data traffic at the physical level (Wavelength colour coding by destination)

Dr Dunne makes the following key observations:

- Server based computing and Internet services are available on current WAN connections, but without any guarantee of reliability or QOS.
- Thin Client computing is available over Internet connection but will not scale up for general use over existing network technologies.
- Typical transactions over Internet will encounter 20 hops or routing points , with variable wait times at each point. Routing becomes a cumulative overhead over WAN.
- Users are familiar with the advantages and the failings of present-day Internet services (the ‘World Wide Wait’ scenario).
- To deliver professional SLA type services over MAN/WAN calls for a new telecommunication technology – Bandwidth-on-Demand

This level of service can be provided by integrating MAN/WAN switching and routing to the physical level , that is tuning the fibre optical wavelength to specify destination.

4.6 Summary

In previous experiments and in the above tests it has been shown that TC computing is a viable solution at the individual level and in a relatively ideal LAN context. Graphics intensive content such as multimedia for multiple users will present problems for even the most advanced LAN connectivity. Delivery over MAN/WAN distances and routing complexity will introduce further limitations for anything more than standard content, and it has been identified how RCP protocols are coded to switch to reduced image quality when bandwidth is restricted. For example, playback of the test Video clip Amazon_720.wvs calls for bandwidth of over 5Mbps for a single recipient , more than the capacity of many typical broadband links.

These limitations call for a new scientific discovery or innovation, probably at the lower level physical and transport layers, which will provide a tipping point to enable true responsive interactive remote computing services over WAN connections. The tests and results above demonstrate the viability and potential of the component technologies, while at the same time highlighting an intrinsic weakness in the VDC model. New research and developments particularly in Fibre Optic switching may provide the impetus to deliver the full TC computing service over very advanced datacomms networks.

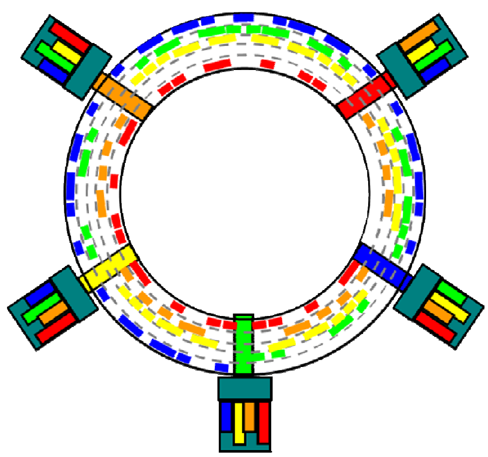

Figure 14: PMM-MCO-090828-RingVid

(Schematic of Intune Network Ltd Tunable FC laser)

5. Evaluation

5.1 Introduction

This section includes a summary of observations arising from the survey of current Virtualisation and Thin Client technologies in Chapters 2 and 3 and from the demonstration Lab system described in Chapter 4.

From Sections 2 to 4 it is possible to summarise the main advantages delivered by Virtualisation/TC technology. These advantages derive from research and developments at the scientific level, engineered and customised by vendors to deliver enhanced performance and cost savings to the user.

A number of limitations will apply to even the most advanced Virtualisation/TC technologies, particularly in the areas of graphics processing and signal latency over WAN connections. Several of the most advanced features are introduced as part of the industry's efforts to overcome connectivity problems, as indicated in the examples below.

5.2 Key Issues

The following items embody the overall evaluation and assessment of Virtualisation/TC technologies as a potential quantum leap in ICT services provision and personal/business computing.

5.2.1 Administrative Issues

Image management, Connection brokers, Composite Image

As with TCO and Systems management, there is a range of VM Management suites which allow for very high availability as an integral feature of the Virtualised DC. Single-copy 'Pristine' OS and application code blocks allow for efficient deployment of custom-optimised user workstations as and where required. The migration to Virtualisation/TC will give the opportunity to review and upgrade the overall Infrastructure Management policies, enabling economies in terms of provisioning, support and maintenance. Monitoring and Security systems can be concentrated within the DC and intensive (autonomic) monitoring applied across all physical and virtual environments

(Ref: VMWare View, Xen Citrix VDC, MS VC-MMC, Ericom PowerTerm)

Dynamic allocation of resources.

It is possible to 'ramp up' CPU Processing power and/or Virtual memory for a typical Thin Client running an intensive computational load. This is an example of the Thin Client performance exceeding normal PC – where the need exists. The cost of powerful Server processing and memory capacity at the DC continues to decrease, meaning dynamic allocation of resources to selected clients need not be considered a serious overhead (Adams et al. 2009).

Dynamic image Provisioning.

A new instantiation of for example a typical PC workstation requires only a cloning from source of a corporate approved image, complete with a specific user Profile settings. A new staff member using a simple Thin Client can therefore be up and running on his/her new PC within minutes of arrival. Similarly, a Server farm supporting an E-commerce site can be augmented by additional Virtual Servers on demand (hosted on normally dormant hardware) to meet peak demand periods. These Servers can in turn be retired when no longer required, providing excellent business responsiveness on commodity Servers at minimum energy costs. (See also Microsoft Core Parking in Section 2.3.1)

True Ubiquitous access to the Desktop or PC service .

Ubiquitous computing refers to the many intelligent devices and sensors in the environment. For the business user, the most important option is ubiquitous access to a secure personal computing environment. This means that the user's docking station (link) is literally everywhere.

It is now becoming possible to avail of 3G and 4G Mobile broadband wireless communications in the form of a standard broadband 'dongle' fitted to a Safebook Thin Client Laptop (Devon IT) or one of the many equivalent 'Net-book' devices.

Subject to adequate coverage (nationwide masts, Thin Client antennae) a user's PC session can be accessed from any location. Once the Safebook Thin Client laptop is switched off, there is no local content exposed to theft or misuse –

meaning an end to a significant security concern. Continuing developments in 3G /4G wireless connectivity are bringing the true ubiquitous PC service ever closer.

Reduced VGA/XGA/DVI graphics reproduction

Subject to latency and bandwidth available to the RCP protocol, the typical Thin Client will not usually handle graphics intensive applications or motion video as well as the standard PC. As a result certain applications (e.g. CAD, 3-D Design, Video editing) are not so far available on the standard Thin Client device. The PC contains a local Graphics Controller, Display Adaptor or Video card dedicated to rendering the local display presentation and driven directly from the local OS kernel data output, normally via the internal Parallel data bus.

In the Virtualisation/TC model, the screen updates must be delivered over the RCP serial data interconnect from the Virtualisation Host Server, either as full bitscreen files (incremental) or in the form of abbreviated commands which are decoded locally by an equivalent Display Adaptor within the TC. In either case, it is difficult for the Thin Client to equal the performance of the full local parallel-bus Graphics Controller card on the PC. This is an area of research which is under constant review. However there is no absolute solution as yet to this Thin Client limitation, although full Video performance has been achieved in experimental configurations (Baratto et al. 2005)

(The Screen Refresh / Bitscreen file transfer overhead is the limiting factor)

See also Section 2.1.3 and the model demonstration results in Section 4

Range of Virtualisation/TC options.

Options range from true Thin Client to Blade PC via Virtual Client which comes with local processing and cache but with zero data retention. Many developers are coming to market with increasingly diverse Virtualisation solutions. Where users will not forego the familiar ‘fat’ desktop PC, it is now becoming possible to retain the advantages of PC (local processing, local graphics generation) while availing of a protected Virtualisation environment (Virtual client with streamed Image). See also Table 3.2 (a) for details of a range of Thin Client alternatives.

