Microsoft RemoteFX for Virtual Desktop Infrastructure: Architectural Overview

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Abstract

Windows Server® 2008 R2 Remote Desktop Services includes a new set of user experience technologies in Service Pack 1 (SP1) called Microsoft® RemoteFX™.

RemoteFX delivers a full-fidelity user experience for Virtual Desktop Infrastructure (VDI) by providing a 3D virtual adapter, intelligent CODECs, and the ability to redirect USB devices in virtual machines. As part of the Windows Server 2008 R2 SP1 platform, RemoteFX is integrated with the Remote Desktop Protocol (RDP), which enables shared encryption, authentication, management, and device support.

This paper provides an architectural overview of RemoteFX in the context of VDI—using a new role called the Remote Desktop Virtual Host (RD Virtualization Host) designed specifically for VDI using Windows Server 2008 R2 SP1 in a Hyper-V server role.
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# Table of Contents

RemoteFX Overview.......................................................................................................................... 3

Virtual Desktop Infrastructure (VDI) .................................................................................................. 4
  Building on Client-Centric Computing................................................................................................. 4
  Transitioning to Host-Centric VDI ..................................................................................................... 5

RemoteFX Remote Desktop Virtualization Host ................................................................................. 6
  What’s New in RDP in 7.1 .................................................................................................................. 6
  New Concepts for RDP 7.1 .................................................................................................................. 7

RemoteFX Platform Architecture ........................................................................................................ 8
  RemoteFX Architectural Concepts ...................................................................................................... 8
  Component Architecture for VDI ......................................................................................................... 8
  RemoteFX for VDI Virtual Graphics and Rendering Pipeline .......................................................... 10
  RemoteFX for VDI Capture and Encoding Pipeline ........................................................................ 11
  RDP 7.1 Client and Graphics Rendering Pipeline ........................................................................... 12
  Encoding and Decoding Options ........................................................................................................ 13
  Device Redirection and Management ............................................................................................... 13
  Architectural Benefits ...................................................................................................................... 14

VDI Deployment Considerations ......................................................................................................... 14
  Application Fit ................................................................................................................................... 14
  Performance ..................................................................................................................................... 14

RemoteFX Ecosystem Partners ........................................................................................................... 16

System Requirements ........................................................................................................................ 16
  Hardware Requirements .................................................................................................................... 16
  Software Requirements ....................................................................................................................... 16

Summary ........................................................................................................................................... 16
RemoteFX Overview

A breakthrough in the way knowledge workers and graphics professionals interact with rich 2D and 3D applications is underway in the data center. Instead of relying purely on local computing power, a new graphics virtualization platform from Microsoft is shifting graphics-processing intelligence to centrally-hosted Virtual Desktop Infrastructures (VDI) deployed in enterprise data centers.

This new set of platform capabilities is provided through the Microsoft RemoteFX graphics virtualization platform, built on Hyper-V, included with Windows Server 2008 R2 SP1, and installed through the Remote Desktop Virtual Host (RD Virtualization Host) system role. Another role called Remote Desktop Session Host (RD Session Host) is also available for scalable Session Virtualization. For more information on RD Session Host, see the following paper:

Microsoft RemoteFX for Session Virtualization: Architectural Overview

RemoteFX enables rich, local-like user experiences for remotely hosted virtual desktops running a media-rich Windows 7 desktop. Users experience virtual desktops in full fidelity, harnessing the graphics processing power of shared Graphics Processing Units (GPUs) and SLAT-enabled processors, installed on Hyper-V hosts. Through new capabilities built into RDP, rich visual experiences are projected from hosted virtual desktops out across an array of client device types and form factors.

This hosted approach to VDI complements thick and thin device deployments, building on industry-standard USB to achieve compatibility with a broad array of end-points. Supported device types include new ultra-lightweight low-power thin clients, traditional thin clients, network monitors serving as end points as well as fully-functional computer workstations. The graphics virtualization architecture of RemoteFX enables customers to better enjoy the benefits of client-side computing and host-side computing through a flexible, familiar approach to VDI.

RemoteFX builds on Hyper-V and integrates RDP (Remote Desktop Protocol) to deliver a new payload designed for hosted VDI desktops. USB peripheral enhancements delivered with RemoteFX and RDP further improve the virtual desktop experience. Irrespective of the device type, users enjoy full-motion video and high-quality DirectX hardware acceleration for virtualized Windows applications—such as Office 2010 or Internet Explorer 9—with the local-like graphics quality of GPU-accelerated clients.

