Abstract - Virtualization enables installation and running of multiple virtual machines on the same computer system. Operating system that communicates directly with hardware is known as the host operating system whereas virtual operating systems have all the features of a real operating system, but they run inside the host operating system. A virtual machine is separated from the computer hardware resources and it runs on the emulated hardware. Performance of the virtual operating system running on the same computer system hardware depends on the performance of the host operating system. In this paper we study how different host operating systems influence virtual machine performance. Windows XP®, Windows Vista™ and Windows 7™ are used as host operating systems using Windows Vista as a virtual operating system. Performance measurement of the virtual operating system is done in the same controlled conditions for all three host operating systems using benchmark applications. Performance measurement results show that the virtual operating system has the best performance when Windows 7 is used as the host operating system.

I. INTRODUCTION

With the increased development of applications, operating systems and the Internet, computer users more often face software incompatibility. Older applications that are important for users often do not work on newer computer systems as they do not support new hardware and new operating systems. Today programmers and application developers are mostly using laptop computers as they must have all necessary tools and applications always available. Since, there is a need for running and testing applications on different software environments without a lot of reinstallation of the existing software, they use virtualization on their laptop computers. Furthermore, when they are going to work outside their main company they do not need to carry more than one laptop rather they have more virtual machines installed on one laptop computer. Also, by using a virtualization they can separate their home and business software environments [1].

For this and lots of other purposes the best solution is virtualization. It is a method that allows installation of other operating systems inside the existing one. The operating system existing on a certain computer system is called a host operating system and a new installed operating system is called virtual. The tool used for installing virtual operating systems creates a virtual computer and a virtual operating system is installed on a virtual computer so it is not directly connected to hardware resources. This virtual computer in combination with the virtual operating system is called a virtual machine. A virtual computer has lower hardware resources than physical hardware since the tool for virtualization emulates older devices with lower performance than physical hardware. A virtual machine manages hardware resources through the host operating system. On the basis of this we can conclude that if a virtual machine runs on the identical hardware, but on different host operating systems, virtual machine performance is not identical for all host operating systems. The goal of this paper is to study how different host operating systems influence virtual machine performance.

Various virtual machine performance studies can be found in literature. In [2] authors focused on the I/O (Input/Output) read performance of the Windows operating system running in a virtual machine. Performance measurements show that I/O throughput highly depends on access modes, request sizes and virtual machine cache configurations. Furthermore, they design a unified virtual machine cache that can support more than one virtual machine synchronously and show that this solution can increase the read performance in most cases. In [3] authors developed a Windows-based OS-level virtualization architecture called FVM (Feather-weight Virtual Machine), which is specifically designed to reduce the invocation latency of a new virtual machine and to scale to a large number of virtual machines by minimizing per-virtual machine resource requirement. Their performance evaluation shows that FVM is more flexible and scalable, requires less system resource, incurs lower start-up and run-time performance overhead than the existing hardware-level virtual machine technologies.

Windows operating systems are most widely used operating systems, so for performance measurement we use three latest versions of Windows as the host operating systems: Windows XP® Professional SP3 (Service Pack 3), Windows Vista™ Business SP2 and Windows 7™ Professional. Microsoft Virtual PC 2007 is used as a tool for virtualization and Windows Vista Business SP2 is used as a virtual operating system. Performance measurement and evaluation is done in the same controlled conditions for all three host operating systems with different benchmark applications. These benchmark applications are used for measuring virtual machine performance and they measure various values. Performance evaluation is done by comparing virtual machine performance measurement results when it is installed on three different host operating systems.

The organization of this paper is as follows. Section 2 presents virtualization and Section 3 describes virtualization tool Virtual PC 2007. Section 4 shows a description of the latest three versions of the Windows operating system. Benchmark applications are presented in Section 5. Section 6 covers performance measurement setup and methodology. Performance measurement results and analysis are presented in Section 7. Section 8 contains the conclusion of the work.
II. VIRTUALIZATION

Nowadays virtualization is ubiquitous and virtualization technologies play an important role in many IT fields. The main advantages of virtualization in general are as follows: it can rapidly reduce cost and dangerousness of the experiments, portability of a virtual machine to another is simple, it has improved security, it enables parallelization, it decreases time expenses needed for administration of a large amount of desktops and workstations, etc.