VDC will be more demanding on Virtualisation Server than simple application Virtualisation.

There is a significant demand on processing power to deliver the full PC per user from the Virtualisation Server. One estimate suggests 15 typical clients per Server, as against 70-80 clients using simple application Virtualisation only. For example a Server running a LOB application may be accessed by 70-80 clients with little degradation in responsiveness. However the increasing availability of computing power and capacity will continue to support VDC implementation. The workhorse of the DC is now the commodity Server - inexpensive and increasingly computationally powerful. The 64-bit Processor is estimated to triple the client-per-processor ratio (Igel/Fraunhofer 2006)

It is important however to consider application-only virtualisation for many LOB solutions, possibly as an interim solution to full VDC deployment.

Total Cost of Ownership (TCO) and Systems Management.

The manageability of the total ICT Infrastructures engineered through the Virtualisation hyper-visor to provide Virtual Machine and image deployments will create significant economies for ICT management. Savings will be achieved on patching, service packs, security updates, re-imaging and full upgrades. There is a potential for a 3-fold increase in the Server/Engineer ratio (IDC, O'Donnell, Neoware 2007). Savings on 3^{rd}-party support costs and on hardware refresh (both calculated on physical units) will also be achieved. There will also be a requirement for new highly trained engineers in the Virtualisation data centre technologies and disciplines – a significant migration cost.

Existing PC’s can serve as TC’s up to write-off using a terminal emulator program or Virtualisation Card (ref: Igel UPC). The new Thin Client having no moving parts (solid state electronics only) will be proof against many of the typical hardware faults arising with standard PC’s.

5.2.2 Staff Access Issues

Remote access – home and offshore workers.

As with the example of a new staff member it may be necessary to provision a complete working environment e.g. a Call centre at a remote or offshore location. It may be necessary to protect all critical data within the Corporate home office. Virtualisation can make available the required workstation facilities by deploying Thin Clients at the remote location, complete with adequate bandwidth interconnect.

Familiar Desktop environment – No staff retraining.

Although Virtualisation/TC is seen as a revolution in personal and business computing, a key advantage is that the technology is transparent to the user. The workstation environment should be exactly as before, except better !

Alternative OS / Image – Select from menu at Boot-up

A further advantage of the Image Management utilities is that alternative images or sessions are freely available to the client from a start-up menu, at the expense of a single additional Image file. In the scenario where a Company wants to upgrade from for example MS XP to Vista, it is possible to publish both options to the users desktop. The significant advantage here is that both images are delivered complete with the appropriate set of applications and Personal settings / Profile per user. This upgrade option illustrates the true versatility and scalability of the Virtualisation/TC and composite image solutions. The user may log on to the XP session and edit a data file. At next logon, the updated file is accessible from a Vista or Windows 7 session having the same profile (permissions) settings as the original XP user. (Composite Images)

Interconnect options.

The link between the Virtual PC hosted on the DC Virtualisation Server and the Thin Client device is critical to the success of the Virtualisation/TC solution. Universal standard serial interface protocols are available including RDP, VNC, ICA and X–Window. (Http/s protocol is used to access Web applications including web PC). Protocols may be run on TCP-IP over Ethernet or on WLAN

802.11*x*. Care must be taken that the physical link is adequate to throughput in terms of bandwidth and latency characteristics. Overload of the physical channel will result in impaired response at the Thin Client side, usually in the form of distorted graphical displays and audio reproduction.

All protocols depend on the underlying datacomms media. Optimised Fibre Channel offers best responsiveness and throughput.

5.2.3 Energy Conservation Issues

Reduced energy consumption.

Details are given in section 2.4 (*Virtualisation - the Ecological dimension*) of the typical savings in terms of energy and materials costs. Server utilisation may be increased from 30% to 80%, resulting in reduced DC power and cooling costs. The typical Thin Client will consume approx 40-60% as compared to the typical PC, even allowing for the incremental increase per VM to the Virtualisation Server workload.

Retrofit to existing Client/Server LAN topologies.

It is possible to roll out a Virtualisation/TC implementation, re-using existing Desktops, pending their actual write-off and upgrade to TC. An Igel UPC PMCIA card can be fitted to the existing desktop PC to connect to the Virtualisation Server, or alternatively a Terminal Emulator software module (e.g. NeoWare) can be installed to the existing PC. Over time the upgrade to Thin Client will realise the energy savings and the ergonomic improvement of the full Virtualisation/TC solution.

5.2.4 Security Issues

Enhanced security.

Using true Thin Client, there is no local asset at the client side other than the Thin Client device. Where a local embedded OS is used , lockdown policy and volatile storage (ram disk) ensure no local exposure. Data Protection measures to comply with Data Protection legislation (DPA2002, Sarbanes Oxley) can now be concentrated within the DC. Loss or theft of devices will not expose system data or programs to malicious access.

Consolidation of ICT resources and ICT assets within secure DC.

In addition to secure storage of ICT assets, there is provision for very high physical security and protection as an intrinsic design feature of the DC.

Business Continuity and Disaster Recover (DR).

Because the complete system content is directly available within the DC, it is only necessary to replicate the Server and Client Images (Typically 1 Virtual Hard Disk file per user) together with standard SAN backup procedures to enable a very fast Disaster Recovery operation (IDC,Egge,Martinez 2009). A number of commodity Servers at any alternative location will 'spin up' the requisite Virtualisation Servers to provide fast client access to all sessions. Data restore from SAN backup will probably be the only delay in recovery of normal business functions. With data replication to disk rather than tape, this delay can also be minimized. Overall the automatic replications of the virtualised environment will have a profound impact on DR and Business Continuity procedures.

5.3 Summary

The new developments in Virtualisation and Thin Client have given rise to many extensive revisions upwards in the delivery of Personal and Business computing services, which can be categorized under Administration , Security, Staff Access and Energy issues.

Not least among these issues is the potential to re-prioritise and re-engineer business process as part of a general improvement in how we do things, within ICT and when using ICT as a business aid in most human enterprise.

Taken together, and with parallel developments in efficiency, security and energy-efficiency of overall ICT equipment, these enhancements offer system designers and mangers new capability to meet the important threats and challenges of modern computing.

6. Conclusions and Future Work

6.1 Conclusions

The objectives of this study were to survey, examine and assess the recent developments in Virtualisation and Thin Client technologies. From these findings it was intended to identify the potential for wide scale adoption of these technologies in order to achieve significant improvements to data security and energy conservation in the ICT industry globally. The results from the survey and from a practical demonstration of the Virtualisation model used in Chapter 4 would verify if this technology can be adopted as a new secure 'green' solution for personal and business computing, and in doing so would also identify the significant inhibitors.

In analyzing the major efforts of the commercial and research communities to enhance their current offerings, it becomes apparent that data communications (including the physical medium, serial data content and the governing protocols) will remain as the scientific challenge to universal acceptance of virtualised computing across the complete range of ICT applications. The problems associated with different permutations of medium, content and protocol are demonstrated in the multi-media tests in section 4.3 and 4.4 and also referred to throughout the citations from the academic and commercial literature. These citations also emphasise the many different approaches being pursued to overcome the connectivity and datacomms limitations.

