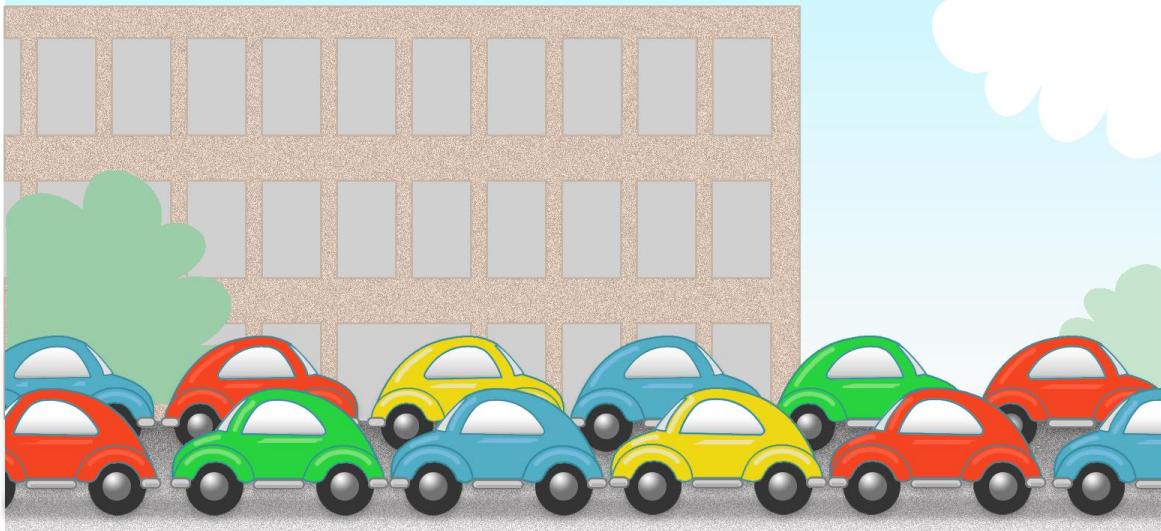


CHROMEBOOK VS. WINDOWS NOTEBOOK NETWORK TRAFFIC ANALYSIS

A Chromebook™ can create nearly 700 times more network traffic

versus a notebook running Microsoft® Windows® applications



Some schools and school systems are considering the new Chromebook systems for their students because they appear to be an inexpensive solution. However, their Web-based software model requires a network connection and their normal use creates significantly more network traffic than a notebook running Microsoft Windows applications. Supporting additional network traffic can be an expensive burden for schools, most of which already struggle with insufficient broadband connections.¹

In the Principled Technologies labs, we measured the network traffic created by two systems, a Chromebook and a notebook running Microsoft Windows 8, during test scenarios that simulate typical student educational activity. Because the Windows notebook performed the majority of these tasks without using the Internet or the local wireless networks, the Chromebook used an average of 152.3 times more network traffic.

Most school systems have limited funds they must use wisely and limited broadband access. Before purchasing Chromebooks, it is essential to consider the impact the choice could have on schools' network infrastructure.

¹ In a 2010 Federal Communications Commission survey of schools and libraries (transition.fcc.gov/010511_Eratereport.pdf), nearly 80 percent of respondents said their broadband connections did not fully meet their current needs.



PAY NOW OR PAY LATER

Chromebooks can be inexpensive, and no school system can afford to ignore what might appear to be a money-saving computing solution. These lightweight and thin systems use Web-based applications that often can be accessed for little to no additional charge, so they appear to offer savings on software. However, the low acquisition cost of these devices will be false savings if the Web-only Chromebook solution does not fit existing teacher and student needs and the school must increase the number and/or quality of wireless routers, local network devices, and speed and bandwidth for Internet connectivity in order to accommodate their typical use in the classroom.

Traditional Windows-based notebook computers run software applications from their hard drives and save files to these same hard drives. The recent emergence of cloud computing shifts this model to one where applications and users' files are no longer stored "locally" on their computers, but are now "out there" in the cloud and accessed through the Web. The computer becomes simply a means of accessing these Web-based resources, an Internet thin client.