Users stay productive working in familiar virtual desktop environments, using the same applications designed for Windows 7. Any graphics application programmed for DirectX or GDI on Windows 7 can take full advantage of RemoteFX without modification. RemoteFX supports 3D business applications (such as Bing 3D), portable graphics content (HTML5, Silverlight, and Flash), Windows Aero, Microsoft Office, Media player or Internet applications, a range of graphics-intensive applications.
Virtual Desktop Infrastructure (VDI)

The promise of Virtual Desktop Infrastructure (VDI) is transformational—shifting compute resources from client computers to data center-hosted architectures. While still an amorphous concept to some, many IT professionals are actively investigating or deploying VDI.

VDI’s recent popularity has been driven by practical IT considerations, such as:

- Server virtualization adoption: IT is familiar with server virtualization. Many enterprises have virtualized large numbers of server applications, from development and test to production workloads.
- Viability of migrating production workloads to virtual environments: Progressively more business-critical production applications and workloads are being virtualized today.
- Data center readiness: Most data centers today operate large-scale virtual environments for both commodity and production workloads. This trend is continuing.
- Virtualization standardization: Among new servers provisioned by IT, virtualization has become the de facto formatting standard in provisioning and deploying new server images.
- New use cases addressed: Specific problems VDI addresses include compliance with regulatory requirements, a trend toward green computing, and driving new efficiencies at scale. VDI also allows IT to better enable new, flexible work scenarios such as offshore contractors or work from home.
- VDI vendor maturity: Hosted desktop architectures and vendor offerings are finally maturing to a level IT can legitimately begin incorporating into enterprise customer environments.

Building on Client-Centric Computing

Microsoft believes VDI initiatives should complement and build on investments already made by IT, including the deployed physical client infrastructure, applications, and user environments. VDI solutions should maintain familiarity for end-users and administrators by providing greater flexibility and improving the user experience (versus degrading or complicating it).

Devices deployed for VDI should be easier to deploy and manage. Customers deploying VDI expect users to plug-and-play IT-approved peripheral devices into primary local devices such as a personal computer, and have new devices just work within a virtual desktop environment. VDI architectures need to support a broad and diverse array of client devices through industry-standards.

Microsoft is committed to enterprise customers deploying VDI solutions and has designed its new Hyper-V and RemoteFX-based platform to bring together the beneficial aspects of both client- and host-centric computing. On the client-side Microsoft has built-in device support for Hyper-V on USB, a universal interface that works with any USB device on any supported platform on the Microsoft HCL. This solution supports device redirection services for many devices, including audio, storage, HID (such as tablets and keyboards), printers, scanners and biometric devices.

In multimedia scenarios for media streaming, the compute power of client devices can be leveraged where available, offloading processing to local clients. In cases where GPU or CPU resources on the
client device are limited or not available, processing can be performed on the host and optimally streamed to the client. This helps enterprises leverage investments in legacy computer hardware and rich client solutions.

**Transitioning to Host-Centric VDI**

A consistent user experience combining the benefits of client-side computing with host-side computing can be achieved through VDI—supporting a broad number of devices and form-factors—by shifting the intelligence and raw computing power away from the client and into the data center.

Traditionally, remoting protocols like RDP have been client-centric. Protocols intercept graphics on the host device and then efficiently forward the intercepted graphics commands (for example, Draw Rectangle, or Draw Line) to the client device. The client end-point then renders the primitives using a client-side counterpart for each corresponding graphics intercept point on the host.

If the client device is powerful, contains the right software, and maintains corresponding graphics intercept points with the host, a high-quality user experience over relatively low-bandwidth can be achieved with a client-centric strategy. But if a less powerful client device such as a low-power thin client is used, this strategy could degrade the user experience (through choppy video or missing graphics, for example) and limits scalability.

Today, bandwidth is less expensive and broadly available. Today’s modern Windows desktop includes rich media and 3D graphics content. Additionally, a wide array of graphics formats (for example, HTML5, Silverlight, Adobe Flash, DirectX, Aero Glass, and Windows Media) are relevant to Windows users. These changing conditions call for the addition of a new host-centric model that can broadly support common graphics types, including 3D, by sending highly compressed bitmaps to the end-point device in an adaptive manner.