Highlighting the problems associated with datacomms also underlines the phenomenal advances in the other component technologies, specifically :

<u>Data processing.</u> 64-Bit Microprocessors addressing up to 32 Terabytes of system memory will continue to enhance computational power at the Data Centre. Processing delays should not be a physical limitation to Virtual Machine performance. Nano technologies will further enhance computational power at the central platform. However processing of multimedia content as demand for this material increases will place significant load on the DC Server if not relegated or redirected to dedicated rendering engines either within the DC or at the remote TC.

Thin Client devices availing of VLSI silicon and very low power requirement will continue to improve in performance, versatility and portability. In addition the design and build quality are directed towards very high reliability and minimum maintenance. This is to reduce TCO and risk exposure per TC device.

From these findings, it may be assumed that further exciting developments will arise in the RCP space which may have the effect of dramatically accelerating the implementation of Virtualisation solutions in the near future, leading to fundamental changes in personal and business computing.

6.2 Industry Responses

From the initial survey of Academic and ICT Industry research into the 3 component technologies (Virtualisation, TC, RCP) it is clear that there is significant ongoing research and development which will impact on Virtualisation/TC performance in the enterprise environment. Among the most relevant developments may be :

- Microsoft Hyper-V, Windows 7 and RDP7
- Citrix Xen VDI/ Citrix Xen Desktop
- VMWare View/VMWare vSphere Cloud Computing
- Teradici and VMware VM
- Sunray and ALP protocol
- HP Neoware
- Igel C300 Universal PC
- Wyse TCX Multimedia 2.7 with Multimedia re-direction

From some of the most innovative examples, it will be seen that more functionality is being transferred back to the Thin Client, with a view to providing PC-like performance whilst retaining the main advantages of Virtualisation and TC. As this process continues it is clear that there is now very little difference between a high-end Thin Client device (e.g. The Igel Universal PC and Wyse TCX Multimedia 2.7 model) and a standard-specification low-cost Netbook or laptop PC.

The laptop PC can be locked down and enabled for secure image streaming only, effectively becoming a secure TC. As these developments continue, it is possible we will see an enlightened convergence of technology and function, delivering a 'Network Device' which will combine the most important advantages of PC, Laptop , Netbook and TC.

In parallel with developments in the Virtualisation process and Thin Client devices, many manufacturers are conducting further research into accelerating the RCP serial (datacomms) interface:

a) By abbreviating and compressing the command strings and screen buffer files sent from Virtualisation Server to TC

b) By dedicating hardware logic to the encryption and compaction of the command and data strings.

Because of the physical structure and properties of copper conductors (STP), there is an absolute limit beyond which data will not travel over UTP or STP cable. Under ideal conditions 10 Gbps may be achieved on short hops but this will not meet the requirements of universal WAN and LAN users. UHF wireless (WAN) datacomms, while providing effective bandwidth and mobility , are vulnerable to atmospherics and environmental topography.

It may be that the ultimate solution to Thin Client performance is to provide Fibre Optic links to all major centres and ultimately to all online users, with local WWAN links (3G,4G) to support mobile users.

Industry specialists and manufacturers have commercialised a number of alternative variants as outlined in Chapter 3, including VDC, Universal PC, Blade PC, Virtual PC, Web PC and Virtualised applications. These offerings will be competitors in a volatile market. In parallel with the promotional and marketing activity by the leading players, there will be ongoing research to enable further enhancements to the core technologies, thus providing a competitive advantage, however temporary, for the most advanced R&D enterprise.

The prize will be a dominant market share for the Virtualisation/TC technology vendor who can cost-effectively transform the legacy distributed Client/Server networks to low-energy high-security virtualised topologies. By virtue of the strong supporting Ecological and Security arguments, it seems inevitable that Virtualisation/TC will become a default network architecture for LAN business computing, and ultimately for PC provisioning to home users over standard WAN broadband connections.

6.3 Future Work

The main inhibitors to widespread Thin Client adoption – datacomms limitations, server capacity, and suitable Thin Client network device - correspond with some of the main research topics in the ICT arena. Potential improvements in any of the key technologies will impact on the performance of the system components and thereby improve overall system performance. Suggested areas for further research would include:

1. *Fibre Optic WAN.* If the absolute capacities of STP cables (Typical maxima 100 Mbps over 100 Metres) is the limiting factor to datacomms, the increased capacity, security, minimal latency and noise immunity of the fibre optic link (1Gbps over 10Kms) may be a cost-effective solution to connectivity problems for *all* users. A costing and feasibility study to connect all users in the country via fibre-optic links may offer a worthwhile infrastructure project to guarantee the long-term national bandwidth requirement. Availing of the advanced tunable laser switching system will further minimise switch latencies over WAN connections. (Dunne & Intune Networks Dublin 2009). Estimated costs can be compared against comparable wireless and satellite systems, while also evaluating the fastest and most reliable signal path. Further research in this area may prove that fibre optic links will provide the most cost-effective, secure and ecological long-term solution to WAN datacomms.

2. *3G and 4G Modem broadband for ubiquitous access to secure personal computing.*

As part of this study a Devon IT Thin Client device was tested over WLAN (802.11b) connection, making available MS XP and Windows 7 virtual sessions at any point within the radius of the WLAN connection. Using a similar configuration over nationwide 3G or 4G cellular broadband would offer a valuable demonstration of ubiquitous highly secure, energy-efficient Thin Client computing at any point within commercial 3G/4G coverage. At this time major 3G providers including O2 and Vodaphone provide up to 90% coverage. The effective bandwidth, nominally 2-14Mbps may fluctuate in certain areas.

***3.** DC Enterprise manager - The ERM solution to ICT Infrastructure Management.*

An interesting offshoot of Virtualised and Thin Client systems is the DC management and Image provisioning systems outlined in Section 2.2.4. An in-depth survey of these Infrastructure Management suites would elucidate the new potential for total system monitoring and security via the Virtualisation Hypervisor access points. These improvements in manageability and systems security may be sufficient justification for the Virtualisation solution in many cases.

***4.** Evaluate 64-Bit Server and Hypervisor*

MS Windows Server 2008 (R2) with Hypervisor is a more recent and powerful version of the Virtualisation Server 2005 platform used in the Lab model in Chapter 4, with additional features as listed in Section 2.3.1. Using the following hardware and software items will provide a more powerful example of a commercial lab simulation model for 30 users:

1 No. Dell Power Edge M600 Quad Core 16GB Intel blade Server (6 X i/o Channel)

(Virtualisation optimised)

I No. Copy MS Win 2008 Core Hypervisor or equivalent + Vista Client + Windows 7

3 No. Industry standard Low-energy Thin Client devices max 100 watt runtime consumption.

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Appendix A: Technical Appendix to the Dissertation

Table of Contents

<u>Item 1</u>: A Survey of RCP Issues: Serial Data Transmissions and Signal Latency

(See also Section 2.1.1. above)

a) Parallel and Serial (WAN) Datacomms

Within the standard PC, the normal Keyboard / mouse input and Video signal output are carried on the internal Parallel bus or Interface, and the serial Interface connections to the local devices are minimal, normally a 1-3 Metre lead attaching to keyboard, mouse and USB peripherals. Therefore the normal PC User experiences effectively no delays attributable to data transmission. The delays are almost entirely based on the processing queue and storage access factors.

With Virtualisation, it is possible to dynamically provision processing capacity to Thin Client users on demand, and data access times are defined by high-specification SAN or File Server architectures. In this optimised environment, an apparent lack of responsiveness is often attributable to the serial data transmission channel which connects the Thin Client to the host Server, and to the associated graphics processing tasks.