While this approach has some advantages, Chromebooks generate more network traffic as compared with Windows-based notebooks—up to 692.2 times as much in our testing—putting additional strain on wireless networks that in many cases can barely meet current user needs (see Figure 1).

Chromebook created up to 692.2 times the network traffic

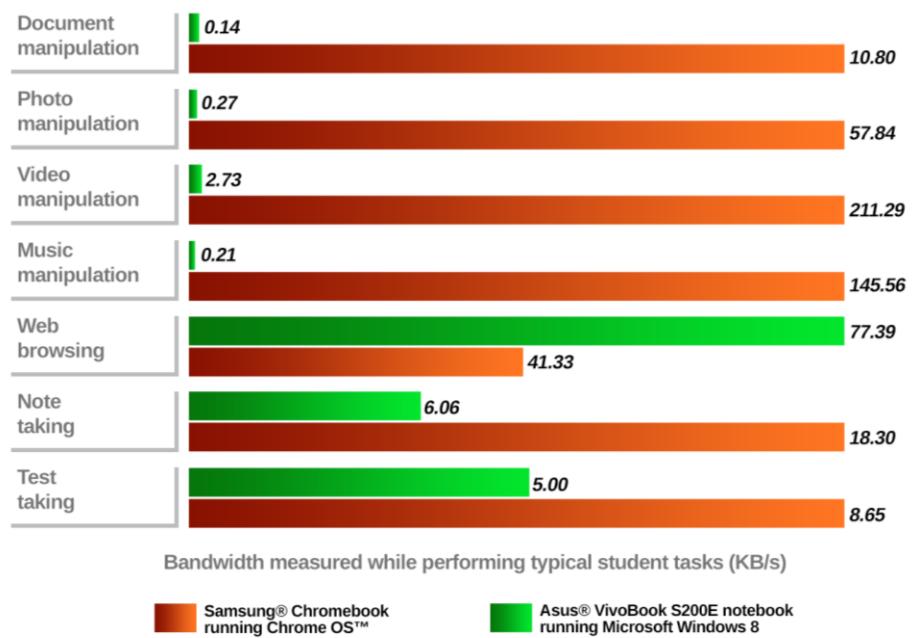


Figure 1: In all scenarios except Web-browsing, the Chromebook created a great deal more network traffic than the Windows notebook. Lower numbers, reflecting less traffic, are better.

In this report, we show the results of seven test scenarios involving computing tasks students typically perform. We conducted these scenarios in our labs on both a Samsung® Chromebook running Chrome OS™ (26.0.1410.57) and an Asus® VivoBook S200E, an inexpensive notebook running Microsoft Windows 8, and measured the amount of network traffic associated with each. Prior to testing, we copied all test files to each system's default storage area. For the Windows notebook, this was the system's hard disk drive. For the Chromebook, this was the cloud-based Google Drive™.

[Appendix A](#) provides detailed configuration information for the two systems. [Appendix B](#) provides our test methodology. [Appendix C](#) shows detailed results.

OUR FINDINGS

Scenario 1: Document manipulation

This scenario simulated a student writing one 205KB paper and converting it to a PDF, creating one 2.23MB slide presentation, and working with a 176KB spreadsheet. We used Google Docs™ on the Chromebook, and Microsoft Office® on the Windows notebook. As Figure 2 shows, there was almost no network traffic with the Windows notebook. This is because the student's work was saved locally to the hard drive. Because Google Docs on the Chromebook continually saves the student's work to the cloud, it generates far more network traffic—76.5 times more—than the Windows notebook does.