The virtual machine described in [4] is a technology that creates one or multiple virtual environments on a single physical machine. The virtual machines are isolated from each other and the underlying physical machine, and they give users the illusion of accessing a real machine directly. The virtual machine is a completely independent computer system and a virtual operating system needs regular updates and antivirus protection and it also has its own IP address. Virtual machines have been widely used in the following applications:

- Server consolidation,
- Intrusion and fault tolerance,
- System migration,
- Virtual appliance,
- Debugging and testing.

There are many ways how to provide the virtualized environment. Virtualization layer or platform supports virtual environments with software approaches. It maps virtual requests from a virtual machine to physical requests. Virtualization can take place at several different levels of abstractions, including the ISA (Instruction Set Architecture), HAL (Hardware Abstraction Layer), operating system level and user level. ISA-level virtualization emulates the entire instruction set architecture of a virtual machine in software. HAL-level virtualization exploits the similarity between the architectures of the virtual and host machine, and directly executes certain instructions on the native CPU without emulation. Fig. 1 shows HAL-level virtualization used in our performance measurements.

Operating system level virtualization partitions the host operating system by redirecting I/O requests, system calls or library function calls. User level virtualization is described in [5]. Authors present a solution for portable Windows applications/customizations based on user-level virtualization technologies. Their solution compared with some existing solutions based on virtual machine technologies is more efficient in performance and storage capacity. Different levels of virtualization can differ in isolation strength, resource requirement, performance overhead, scalability and flexibility [6]. In general, when the virtualization layer is closer to the hardware, the created virtual machines are better isolated from each other and better separated from the host machine, but with more resource requirement and less flexibility.

III. VIRTUAL PC 2007

Performance evaluation of different virtualization tools is presented in [7]. The tools compared are native OS, Microsoft Virtual PC, VMware server on Windows and Linux host OS and XEN. We chose Microsoft Virtual PC because we have been using Microsoft operating systems as virtual host operating systems.

Virtual PC is based on the VMM (Virtual Machine Monitor) and it allows running of multiple operating systems at the same time on a single computer system. It can be used to run many different versions of operating systems (such as MS-DOS®, Windows 98, Windows XP, OS/2, Windows Vista or Windows7). In our performance measurement we use Microsoft Virtual PC 2007 with SP1, version 6.0.192.0, with the following features [8]:

- Optimized for Windows Vista,
- Improved performance based on Microsoft Virtual Server 2005 R2,
- Provides support for 64-bit host operating systems,
- Provides support for sound devices in Windows Vista guest operating systems.

Virtual PC emulates all components of a standard 32-bit x86-based personal computer except the CPU, as shown in Table 1.

![Fig. 1. The virtual machine concept](image)

<table>
<thead>
<tr>
<th>Component or Device</th>
<th>Emulated hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOS</td>
<td>AMI BIOS</td>
</tr>
<tr>
<td>Chipset</td>
<td>Intel 440BX</td>
</tr>
<tr>
<td>Sound card</td>
<td>Creative Labs Sound Blaster 16 ISA Plug and Play</td>
</tr>
<tr>
<td>Network adapter</td>
<td>Intel/DEC 21140A 10/100</td>
</tr>
<tr>
<td>Video card</td>
<td>S3 Trio 32/64 PCI (8 MB Video RAM with VM Additions)</td>
</tr>
</tbody>
</table>

IV. WINDOWS OPERATING SYSTEMS

Windows operating systems are most widely used operating systems on desktop and portable computers. Every new version of Windows brings many new features and enhancements. When Windows XP was launched in
2001, it brought revolution to operating systems. It had a new graphical user interface with lots of visual effects, new features, improved performance, stability and security. To achieve better performance, Windows XP uses numerous techniques such as asynchronous I/O, optimized protocols for networks, kernel-based graphics and sophisticated caching of file-system data [9].