In summary, the bandwidth requirement for Data Input (the Keyboard + Mouse component of KVM) is minimal and can be supported by a simple 56 Kbps dial-up connection. The 10Mbps+ capacities of typical LAN data links (and of many WAN links) will be more than adequate for data input. However the V (Video or Graphics) component of KVM is a potential inhibitor to universal TC/Virtualisation adoption, in that the full Screen Update command stream (incremental) must be carried and processed in real time over the RCP connection. This is relatively simple in the case of standard display screen updates (Word-processing, background images, Numeric processing) where local caching (typically 16MB discrete graphics memory – HP T5710 TC) will minimise the update frequency. Alternatively some developers favour the transmission of primitive Graphics commands, with local Graphics decoders (codecs or ASIC's) processing the command stream at the Thin Client side. This in turn will reduce the traffic on the RCP link (allowing for greater responsiveness and throughput) at the expense of adding back some functionality - a local graphics card or software layer - to the Thin Client.

One new example of relegation of function to the Thin Client is referred to as 'Multimedia Redirection', which allows for video (e.g.MPEG4) decoding by a special layer of software at the Thin Client as in the HP T5710 Thin Client referred to above (See also section 3.4.3)

According to a recent summary from a prominent industry consultant there is an increasing tendency to deal with the remote video over RCP problem by providing further decoding and rendering at the Thin Client side, or by using dedicated accelerator hardware:

"Historically, ICA and RDP were designed to flush the video frame buffer to the client roughly once every 100 milliseconds, which is fine for most Windows GDI apps, but not suitable for graphics-intensive apps, the (Vista) Aero experience, 3D apps, and especially apps that require audio-video synchronization. We hardly had much use for more than this functionality until recently. But now that VDC is being promoted as a "desktop replacement," remote display protocols will have to rise to the occasion".

Additional 'smart' rendering is achieved by caching of stock image sectors:

"Over the years, this screen-scraping has become very advanced. RDP, ICA, and other protocols don't simply look at pixels on the screen and compress them into graphical images. Instead this process is enhanced by analyzing the screen content and identifying screen regions that are being reused (such as icons, fonts / glyphs, dialog boxes, etc). Those graphics elements can be cached at the client side, so if the host needs to send one of these elements, it only transmits the reference number of the cached element and the new coordinates. This dramatically reduces the amount of data transmitted and thus increases performance and user experience. This cached information can even be used for enhanced local echo effects, like Citrix's Speedscreen Local Text Echo for the standard GDI output.

So even though the specific term "screen scraping" is no longer an exact literal representation of what is happening, the term is used more broadly to describe this general concept"

http://www.brianmadden.com/blogs/brianmadden/archive/2007/11/05/remote-display-protocols-for-VDC-will-RDP-be-enough.aspx

The overall industry position on Thin Client graphics rendering is subject to constant re-evaluations and updates. It may be that the Net2Display standard (Ref Section 2.2.1) will receive widespread acceptance in the industry, thus ending the ‘protocol war’ with a positive technical standards compromise. If agreed and adopted by the main players, Net2Display could provide the basis for a universal Virtualisation/TC solution with full graphics rendering over guaranteed serial datacomms standards.

Reflecting the current unresolved position concerning RCP’s and Graphics processing many Thin Clients today incorporate significant amounts of Display decoding and rendering, and the trend appears to be that Graphics processing will be increasingly relegated to the Thin Client end, with concise and compressed command languages carrying the image specification over the serial RCP. This is part of a trend towards a powerful CPU and basic OS at the Thin Client end, giving further support to the Hybrid or near-PC model of Thin Client computing. As the Thin Client acquires more of the standard PC features, the question of system security will arise in that any local system is potentially exposed to intrusion. Eventually the Thin Client may be equipped with a full CGI/GPU Graphics processing capability, reducing as much as possible the data volume carried on the RCP line.

At the other end of the spectrum, a powerful version of the ASIC solution is provided by Teradici which has a dedicated “chip pair” to govern the pc-client interconnect over IP from Host to Thin Client, incorporating all security, encryption and compaction algorithms in the hardware ASIC. See also section 2.3.4 (Teradici). This is an example of the true zero-state Thin Client option, readily available as a complete PC replacement over standard LAN bandwidths. Rather than the near-PC option, the zero-state Thin Client requires minimal management and support, and constitutes almost zero security exposure (Pixels only transmissions).

b) RCP and Bandwidth

It is essential to provide adequate Host Server-to-TC link bandwidth (measured in Megabits Per Second carrying capacity) to carry the volumes of data (Mbps) on the RCP line, specifically for high-volume content such as video or screen buffer files and optional USB file transfers. The weakest link will determine the effective bandwidth. A local loop capacity of nominal 2 Mbps bandwidth (typical for a home broadband DSL connection over twisted pair Voice-grade phone lines) may result in screen image distortion. (See also functional tests on 250 Kbps link in Chapter 4 – The Lab Model). It is a measure of the development of modern electronic signal processing that this volume of data transmissions can be achieved over what are basically voice grade telephone lines. The fact that these lines are already in position to most houses gives a commercial incentive to deliver bandwidth over the local loop, resulting in very advanced electronic circuitry and line conditioning applied to the Voice Grade phone lines.

Compaction and compression of data by reducing the volume transmitted will also improve the bandwidth performance. The physical limitations of the medium (copper, optical fibre, UHF radio) will remain as a challenge to current technologies.

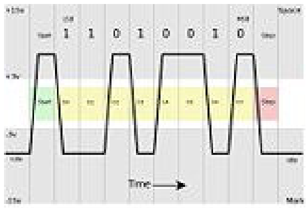
For the present, many vendors continue to promote their proprietary RCP standards (Microsoft, Citrix, VMWare *et al*). It is beyond the scope of this paper to validate rival claims as to performance, except to note the absolute limitations confronting all data link protocols. All the link media at the physical layer of the ISO/OSI Protocol model – copper, fibre channel, radio waves – are subject to immutable physical laws. Inductance, Capacitance and Resistance phenomena will affect pulse coded modulations over distance and subject to frequency/baud rate. A baseline is the optimal structure of Category 5 STP (STP ISO/IEC 11801 Category 5) cable which will transmit 100 Mbps over 100 metres distance. Increases in either frequency or distance will lead to increased slew rates and reflections affecting the pulse coding, distorting the binary values. The more intelligent RCP protocol will make best use of the available bandwidth (e.g. by compression, compaction and minimising RPC calls) and may also mitigate the latency problem by prioritising latency-sensitive data, but cannot increase the actual throughput of the physical link media. Fibre channel is effectively noise-immune and offers high-bandwidth and minimal latency. Costs of installation and physical vulnerability as compared to standard copper links remain as an inhibitor to Fibre Channel WAN links.

c) RCP and Signal Latency.

Given adequate bandwidth there is still the question of latency, which is the propagation delay usually measured in Milliseconds for signal transmission e.g. the delay between pressing the ‘K’ key on the Thin Client keyboard and the appearance of ‘K’ on the Screen. The Ascii Bit Pattern for ‘K’ character (together with framing and CRC data bits) must traverse the WAN back to the Virtualisation Server, and the screen update frame be returned to the local Thin Client LCD screen, all within 100 Milliseconds.

(Responsiveness within 100 Milliseconds is the norm. Research shows that a delay of 100 Milliseconds or greater will be perceived as a problem by the Thin Client user) (Dabrowski & Munson 2001).