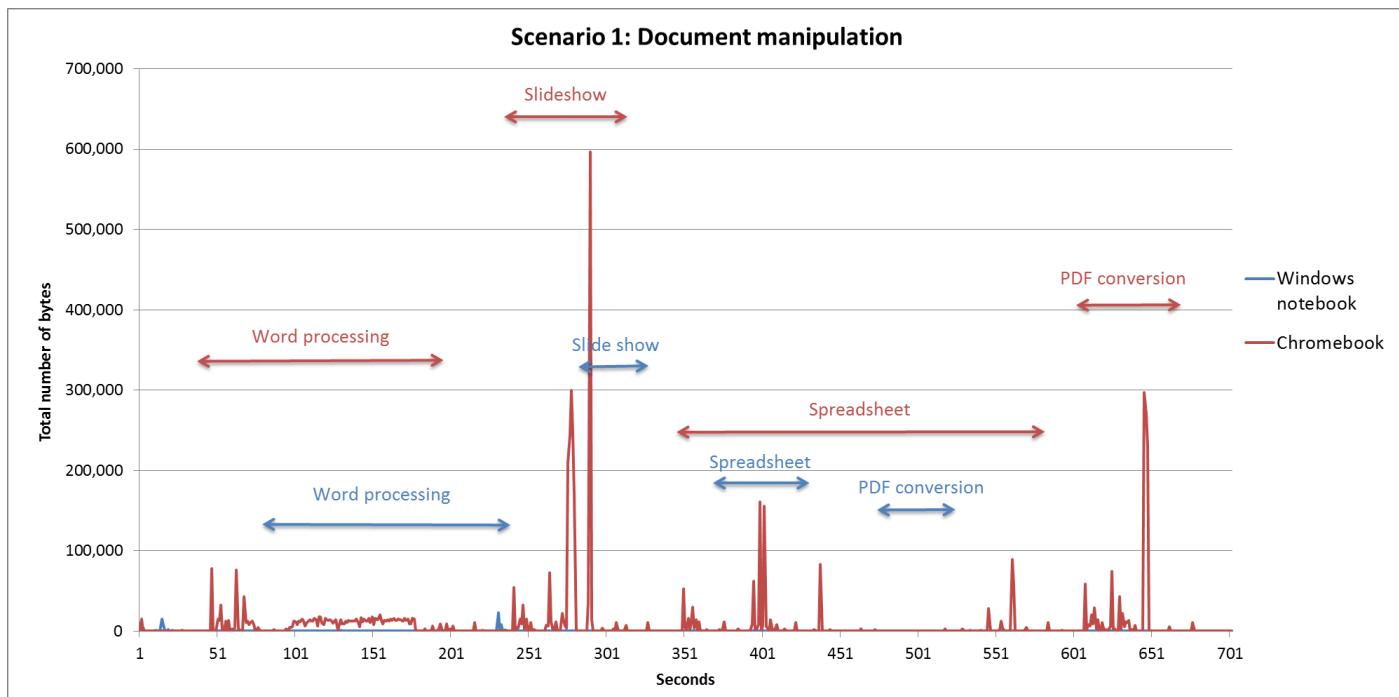


Figure 2: Network traffic for the two systems during the document manipulation scenario.

In addition to the increased bandwidth usage, we observed several other issues when we performed these tasks with the Chromebooks:

- Microsoft PowerPoint® slide decks opened in Google Slides had formatting and sizing issues.
- Microsoft Word files opened in Google Docs were missing images, headers, footers and other objects, and the page breaks and formatting were incorrect.
- Working in spreadsheets in Google Sheets seemed slow and the constant saving caused slight response delays that became irritating.

Scenario 2: Photo manipulation

This scenario simulated a student manipulating photographs, as they might do for the school newspaper or yearbook.

First, we converted three photographs (ranging in size from 4.70 MB to 6.29 MB) from the JPEG format to PNG format. On the Chromebook, we used the Google app CloudConvert. On the Windows notebook, we used Microsoft Paint.

We also used the default photograph-editing tool on each system to perform basic editing tasks, such as auto adjust or auto fix, while monitoring network traffic. The Chromebook has a built-in photo editor. When a user opens a photo, the edit option becomes available. Because Windows 8 does not come with a default photo editor, we used Microsoft's Photo Gallery (available free of charge from windows.microsoft.com/en-us/windows-live/photo-gallery#photogallery=overview).