When compared to Windows XP, Windows Vista presents a lot of new features and a new kernel. Almost every part of Windows Vista has some changes. Areas of Windows Vista that have major changes influencing performance are: processes and threads, I/O, memory management, power management, startup and shutdown, reliability and recovery, and security. A new CPU scheduling policy improves performance by bringing many enhancements in the area of processes and threads. Memory management includes numerous new technologies that improve performance like: SuperFetch™, ReadyBoot, ReadyBoost™, and ReadyDrive™. SuperFetch logs user activities and preloads software into memory to reduce their load times. ReadyBoot analyzes the boot process and allocates additional random access memory to optimize the process. ReadyBoost uses a flash memory as a drive for system caching. ReadyDrive enables disk caching on hybrid hard disk flash memory to boot up faster, resume from hibernation in less time, and preserve battery power. Furthermore, other improvements include: new Multimedia Class Scheduler Service that supports glitch-free audio and video streaming, new display driver architecture called WDDM (Windows Display Driver Model) that gives users better performance, stability and security and DirectX® 10 support. Other improvements can be found in [10] and [11].

The underlying design goal for Windows 7 was performance improvement in key user scenarios with focus on user responsiveness. Windows 7 is built on the same core architecture as Windows Vista and therefore all features from Windows Vista are retained in Windows 7 and most of them are enhanced. ReadyBoost improvements include support for caching pagefile-backed pages, concurrent use of multiple flash devices and support for a 32 GB cache. ReadyBoot is improved by using compression and reducing memory footprint. Memory manager is improved by adding own working set to system cache, paged pool, and a pageable system code. Also, registry operations are enhanced by removing memory mapping. Improved DWM (Desktop Window Manager) reduces memory footprint per window by 50%. Kernel Dispatcher Lock is replaced with several finer-grained synchronization techniques thus effectively distributing resource contention. UMS (User Mode Scheduling) improves performance by separating a user-mode thread and a kernel-mode thread. Scalability for applications that manage large amounts of memory is improved by removing the memory manager PFN (Physical Frame Number) global lock. DirectX 11 improves scalability and performance by introducing new features. Core Parking improves power efficiency by dynamically selecting a set of processors (sockets) that should stay idle and Windows 7 includes support up to 256 logical processors. The main benefit from a new kernel part of Windows 7 called MinWin is that it can be built, booted and tested separately from the rest of the system [12].

V. BENCHMARK APPLICATIONS

Benchmark applications are specially developed for measuring the overall performance of computer systems or for measuring performance of certain components. Components with the greatest impact on the performance of the computer system are: CPU, memory, graphics subsystem and hard disk. Most computer users use these applications for mutual computer systems performance comparison. We use these benchmark applications on the same hardware but on different host operating systems so performance measurement results will show which host operating system has best performance on this hardware. In addition to this, with two different programs we measure the time required to perform some complex operations which demand a lot of hardware resources. Benchmark applications and programs used are described below.

A. Maxon Cinebench 10

Cinebench [13] is a real-world cross platform benchmark application that evaluates computer systems performance capabilities. It uses user’s common tasks within Cinema 4D to measure a system’s performance. The test procedure consists of two main components: the CPU performance test and the graphics subsystem performance test.

CPU performance test scenario uses all of computer system’s processing power to render a photorealistic 3D scene, which uses various different algorithms to stress all available processor cores. The graphics subsystem performance test uses a complex 3D scene depicting a car chase and measures the performance of the graphics subsystem in an OpenGL mode. The results are shown with the number of points whereby the higher the number implies the better performance.

B. Futuremark PCMark®2002

PCMark2002 [14] has the ability to benchmark the CPU, memory, graphics memory and hard disk. In our performance measurements we are using memory and hard disk test suites. The results are shown with number of points and the higher result mean better performance.

C. Super PI mod 1.5

Super PI [15][14] is a benchmark program that overloads memory and the CPU by calculating number PI to a specified number of digits after the decimal point up to a maximum of 32 million. We measured times needed to calculate 1 million and 32 millions digits. For calculation it uses the Gauss-Legendre algorithm that tests the decimal floating point and mathematic performance of the CPU. The result is given in seconds whereby the shorter the time the better the performance.