Table 16: The Letter 'K' as represented in ASCII



Example: The Letter 'K' as represented in ASCII value and as electronic pulse value

A Ping or Traceroute command (ICMP Commands) can be used to identify the latency between any 2 node points (See test 2 in Chapter 4 Section 4). For example a Ping command to a Server in New York may complete the round trip within 12 Milliseconds, hence ideal for Thin Client. (See Ping and Traceroute result tables on next page). However certain 'chatty' applications with high-frequency RPC round trips may require even lower latency than the recommended 100Msecs.

A Traceroute (ICMP) command to a Server in Germany may indicate a 50 Millisecond delay on the London / Hamburg segment or 'hop' of the signal path, identifying a relatively poor link in the connection which could contribute to excessive latency, resulting in perceived system failure or 'video lag' at the client side.

The Fibre Optic cable connection between Ireland and USA accounts for the excellent results in the first case. Simple Unscreened Twisted Pair (UTP) or Screened Twisted Pair (STP) copper cables will have a latency based on the resistivity of the copper conductors over distance in Metres (see also section 2.1.3).

Existing Voice Grade (phone) lines – often the path available on the 'Local loop' - may be the weak link in the signal path for a home user.

Satellite comms have a default latency of up to 2 seconds, to allow for the UHF signal latency between geostationary satellite and target host. There is also a question as to full coverage as atmospheric conditions can affect the signal, thus ruling out the Satellite option for standard Virtualisation/TC.

Improvements on the performance of Satellite WAN links is ongoing (ref Cisco NCE) and for Global and mobile applications Satellite may be a best option subject to the latency and interference calculations.

"Despite these benefits, sending data through a high-altitude satellite introduces a significant signal propagation delay that has a noticeable effect on the quality of user experience with satellite links. For geostationary orbit satellites (GEO), the round-trip delay is 500 to 600 milliseconds. This high latency and other technical factors, such as asymmetric data rates and high packet loss, affect the response time of content-rich and interactive Internet applications".

(http://www.cisco.com/en/US/prod/collateral/modules/ps2797/solution_overview)

Use of Ping and Traceroute ICMP commands to measure signal latency.

Example of Ping operation to and response from remote host. (Ref: Chapter 4,test)

Pinging NYSE a789.g.akamai.net [92.122.124.10] with 32 bytes of data:
Reply from 92.122.124.10: bytes=32 time=11ms TTL=61
Reply from 92.122.124.10: bytes=32 time=14ms TTL=61
Reply from 92.122.124.10: bytes=32 time=14ms TTL=61
Reply from 92.122.124.10: bytes=32 time=11ms TTL=61
Ping statistics for 92.122.124.10:
Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milliseconds:
Minimum = 11ms, Maximum = 14ms, Average = 12ms

It is clear from these results that a problem of latency may occur on a single segment or 'hop' of the WAN signal path. We also see in the Ping example that a Thin Client connection to a Virtualisation Server in New York (NYSE.com) is perfectly viable for a Thin Client user in Dublin (Average 12 Milliseconds latency on the Ping round trip). As a general rule LAN latencies will be adequate to support TC. Many long-distance WAN connections will also function perfectly well, whereas a relatively short-haul connection over slow lines may rule out a WAN Thin Client connection. The Traceroute from Dublin to Perth WA going via New York and Singapore would rule out a Thin Client connection between these sites. (Average 381 Milliseconds latency)

d) RCP – the new Net2Display proposal.

In addition to the number of existing link protocols in use, there is at present a working group of leading experts preparing an Industry standard RCP, to be known as Net2Display. (Ocheltree et al. 2007)

The speed and responsiveness (usability) of the VDC solution is largely dependant on the RCP and the underlying datacomms channel. The arrival of Net2Display as an agreed standard will be of great significance to the industry. Proposed improvements in Compaction, Encryption and general standardization will make VDC a viable option over previously unavailable WAN distances. (Ref: Latency and Bandwidth in Section 2.1.3 Serial data communications). See also section 1.1

e) RDP Version 6.1 to Version 7

Recent upgrades to the Microsoft RDP protocol have introduced new 'compressors' to achieve gains in bandwidth efficiency for standard screen displays, including new Vista *Aero* translucent rendering. The table 16 below gives an indication of up to 20% efficiency gains over V 5.2. The newly available Version 7 used in conjunction with Server 2008 R2 and Windows 7 will undoubtedly further improve the user experience.

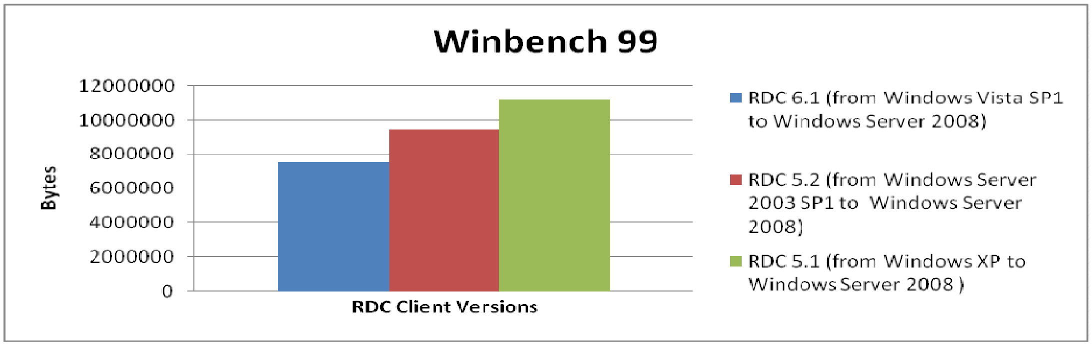
(See Video playback test in Chapter 4 Section 4)

"Table 15 and Chart 12) show the bytes sent over the wire running tests by using WinBench 99. The tests were conducted between different clients and the same server running Windows Server 2008. This ensures that we are sending the same amount of graphics data across the channel. The tests were conducted at ***16-bit color depth*** *with WinBench 99 on the server."*

Table 17: Bytes sent over the wire running tests by using WinBench 99

RDC Client Version	Server-Side Operating System	Bytes	Performance Gain Using RDP 6.1
RDC 6.1 (Windows Server 2008)	Windows Server 2008	7559075	
RDC 5.2 (Windows Server 2003)	Windows Server 2008	9450351	20%
RDC 5.1 (Windows XP)	Windows Server 2008	11185633	32%

Table : Bytes sent over the wire running tests by using WinBench 99



Bytes sent over the wire running tests by using WinBench 99 Flow Control

Chart 12: Bytes sent over the wire running tests by using WinBench 99 Flow Control
© Ref : Microsoft Technet sources 2009

Item 2: Serial Data Transmission – From current pulse Telegraphy to Ethernet 10Gbps with details of relevant EIA Standards

(See also section 2.1.3.3)

Switching devices may be as slow as the manual keying of characters into the Teletext device. (Bytes per Minute). At this fundamental level, the basic electrical circuit will register clean pulses with minimal distortion over very long distances. In the early days, it was only necessary to amplify the current source to ensure that a 20 Milliamp current pulse could traverse the circuit and be read as a clear '+ve' bit at the receiving end. In the same way, the current-carrying capacity of the link cable was the sole determinant of signal attenuation. A calculation of the Resistance of for example a transatlantic Copper cable link (3000Miles X Resistivity Copper) would indicate the source supply (and possible number of relay or boost stations) required to ensure clear reception – a clean pulse wave form.