Host-based VDI solutions built on RemoteFX and Hyper-V ensure a consistent end-user experience across a wider array of devices by consolidating a large portion of the client software and hardware into the datacenter. With host-centric remoting, all the graphics can be intercepted on the host at an optimal layer in the software stack. All graphics are rendered on the host into a single frame buffer (a temporary holding station for graphical updates) that represents the end-user display. Changes to the frame buffer are sent to the client at a frame rate that dynamically adapts to network conditions and the client’s ability to consume the changes.
RemoteFX Remote Desktop Virtualization Host

For VDI, RemoteFX and its associated components are installed through a new system role called Remote Desktop Virtualization Host (RD Virtualization Host) first introduced with Windows Server 2008 R2, and included with Windows Server 2008 R2 Service Pack 1. RD Virtualization Host integrates with Hyper-V to provide VM-based virtual desktops for RemoteFX, remotely accessed using RDP 7.1 (see Figure 1).

Administrators have the ability to configure personal virtual desktops to provide a similar desktop experience to physical computers. Alternatively, VDI desktops can be pooled and dedicated to a specific set of applications.

Applications run inside virtual machines without modification. The RemoteFX virtual GPU (described in detail on page 6) is application-agnostic, supporting standard Windows graphics application APIs such as DirectX and GDI.

What’s New in RDP in 7.1

While much of RDP has not changed, a new graphics channel payload is a key innovation. This payload integrates familiar and new RDP capabilities with an extensible decoder for RDP client devices. The new payload provides a single, low-level intercept point for host-side processing of RDP. The resulting architecture supports real-time rendering, compression, and decoding—projected across the network using a diverse ecosystem of RemoteFX-ready device types.

Through this architecture, RDP supports a broader range of content types and formats. As new media-intensive standards emerge, such as HTML 5, host-based hardware acceleration using RemoteFX over RDP will vastly improve the experience and enable broader adoption of these new formatting standards. Visually rich audio and video playback can be experienced in real-time over the network on a broad range of device-types, including new low-power chip designs embedded in a variety of form factors.
## New Concepts for RDP 7.1

<table>
<thead>
<tr>
<th>RDP Client-side Rendering</th>
<th>RDP Host-side Rendering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate intercept points for each graphic stack and equivalents were prone to gaps in user experiences</td>
<td>Single intercept point for all graphics processing—offers consistent, predictable, and complete user experiences</td>
</tr>
<tr>
<td>Relies purely on software and hardware capabilities of rich client computers and workstations</td>
<td>Supports diverse thin client base by shifting workload and complexity to host</td>
</tr>
<tr>
<td>Conserves bandwidth through local processing of intercepted graphics types</td>
<td>Although optimized for efficient delivery, typically requires higher bandwidth for sending compressed bitmaps and other formats over the wire</td>
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RemoteFX Platform Architecture

RemoteFX is a new Hyper-V platform capability for host-based graphics virtualization for VDI. At the heart of RemoteFX is a virtual graphics processing unit (the vGPU), which abstracts the relationship between guest OS virtual machines (virtual desktops) and physical GPUs to optimally share GPU resources in a hosted multi-user environment.

RemoteFX Architectural Concepts

<table>
<thead>
<tr>
<th>Enabling Technology</th>
<th>Customer Value</th>
<th>Differentiating Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual GPU (RD Virtualization Host only)</td>
<td>Full rich Windows experience</td>
<td>Content- and hardware-independent intercepts and rendering Single or multiple shared GPU(s) for multiple virtual machines</td>
</tr>
<tr>
<td>Host-side Rendering (RD Session Host and RD Virtualization Host)</td>
<td>Remoting of any content</td>
<td>Applications run at full speed on host</td>
</tr>
<tr>
<td>Intelligent screen capture and hardware-based encode (RD Session Host and RD Virtualization Host)</td>
<td>High-fidelity user experience</td>
<td>Screen deltas sent to clients based on optimization policies and client and network availability</td>
</tr>
<tr>
<td>Bitmap remoting and hardware-based decode (RD Session Host and RD Virtualization Host)</td>
<td>Broad range of client device support</td>
<td>CODEC designed for text and image content Single CODEC for VDI and session virtualization scenarios Choice of software and hardware decoding options</td>
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</table>

Component Architecture for VDI

The following section provides an overview of the RemoteFX architecture—from its integration with Hyper-V to the component architecture and process flow.

Integration with Hyper-V

RemoteFX and its associated components, including RDP, are integrated with Hyper-V, a native type-1 hypervisor, in Microsoft Windows Server 2008 R2 Service Pack 1. Hyper-V uses the concept of parent partition and child partition, units of isolation in which OS processes and guest OS processes safely execute. RemoteFX includes graphics processing infrastructure components that run in both the parent and child partitions of Hyper-V.