D. Passmark Performance Test™ 7.0

PerformanceTest [16] objectively benchmarks computer systems by using a variety of different speed tests. Standard test suites are:
- CPU tests - mathematical operations, compression, encryption, SSE and 3DNNow! instructions,
- 2D graphics tests - drawing lines, bitmaps, fonts, text, and GUI (Graphical User Interface) elements,
- 3D graphics tests - simple to complex DirectX 3D graphics and animations,
- Disk tests - reading, writing and seeking within disk files,
- Memory tests - allocating and accessing memory speed and efficiency,
- DVD test - test the speed of a DVD drive.

The result is expressed as the overall “Passmark Rating” whereby the higher the result means the better performance.

E. CPU Free BenchMark 2.2

CPU Free BenchMark [17] is a benchmark application that measures performance of CPU registers, FPU (Floating-Point Unit), and ALU (Arithmetic Logic Unit). There are 3 major tests (registry, floating-point operations and integer operations). Each test is built based on specific equations and operations depending on the test. The result is given in seconds whereby the shorter the time the better the performance.

F. Video encoding

Video encoding is performed with program Total Video Converter 3.50, available at [18]. The initial file format is AVI (Audio Video Interleave) and the size of a video file is 400 MB. The destination file format is MPEG-1. Video encoding overloads memory and the CPU and the result is given in seconds, so that the shorter the encoding time the better the performance.

G. Data compression

WinRAR 3.90 [19] is an application that uses a highly sophisticated and original compression algorithm for data compression or decompression. For performance measurement we use a built-in speed compression test (the result is given in KB/s, the higher the better). Furthermore, we measure the time needed to compress a 400 MB AVI file to a RAR format (the result is given in seconds whereby the shorter the time the better the performance).

VI. PERFORMANCE MEASUREMENT SETUP AND METHODOLOGY

For the host operating system, a virtual machine is just another running application that requests hardware resources. Performance of a virtual machine depends on host operating system resource management. A host operating system that has more efficient hardware and software resources allocation will provide better performance for running a virtual machine. Hardware components with the greatest influence on the performance are as follows:

- Memory – memory size of a virtual computer can take at most half the size of system memory. In performance measurement we use a virtual computer with 1 GB of memory. Because of new memory management presented in Windows Vista and Windows 7 we expect these operating systems to have better performance than Windows XP,
- CPU – as Virtual PC does not emulate the CPU, a virtual machine executes a certain instruction directly on system CPU. Furthermore, performance measurement is done on a laptop computer connected to an AC power during measurements because mobile processors lower their performance to save energy when a laptop computer is not connected to an AC power,
- Graphics subsystem – as an emulated graphics subsystem has only 8 MB of memory, we could not run new graphics benchmark applications. Furthermore, resolution and the number of monitors can also affect performance so we use only a laptop monitor with the screen size of 17 inches,
- Hard disk drive – a virtual machine uses hard disk drive resources by creating virtual disk partition. Performance measurement is performed on a laptop computer Notebook Forcebook Vision Mitac 8207D with hardware and software characteristics shown in Table 2.

![Table II](https://via.placeholder.com/150)

<table>
<thead>
<tr>
<th>Hardware components</th>
<th>Memory</th>
<th>CPU</th>
<th>Graphics subsystem</th>
<th>Hard disk drive</th>
<th>Host operating systems</th>
<th>Virtual operating system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 x 1 GB DDR2 533 MHz</td>
<td>Intel® Core™ Duo Processor T2050 (2M Cache, 1.60 GHz, 533 MHz FSB)</td>
<td>ATI Mobility Radeon™ x1600 256 MB</td>
<td>Hitachi SATA 100 GB, 5400 rpm, 8 MB</td>
<td>Microsoft Windows XP Professional SP3 32-bit</td>
<td>Microsoft Windows Vista Business SP2 32-bit</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Microsoft Windows Vista Business SP2 32-bit</td>
<td>Microsoft Windows 7 Professional 32-bit</td>
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<td></td>
<td></td>
<td></td>
<td>Microsoft Windows Vista Business SP2 32-bit</td>
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</tbody>
</table>