With modern switching devices (e.g. the output Transistor in a data Transmission IC switching at 3Gbps), the capacity of link cables to transmit this data serially over distance is seriously compromised. Improvements in cable design and WWAN technologies have gone some way to improve this new situation but the transfer of multiple Gigabit-per-second (Gbps) parallel data signals through a single serial data-transmission channel will always present a capacity/time problem.

(Ref: "Each (parallel) data channel supports speeds up to 3.2 Gbps, providing total throughput of over 200 Gbps" / ref : Agilent Technologies HDMP-3268 switch IC")

Noise immunity requirement has led to screening of the data cable conductors to reduce electro-magnetic interference. Fast data rates mean a single brief (1-second) interference may corrupt many megabytes of data on the serial line. Twisted cables are used to ensure that any induced voltages are equalised on both conductors, the signal value (the binary 1 or 0 of the pulse) being derived from the voltage differential between the 2 conductors. In this way induced Voltages and EMF distortions are decoupled from the signal values. Even using UTP and STP cables, the intrinsic capacitance of the conductors will lead to signal distortion and the conductor sizes are therefore reduced to a minimum.

(Ref: 0.08mm sq. for Belden 8134 Ethernet Category 5 Specification 8134 Belden Low capacitance RS485 cable 28awg Gauge= 0.0810 mm Sq)

The nett result of these enhancements to cable design is that a typical twisted pair meeting the EIA-568 Category 5 specification will transmit data reliably at 10Mbps using RS485 signaling levels over 100 Metres, with significant signal degradation beyond these limits.

(Ref: IEEE 802.3*. Electrical Characteristics of Ethernet /RS 485)*.EIA/TIA -568, ISO 11801. (T120))

With Multi-node Communication using Ethernet protocol over dual and quad STP cables, the nominal data transmissions have increased from 10 Mbps to 100Mbps, and to 1 GB and beyond for Ethernet over Fibre Optic cable. Actual throughput may be reduced by the carrier sense, multiple access with collision detection (CSMA/CD) Ethernet protocol. Nonetheless Ethernet has become the industry default LAN Network communications worldwide.

"*Most experts agree Ethernet is the high-speed industrial communications medium of the future, no matter whether it platforms on copper cable, fiber, or wireless media"* (PARASCHIV et al. 2008)

Given the absolute physical limitations of copper conductors, it is notable that the most popular and efficient LAN data comms link is the Ethernet protocol running over STP conductors, usually with a maximum of 100 metres between nodes. In this respect it is true that the 'market has spoken'. Over 80% of LAN topologies worldwide are built on Ethernet protocol running on

Screened Twisted Pair conductors. ("The market has spoken…. 85% of LAN's worldwide today run Ethernet")

Ethernet is the most popular local area network or LAN technology. More than 100 million Ethernet nodes have been deployed") (PARASCHIV et al. 2008).

This is the Datacomms environment in which modern Client/Server and Server/Based (Virtualisation/TC) computing models will compete. It is generally accepted that Ethernet over LAN distances will not present either latency or bandwidth problems for RCP traffic, except in the graphics-intensive and motion-video scenarios. WAN connectivity, essential to the more general adoption of Thin Client computing, will continue to present problems of latency and bandwidth capacity.

The developments in serial data comms since the introduction of telegraphy signaling can be traced in the evolution of Electronic Industry Alliance (EIA) and IEEE Standards governing the specifications of inter-connectors and the protocols for data transmission over these physical connectors. (EIA standards are also referred to as TIA and are affiliated to ISO, ANSI and other international standards associations)

20 mA Current Loop. Analogous to the original telegraphy system, the current pulse represents the binary value '1'. The data stream can be ASCII characters using standard binary code. While not an EIA standard, the current loop interface is more robust and less susceptible to noise than the voltage-level based EIA standards listed below. Current loop can be converted to/from the voltage based signals in situations where a noise-immune segment is required e.g. in electrical transformer and motor rooms and in high fire-risk areas.

EIA/RS232. The Voltage level falling below 12.2 Volt represents a '1', otherwise 0

EIA/RS 422. A Voltage differential between conductors (to filter out any induced voltages which will apply to both), with a binary '1' value represented by –5Volt against 12V+

Intel's Universal Serial Bus (USB version 2.0) is used as a replacement for RS-232 with multi-point connection up to 127 devices. USB will support a theoretical maximum of 480Mbps over 70 metres on STP category 5 connection.

IEEE 1394 Firewire provides a local serial interface (up to a maximum 4.5 Metres distance) at capacity of up to 400 Mbps.(Ramamurthy & Ashenayi 2002).

(Note: It is important to note the bandwidths achieved on these recent versions of the standard serial interface. At the same time it is very relevant to this study to identify the strict limitations as to distance, which preclude the adoption of these protocols alone as a solution to LAN or WAN connectivity. Where special cables and signaling electronics are developed to enhance data throughput, it is inevitably at the expense of distance traveled, and vice versa).

RS485. As for RS422 with multi-drop and repeater station facility, now available with direct conversion to Ethernet, allowing LAN machine networks to be interrogated and controlled via Internet remote access. Transmission speeds of 10Mbps are achieved over STP to a maximum of 100 metres distance. (PARASCHIV et al. 2008)

Parallel Bus. The IEEE parallel bus can deliver data transfer rates of typically 200GBbps, usually on the backplane within the Server cabinet. For LAN and WAN communication, the data transfer must be converted into serial mode. (Exceptions would be the Centronics parallel printer interface, which was a parallel bus limited to max 20 metres distance over special cable and the newer iSCSI parallel data Interface limited to 25 metres from server to SAN/LUN).

*Ethernet Protocol IEEE 802.3 i*s the most popular and universally adopted data link protocol in computer networking. Four data rates are defined by the Institute of Electrical and Electronics Engineers (IEEE), for operation over optical fiber and twisted-pair cables:

Ethernet 10Mbps (IEEE 802.3) was the original LAN standard over unscreened twisted pair

Ethernet 100Mbps (IEEE 802.3u) became available in recent year normally over Screened Twisted Pair (STP) and using more advanced Switch and Hub technology.

Ethernet 1GB (IEEE 802.3z) is normally used over Fibre optic as a Network Backbone (maximum bandwidth) on LAN and WAN infrastructures.

(Note : The optical datum is a pulse of light and therefore immune to the electrical factors and environmental interferences which affect voltage/current pulse transmission on copper cables. The Fibre Optic channel is effectively noise-immune, although not as physically robust as standard STP copper cables. Because fibre neither generates nor is affected by electro-magnetic frequency (EMF) radiation, it is a secure data channel for hazardous areas. Even more importantly in terms of data security, the fibre channel can not be EMF-detected or ‘sniffed’ with standard EMF inductance detectors which can be used to detect and capture the complete data stream on any adjoining copper conductors, e.g. a printer or network cable. Further developments by Intune Networks Ltd will seek to extend the reach of the single-mode Fibre optic link,. The latencies arising at the transport layer (switch and router negotiation) will be minimized by exciting new developments in colour coded lasers, further enhancing the potential for near-lossless WAN TC computing. (John Dunne & Intune Networks Limited 2009)

As the fundamental laws of physics in relation to fibre channel will never change, a national and global Fibre Optic WAN would enable improved RCP and datacomms in general. Fibre optic networking could then provide a comprehensive solution to the RCP problem. (See also the NYSE Ping example in Section 2.1.1 and Opportunities for Further Research in Section 6).