The Hyper-V parent partition includes the RemoteFX management components for graphics processing, process management, rendering, capturing, and encoding. Hardware-optimized drivers for GPUs and embedded host-based encoders, such as ASICS, are also installed in the parent partition. A WDDM (Windows Display Driver Model) device driver and GPU-specific drivers are the primary interface to the GPUs.
RemoteFX components running in the *guest partition* include the vGPU, UMTS, and RDP. This includes new functions built into RDP 7.1, which now runs in user-mode instead of kernel-mode. The new RemoteFX payload for RDP 7.1 is tied to a Windows Server 2008 R2 SP1 host.

**The Virtual Graphics Processing Unit (vGPU)**

At the core of RemoteFX on Hyper-V is a graphics virtualization engine called the virtual graphics processing unit (vGPU). The RemoteFX vGPU provides a virtual graphics adapter installed by each virtual machine hosted on Hyper-V. The vGPU abstracts graphic processing for multiple virtual machines utilizing one or more GPUs within the host. When an application running in a virtual machine invokes a graphics operation through DirectX or GDI, the vGPU uses the VMBUS (a communications channel between the parent and child partitions) to obtain resources from the GPU.

**Intra-host Communication through VMBUS**

As display commands are made from within the virtual machine to the vGPU, they are passed from the child partition to the Hyper-V parent partition using the VMBUS, a communications channel within Hyper-V used for memory sharing and other functions specific to the vGPU. This provides an essential integration mechanism directly into Hyper-V, where all resource requests—for graphics, audio, and USB devices—are transferred.

**Remote Desktop Virtual Graphics Manager (RDVGM)**

The RDVGM manages resource assignment and process control between RemoteFX components in the Hyper-V host partition and vGPU resource assignment into each virtual machine guest OS.

These functions include:

- Managing the RCC (Rendering, Capturing, and Compression) or encoding processes. (This pipeline is described in more detail in the following section.).
- Assigning physical GPU resources to individual virtual machines through the vGPU.
- Assigning resource policies to individual virtual machines.
- Load-balancing GPU resources across multiple virtual machines within a host.
- Managing processes: The RDVGM assigns appropriate GPU resources to individual virtual machines at boot time.

**Rendering, Capturing, and Compression (RCC)**

Integrated with the RDVGM is the RCC engine, which handles rendering, capturing, and compression. The RCC receives graphics requests as output from each virtual machine, and translates those requests into DirectX-compliant commands on the parent partition. The VMBUS provides a high-speed communications backplane to proxy DirectX requests from individual hosted applications running inside virtual machines to DirectX requests for physical GPU resources on the parent partition. This virtualization layer, complying with DirectX syntax, provides both a GPU- and application-agnostic approach to graphics virtualization. Applications running in virtual machines need to support DirectX 9 or later. GPUs installed in the parent partition, by contrast, must support DirectX 10.
- **Rendering** refers to the process of translating raw display calls (such as Rotate, Flip, and Draw) made by applications running within a virtual machine through the vGPU, honoring those requests to the GPU, and thus rendering content. This is based on standard DirectX syntax.

- **Capturing** refers to the process of taking rendered application content—on-screen bitmap or frame changes—and intelligently capturing only what’s changed. A secondary function is assigning quality of service policies—for capture quality and encoding level.

- **Compressing** (or encoding) refers to the process of optimally and equitably delivering GPU resources through the vGPU—and over RDP 7.1—to individual client devices. The quality of network conditions and target device type determine the type of compression/encoding used to optimally deliver captured content.

**RemoteFX for VDI Virtual Graphics and Rendering Pipeline**

When an installed application running within a VM issues display calls (such as Draw, Resize, and Rotate), the vGPU is the key component that brokers all rendering requests. This entire virtualization path is transparent to each guest OS.

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**Figure 2: Graphics Rendering Pipeline**

Graphics processing commands are intercepted by RemoteFX on the Hyper-V parent partition at a low level in the software stack. Once inspected and optimized, graphics are rendered on the host into a single frame buffer (a temporary holding station for graphical updates). This frame buffer represents the virtualized end-user display. Rich graphics applications, 3D plug-ins, and other embedded graphics components run exactly as they would on Windows 7 deployed on a physical workstation. Graphics calls made to Windows through DirectX, GDI (Graphics Device Interface), or other generic display commands
are honored; calls are made just as if the applications were running on a dedicated Windows 7 workstation containing a GPU.