In performance measurement we use similar editions of the three latest versions of Windows as the host operating system: Windows XP Professional SP3, Windows Vista Business SP2 and Windows 7 Professional. These editions are chosen as they have similar features and they are targeted for power users. All editions are 32-bit and have the latest service packs installed as they include updates and enhancements that improve performance and stability. After installing operating systems, in order to have a computer system “up to date” the newest device drivers and operating system updates were installed. To avoid errors during performance measurements and to ensure the same conditions for all operating systems, in every operating system the following steps were performed:
1. Install the host operating system,
2. Install the latest device drivers and operating system updates,
3. Install Microsoft Virtual PC 2007,  
4. Set a virtual machine with 1 GB of memory and 40 GB of virtual hard disk,  
5. Install a virtual operating system (Windows Vista Business SP2),  
6. Install the latest device drivers and operating system updates for a virtual operating system,  
7. Turn off network, screen saver, system restore and user account control (only for Windows Vista and Windows 7),  
8. Install the benchmark application,  
9. Reboot computer system three times,  
10. Run Virtual PC,  
11. Run the benchmark application,  
12. Uninstall the benchmark application.

Beside the operating system, Virtual PC and benchmark application there was no another application installed on the computer system. To ensure results’ accuracy every measurement was repeated three times (steps 9 – 11) and the arithmetic mean was calculated. For every new benchmark application steps 8 – 12 were repeated.

Performance evaluation is done by comparing virtual machine performance measurement results for every benchmark application on three different host operating systems. Results are evaluated by means of the following metrics:

- Number of points (obtained in benchmark applications),
- Speed (of compression test in WinRAR),
- Time (required to complete complex operations).

VII. Results and Analysis

In our performance measurements, we tested performance of computer system components with benchmark applications installed on a virtual operating system. Extra emphasis is placed on the following hardware components: CPU, memory, graphics subsystem and hard disk drive. By comparing the same performance measurements on different host operating systems we can determine which host operating system provides the best performance for a virtual machine. Performance metrics used represent a view of real-world performance. All performance measurement results are shown in Fig. 2.

When measuring graphics subsystem performance with Cinebench 10, Windows Vista and Windows 7 show equal performance that is 6.15% better than in Windows XP. The identical graphics performance measurement result for Windows Vista and Windows 7 shows that new graphics architecture presented in Windows Vista is also used in Windows 7. CPU performance shows similar performance for all three operating systems. PCMark2002 results show that memory management is handled best in Windows Vista. Hard disk drive performance measurement shows that Windows 7 won more than twice the number of points when compared to Windows XP and Windows Vista. This means that hard disk drive management has huge improvements in Windows 7. The shortest times needed to calculate 1 million and 32 millions digits of number Pi are obtained in Windows 7. As Super PI overloads memory and mostly CPU, these resources are best allocated in Windows 7. Passmark Performance Test measures performance of all computer system components and gives a good overview of the overall performance. Since the
overall Passmark Rating is similar for Windows Vista and Windows 7, we can conclude that these operating systems are built on the same core architecture. Passmark Performance Test shows that their overall performance is around 7% better than Windows XP performance. Again, CPU Free BenchMark shows similar results for Windows Vista and Windows 7, which are slightly better than Windows XP. Video encoding is shortest in Windows 7 (25.55% shorter than in Windows Vista) and in Windows XP (20.88% shorter than in Windows Vista), so we can conclude that for this real-world usage Windows Vista would be the worst choice. Data compression is fastest and shortest in Windows 7, so the CPU and memory allocation for this usage is best handled in Windows 7.

VIII. CONCLUSION

This paper attempts to evaluate performance of a virtual machine when it is installed on the three latest versions of Windows operating systems, XP, Vista and 7. Performance measurement and evaluation is done in the same controlled conditions for all three host operating systems with different benchmark applications and programs.

In comparison with Windows XP, Windows Vista and Windows 7 have many new features and enhancements in almost all parts of the operating system. Performance measurement results show that in almost every measurement Windows 7 has the best result. Windows Vista and Windows 7 are built on the same core architecture so in some performance measurements Windows Vista has similar results as Windows 7. However, other results indicate poor performance of Windows Vista, even worse than Windows XP. From performance evaluation we can conclude that the virtual operating system has the best performance when Windows 7 is used as the host operating system.

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