Ethernet 10GB (IEEE 802.3ae). Standard 802.3ae™ (IEEE), extends the speed of Ethernet operations to 10 Gbit/s and makes provision for linking Ethernet local area networks (LANs) to municipal and wide area networks (MANs and WANs). The standard reflects Ethernet's ongoing evolution toward higher speeds as network and Internet traffic continues to grow exponentially. *(Ref IEEE.org http://standards.ieee.org/getieee802)*

Ethernet 802.11(b) is the corresponding standard for Wireless WWAN communication, delivering approx 11Mbps subject to physical environment, atmospherics and interference.

Ethernet 802.11g is the corresponding standard for Wireless LAN communication, delivering approx 54Mbps subject to physical environment, atmospherics and interference.

Table 17: Listed below are the standard segment lengths associated with the 3 main datacomms channels referenced in the dissertation: STP cable and Fibre Channel (Ethernet 802.3) and Wireless radio (Ethernet 802.11).

Table 18: Standard Segment Lengths

Standard Segment Lengths

Medium	**IEEE Standard**	**Maximum Distance**
Wireless	802.11b	100 m
Fiber Optics[1]	802.3	2000 m/5000m
Twisted Pair	802.3	100 m

1. 2000 meters is for multi-mode. There are no standards for single-mode. 5000 meters is for gigabit transmissions.

(Pack, JH. Associates 2009)

Figure 12: Sample values of Ethernet bandwidth/distance tradeoff using American Wire Gauge STP copper. Belden 8134 = 10Mbps@100M

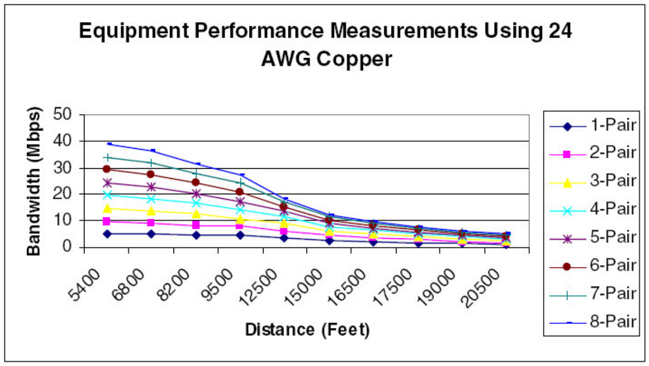


Figure 15: Sample values of Ethernet bandwidth/distance tradeoff

Table 18: Outline of Kwh per annum – Dell PC

PC model	Usage[1]	Power rating (W) (from measured figures in Cartledge 2008a)			Annual energy consumption (kWh/y)[2]	Annual energy costs (£, at 12p per kWh)
		Active	Idle	Standby		
Dell Optiplex 210L	High usage	135	70	2	505	61
Dell Optiplex 210L	High usage with power management	135	70	2	411	49
Dell Optiplex 210L	Low usage	135	70	2	155	19
Dell Optiplex 210L	Low usage with power management	135	70	2	37	4
HP DX5 150S	High usage	87	43	2	326	39
HP DX5 150S	High usage with power management	87	43	2	269	32
HP DX5 150S	Low usage	87	43	2	101	12
HP DX5 150S	Low usage with power management	87	43	2	25	3

1 High usage assumes active 8 hours a day, idle 4 hours a day, standby 12 hours a day, every day, 52 weeks per year, i.e. always on. Low usage assumes active 1 hour a day, idle 7 hours a day, standby 16 hours a day, 5 days per week, 46 weeks per year, and on standby for remaining hours. High usage with power management assumes the PC powers down to standby after 20 minutes idle activity, i.e. active 8 hours a day, idle 20 minutes a day, standby 15 hours 40 minutes a day. Low usage with power management assumes that the computer powers down to standby after 20 minutes and the computer is turned off at weekends and vacations.

2 Calculated from annual usage and power rating in different modes.

Item 3: Teradici – A summary of Key Advantages and Limitations

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The Teradici example of a true zero state Thin Client device (No local OS, GPU or data storage) provides a complete desktop PC replacement option using Blade PC's within the DC. When this zero-state Thin Client will function for Virtual Machines (VM) running on a Virtualisation server, the potential for upgrades will be hugely increased.

The enumeration of advantages claimed by Teradici for their technology provides a valuable summary of the potential gains of Virtualisation while also highlighting specific areas (Medical, CAD, Video etc) which require 'Lossless' transmissions (for example no frame drops or skips). These values offer a cross-check of what has been achieved and the further potential. Where a 'Lossless' standard of graphics reproduction is a requirement, the standard software-based RCP algorithms will often fail to comply over typical LAN bandwidth and latencies.

A summary of the advantages of Teradici Thin Client as provided by manufacturers

(ref: Teradici fact sheet "Unique benefits of Teradici PC over IP solution" 2009)

- *"The PC-over-IP protocol compresses, encrypts and encodes the entire computing experience at the data center and transmits it 'pixels only' across a standard IP network to stateless PCoIP-enabled desktop devices".*
- *Supports two DVI interfaces, each with resolution up to 1920x1200.*
- *Provides **lossless** image transfer (needed for applications such as high-end CAD, medical, and security command/control).*
- *Supports all image content including 3D graphics, video, animation, ClearType®, Windows®AeroTM for Vista, DirectX®, and more.*
- *Creates a true PC experience with a completely uncompromised Graphical user interface (GUI).*
- *Built to run on standard IP networks.*
- *Remains responsive under reduced bandwidth conditions.*

- *Provides the best possible image during varying network conditions.*
- *Provides a true, uncompromised PC experience for the end user.*
- *Minimizes latency while providing the best image quality.*
- *Builds to a lossless image as network bandwidth permits.*
- *Superior image quality and responsiveness over alternative solutions.*
- *Generates less bandwidth than remote display solutions such as RDP and ICA.*
- *Complete USB and Audio Functionality*
- *Allows true USB bridging over IP networks with the same plug and play experience as traditional PCs.*
- *Simplifies USB functionality by using standard existing peripheral drivers on the host, solving issues experienced by IT using alternative centralization technologies.*
- *Provides flexible user authorization by allowing USB port disabling or filtering. On-Board High Definition Audio controller connects to standard audio codecs to support HD audio.*
- *Dual Display Full DVI Resolution and Quality Low Latency Image*
- *Compression Algorithms Low Bandwidth*
- *Supports the complete Windows AeroTM for Vista user interface experience.*
- *Host PC runs OS and applications without modification.*
- *Connects to the PC using standard DVI and PCI interfaces.*
- *Provides familiar GUI for both the IT professional and end user. Eliminates the need for regular desktop support by IT because PC-over-IP hardware bridging does not require driver support. Security by Design*
- *No local application execution or data storage creates a more secure environment.*
- *Flexible Desktop Portal implementation across the enterprise. One SKU fits all user profiles to reduce management overhead.*

- *Provides a lower cost solution because the desktop portal does not run a host OS, which also eliminates virus vulnerabilities.*
- *No GPU. No CPU. No DRAM. No storage.*
- *The PC-over-IP TERA Host and Portal act together to implement a virtual bridge that connects displays and peripherals to a host PC without compromise.*
- *Protects all desktop PC communications (display, USB and audio data transfers) with IPSec by employing full-bandwidth hardware-accelerated 128-bit AES encryption and authentication tags.*
- *Protects all management communications with secure SSL tunnel.*
- *Simplifies the end-solution by integrating the 10/100/1000 MAC while delivering additional security and control.*
- *Improves security by ensuring that PC-over-IP traffic is not visible by the host OS to avoid compromise due to spyware or rootkit software that may be present on host PC*
- *Additional features such as VLAN and priority allow PC-over-IP traffic to be managed and isolated on a separate logical network.*
- *Microsoft® Windows® Vista Compatible*
- *100% OS and application Independent*
- *100% PC Compatible*
- *Zero-Management Desktop Portal*
- *Stateless Desktop Portal*
- *Secure Host-Desktop Portal Connection*
- *Dedicated Ethernet MAC "*