The vGPU also provides a quality of service mechanism to virtual machines: equitably delivering physical GPU resources to individual or multiple virtual machines based on policies, similar to load-balancing, in a way that makes most efficient use of the GPU.

**RemoteFX for VDI Capture and Encoding Pipeline**

Once content is rendered, frames are decomposed, captured, encoded, and delivered to RDP clients. Using DirectX 10-compatible GPUs, capturing and encoding interfaces are designed to optimally capture and transfer changes from GPU VRAM into system memory.

![Figure 3: Capture and Encoding Pipeline](image)

Using RemoteFX on the Hyper-V parent partition, content is rapidly and efficiently captured. Each frame is divided into manageable units. Change regions are then processed through an optimization capability provided by the capture engine. Through this mechanism, RemoteFX intercepts individual frames for display changes. Only those areas within a frame that have changed are captured for encoding.

**Encoding Prioritization**

There are two prioritization schemes for encoding captures. The encoding process can be controlled through both administrative tools (giving certain virtual machines higher or lower priority) or dynamically, by the size of the change region within a captured frame.

What further optimizes the capture and encoding process is the payload structure: RDP provides frame-rate optimization based on network usage and fairness.
The encoder reaches out to an RDP listener process to assess the state of the RDP client, including its on-board decoding capabilities. Changes to the frame buffer are sent to the client at a frame rate that dynamically adapts to network conditions and the client’s ability to consume the changes.

The encoded output is tunneled within the RDP protocol and sent out to the client device.

**RDP 7.1 Client and Graphics Rendering Pipeline**

Once an encoded payload is ready to leave the Hyper-V host, RDP streams the optimized output across virtual channels, a form of connection within RDP. Virtual channels are software extensions that can be used to extend RDP (for example, support for special types of hardware and audio). The RDP protocol provides multiplexed management of multiple virtual channels.

A virtual channel application has two parts, a client module and a server module. The server module is an executable program running on the Remote Desktop Session Host (RD Session Host) server. The client module is a DLL that must be loaded into memory on the client computer when the Remote Desktop Connection (RDC) client program runs.

RemoteFX uses a special graphics virtual channel to distribute screen information to clients (and other channels for audio, device input, etc.). Through this virtual channel in RDP, data is sent to a client-side RemoteFX decoding abstraction layer where data is decompressed. From this layer, there are two main scenarios for delivering streams through RDP to clients:

1. **Classic RDP (Non-RemoteFX using RDP 7 or earlier).** In this case, the client is responsible for rendering data, based on the content-specific formatting, using graphics providers (such as for GDI, Aero, or Windows Media) loaded by the RDP client. The benefit is low network traffic, but requires
client devices capable of rendering graphics content. These devices are typically more complex and expensive.

2. RemoteFX Host-Optimized Decoding: In cases where the content was delivered from RemoteFX using RDP 7.1 or later, data is streamed across virtual channels into a RemoteFX decoding abstraction layer. Based on the target device capability, content is either decoded in software using client-side GPU or CPU resources, or directly in client-side hardware, through a dedicated decoder. These clients can range from fully functional to simple, low-cost device types.

**Encoding and Decoding Options**

The basic decoding requirement for the client end-point is supporting the ability to decode and display highly compressed bitmaps. At a minimum, the client needs the decoder counterpart to the encoder that was used on the host as well as very basic graphics display capability.

Encoding can be performed through software or dedicated hardware on the server host. Through software, the local GPU and CPU resources of the host system are used. Microsoft is also working with hardware partners to provide RemoteFX-ready hardware encoders in the future to further offload the process.

Decoding can be performed through software or hardware, based on the client device-type, and its onboard capabilities. If data streams are decoded using software, the CPU of the target device is used. If data streams are decoded using hardware, this can be achieved using the CPU or GPU of the target, or combination of the two. Another hardware-based decoding scenario is when an ASIC or another embedded chip design is available for decoding. In this case, decoding can be offloaded from software on the target client.

**Device Redirection and Management**

**USB-enabled Devices**

RemoteFX USB Redirection allows many devices to be redirected to an RD Virtualization Host server at the USB level. Advantages of this solution include that no device drivers are required on the client computer, and a universal interface is provided that works with any USB device on any platform where RemoteFX USB Redirection is supported. This solution redirects many types of devices, including audio devices, storage devices, human interface devices, all-in-one printers, and scanners. USB redirection complements the high-level device redirection capabilities of previous versions of RDP.

**RemoteFX Architectural Benefits**

There are a number of benefits to this host-based architecture:

- **Network agnostic:** Any standard IP network can be used across the same established RDP security ports and policies. Networking security remains consistent with RDP.
- **Client agnostic:** RDP 7.1 supports a wide range of clients with various hardware and software decoding options.
- **Payload-optimized:** RemoteFX provisions and transports only relevant delta changes through an innovative differencing algorithm. This is similar to network-based deduplication and compression techniques.
- **Frame-rate optimized:** Payloads can be controlled through Group Policy in Active Directory and based on network conditions, such as availability.
- **Device-transparent:** The decoding process is transparent to the user and device. While the output to the client depends on client type, the payload decision is processed on the server. For example, a regular computer might receive one format while a light thin client would receive a bitmap.

**VDI Deployment Considerations**

**Application Fit**

Any application running on Windows 7 can take full advantage of RemoteFX without modification. RemoteFX enables full-fidelity virtual desktop experiences across the wire, supporting 3D applications, portable graphics content (Silverlight and Flash), Windows Aero, Microsoft Office, Media player or Internet applications, a range of graphics-intensive applications designed around many vertical lines of business applications.

**Performance**

Performance between the RD Virtualization Host system and individual client device depends on a number of factors. Detailed performance guidelines are outside the scope of this paper.

Generally, performance factors include but are not limited to:

- **Host capabilities:** The scale of server and GPU and configuration. RemoteFX supports multiple GPUs on the host and is designed for scaling in the enterprise.
- **Client device capabilities:** Performance can be increased by utilizing dedicated hardware-based decoders.
- **Network capabilities:** In certain cases more bandwidth can be consumed to enable higher performance.
Policy-based Frame-rate Control
Bandwidth utilization and frame-rate quality can be controlled on a per-device basis through Group Policy Objects (GPOs) configured in Active Directory. Levels for frame-rate quality and network bandwidth usage can be controlled to match the use cases. For users that don’t require higher frame rates and have slower link speeds, a Medium or Low level can be set. For users requiring higher quality output, a setting of High can be used.

The “lossiness” of the CODEC can also be controlled through Active Directory Group Policy. When screen capture rates and image quality options are set to a lower quality level (through the Group Policy drop-down dialog that follows), bandwidth can be conserved.

Network Characteristics
Generally, most enterprise VDI deployments will require higher speeds (up to 10Mbps per-user), depending on the scenario. While the RemoteFX platform is optimized for LAN environments, Microsoft is working closely with partner ISVs and IHVs on wide-area optimization solutions to enable high fidelity experiences across higher latency and lower bandwidth WANs.
RemoteFX Ecosystem Partners

Microsoft has a large partner ecosystem building solutions on the Remote Desktop Services platform, including RemoteFX. RemoteFX provides a platform architecture upon which software and hardware ecosystem partners build solutions—RemoteFX-ready servers and decoders. These solutions range from host-side GPUs and ASICs to embedded client-device "system on chip" architectures where a chip has multiple capabilities.

System Requirements

 Hardware Requirements
To take advantage of RemoteFX functionality when connecting to virtual desktops, a Hyper-V server must meet the hardware requirements listed in the Windows Server Technical Library. For more information about the hardware requirements, see Hardware Considerations for RemoteFX.

 Software Requirements
RD Virtualization Host Physical System
Windows Server® 2008 R2 SP1 Remote Desktop Services Virtualization Host (RD Virtualization Host).

Virtual Machine Guest OS
Windows 7 with SP1—Enterprise or Ultimate Editions. 32-bit and 64-bit versions.

RDP Client
Host-optimized RDP clients using RemoteFX: any device supporting RDP 7.1 or later.

Summary

RemoteFX enables rich, local-like user experiences for remotely hosted virtual desktops running media-rich Windows 7 applications. Users experience their virtual workspace in full fidelity, harnessing the graphics processing power of RemoteFX on Hyper-V, projected across a diverse array of partner client devices, designed for RDP 7.1.

RemoteFX takes advantage of industry-standard Graphics Processing Units (GPUs) and SLAT-enabled processors—installed on Hyper-V host systems. Graphics are efficiently rendered, captured, encoded, and optimally streamed and decoded—through an ecosystem of innovative software and hardware-offload partner device solutions.

This approach complements traditional graphics processing solutions, building on industry-standard USB to achieve compatibility with a broad array of end-point devices. These include new ultra-light low-power thin clients, traditional thin clients, and fully-functional computer workstations. The RemoteFX
graphics virtualization architecture enables customers to better enjoy the benefits of client-side computing and host-side computing through a flexible, familiar approach to VDI.