Teradici : Note from an industry consultant:

*"**Teradici** has engineered what it calls a "PCoIP Chip" (PC-over-IP). The solution entails one chip that resides on a Blade computer (called a Blade PC) in the data center and another that resides in a small box on the users desktop that requires no management. These chips communicate with one another via Ethernet and can do so through switches and over great distances, breaking the link between a user and his/her PC. Teradici's secret sauce is in how they analyze, compress, packetize and then transmit two full DVI graphics streams, USB (keyboard, mouse and peripherals) and hi-definition stereo audio over standard Ethernet with almost no noticeable latency and almost no loss of image quality. Think of it as a kind of KVM on steroids. This concept has been around for years in the form of Thin Client s. The one problem that Thin Clients have had that has prevented them from achieving higher penetration in the market is that they are in effect just thinner computers. That means they also require management to nearly the same extent that IT departments manage PCs on corporate networks. Thin Client s run a host OS and are susceptible to hostile attack by hackers, viruses, bugs and physical theft just like desktop PCs. So instead of easing IT managers jobs by eliminating touch points, Thin Client s actually cause them to now have to manage two devices instead of one. The key benefit to Teradici's desktop portal solution is that there's nothing on the desktop to manage"*

Multimedia information may include discrete media data, such as text, data, and images, and continuous media data, such as video and audio

Item 4: Link to Ecological Report by Fraunhofer Umsicht Institut on behalf of Igel GmbH

it.umsicht.fraunhofer.de/TCecology/docs/TCecology_en.pdf

http://it.umsicht.fraunhofer.de/TCecology/docs/TCecology_en.pdf

Glossary

Acronym **ASP**
Term Application Service Provider
Usage Provision of server based Application over data link
Pointers often delivered over Internet as Web service

Acronym **Audio**
Term Video soundtrack
Usage Parallel Channel 50Kbps with Video
Pointers Must be kept in Sync with Video transmit. Slowest wins

Acronym **Autonomic**
Term Autonomous self-regulation
Usage System of sensors with feedback loops
Pointers Used to maintain system responses

Acronym **Bandwidth**
Term measured in Mbps
Usage measure of carrying capacity of data link
Pointers Identifies carrying capacity of connection
See Also Mbps

Acronym **Buffer**
Term Temporary store
Usage Refers here to screen buffer
Pointers The data file sent to drive screen image/pixels

Acronym **Cache**
Term Temporary store of data
Usage Stock images can be saved at TC to reduce file xfrs
Pointers Video all pixels change per frame-No caching

Acronym **Cloud**
Term Cloud Computing
Usage Delivery of ICT services/utilities from many sources
Pointers Online TC can access Cloud services from any online device
See Also Grid

Acronym **Codec**
Term Coder/Decoder
Usage Converts primitive commands to pixel driver files
Pointers At Server or TC side. At TC to reduce file xfr Mbps

Acronym **Current**
Term electron flow
Usage Pulse per bit in PCM
Pointers Original 'current loop' data signaling

Acronym **Ethernet**
Term Data link Protocols
Usage IEE standards governing data communications
Pointers uses collision detect/resend on open Bus

Acronym **FC**
Term Fibre Channel
Usage Optical laser used to send Photon as datum
Pointers Faster and noise immune compared to electronic
See Also LAN,WAN

Acronym **Gbps**
Term Gigabits per second
Usage Billion bytes. 1 byte =8 bits , also =1 character
Pointers Identifies carrying capacity of connection

Acronym	**GPU**
Term	Graphic processing Unit
Usage	Integral module with parallel interface to PC bus
Pointers	dedicate processing of Graphics kernel output

Acronym	**Graphics**
Term	Screen Image
Usage	A set of signals driving Pixel colour & format on LCD
Pointers	Video graphics may mean Mbps per frame @25 FPS
See Also	FPS, Pixel

Acronym	**KVM**
Term	Keyboard, Mouse, Video
Usage	Signals between TC and Vn server
Pointers	Video signal may demand multi-Mbps bandwidth

Acronym	**Latency**
Term	signal delay
Usage	measure of delay between signal send and receive
Pointers	Msecs between press 'A' and 'A' appears on screen

Acronym	**MAN**
Term	Metropolitan Area Network
Usage	Datacomms link over 5-50 Km
Pointers	WAN serving city area or business community
See Also	WAN,LAN

Acronym	**MB**
Term	Megabytes
Usage	Million bytes.1 byte=8 bits and = 1 character
Pointers	measure of file size or total data xmit
See Also	Ascii

Acronym	**Mbps**
Term	Megabits per second
Usage	Sequence of data bits .
Pointers	Identifies carrying capacity of connection
See Also	Bandwidth

Acronym	**MPEG**
Term	Moving Picture Expert Group
Usage	Define formats for video file processing
Pointers	MPEG compression may reduce file size by 90%

Acronym	**Parallel**
Term	data sent over multiple paths
Usage	Bus may be 8,16,32 bits wide
Pointers	Faster than serial e.g. 32 bits per clock pulse

Acronym	**PCM**
Term	Pulse coded modulation
Usage	Pulse per bit in PCM
Pointers	machine code using pulse amplitude

Acronym	**RCP**
Term	Remote computing protocol
Usage	A set of routines to handle remote input and graphics
Pointers	Coded to minimise traffic per TC/Vn Server transaction
See Also	RDP,ICA,RGS

Acronym	**Redirection**
Term	Xfr of function to remote CPU
Usage	Multimedia redirection moves MM processing to TC
Pointers	Use to reduce demand on Vn CPU and on RCP

Acronym **SAN**
Term Storage Area Network
Usage Distributed data storage facility
Pointers Designed to meet very fast data retrieval for TC

Acronym **Scrape**
Term Copy Pixel data from LCD
Usage Screen scrape: basic method to xfr image to TC
Pointers 3 Bytes per pixel means @1024X768 pixels=2Mb file

Acronym **Serial**
Term Data in sequential time slots
Usage I bit per unit type or per system clock pulse
Pointers Slower than parallel path

Acronym **TC**
Term Thin Client
Usage Slim device connecting to server-based services
Pointers Uses a data link to deliver computing service

Acronym **UbiComp**
Term Ubiquitous Computing
Usage Computing devices everywhere in the environment
Pointers Here , delivery of the PC service to any online device

Acronym **UHF**
Term Ultra High Frequency
Usage Refers here to radio frequencies from 300Mhz-4Ghz – the full range of WLAN-WWAN
Pointers Affected by topography , atmospherics and EMF radiation

Acronym **Video**
Term Motion graphics
Usage Refers here to Motion video over RCP
Pointers The video signal may exceed 1MB/ frame @ 25 FPS

Acronym **Vn**
Term Virtualisation
Usage Delivery of several virtual via a single physical entity
Pointers Allows maximum utilisation of physical resource

Acronym **WAN**
Term Wide Area Network
Usage Datacomms link over 5Km+
Pointers Inter-company, Internet and international links
See Also LAN,MAN