As Figure 3 shows, performing these tasks on the Chromebook created much more network traffic—214.9 times more—than on the Windows notebook. The conversion task on the Chromebook uses a Web-based app requiring an Internet connection to convert and the photos are stored in the Google App cloud. This requires the changes to be saved over the network to the cloud storage. With the Windows notebook, both tasks are performed using only the system's hard drive for storage, so no network usage is required.

In addition to the increased bandwidth usage, we observed that opening and editing photos was very slow on the Chromebook.

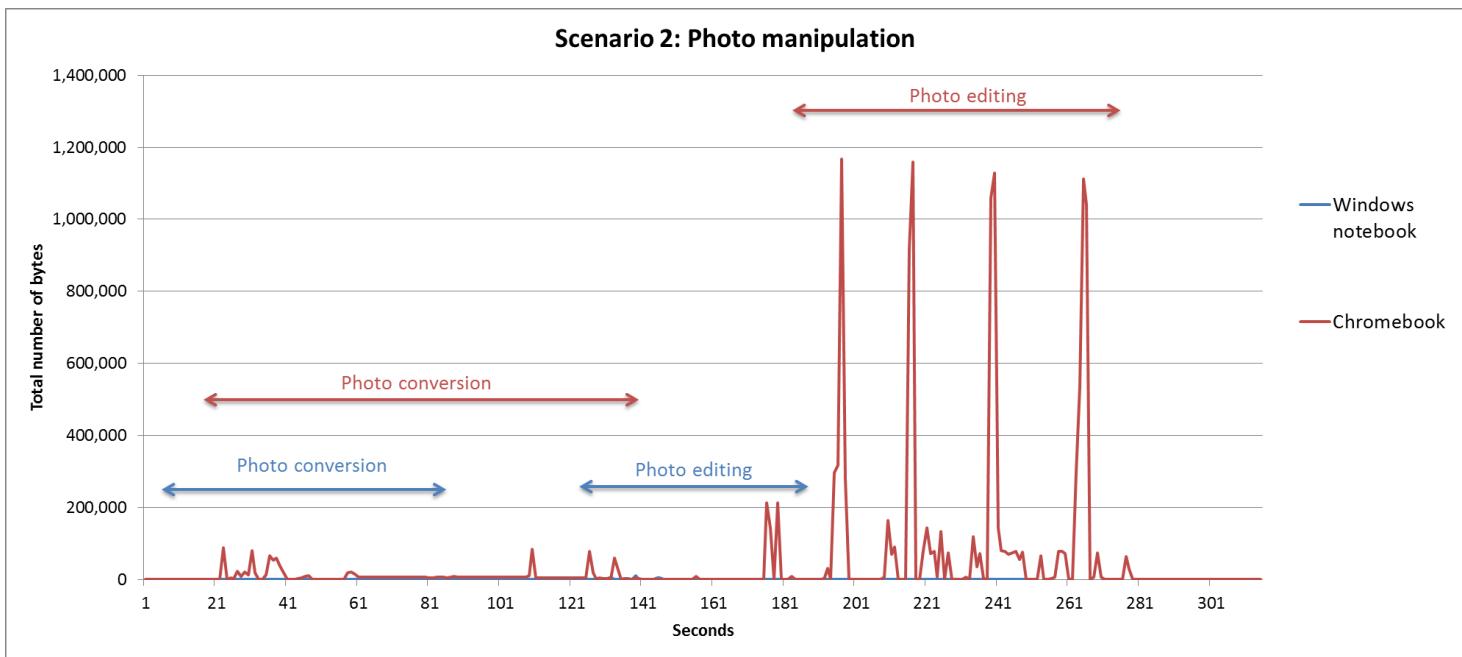


Figure 3: Network traffic for the two systems during the photo manipulation scenario.

Scenario 3: Video manipulation

This scenario simulated a student creating and editing videos, as they might for classes and extracurricular activities. We converted a 1-minute video file (170 MB in size) from MP4 to MOV format using the Google app CloudConvert on the Chromebook, and Smart Converter (found in the Microsoft store) for the Windows notebook.

We also watched the same video using the default video viewing software on each system. The Chromebook has a built-in video viewer. Windows 8 systems have a default Video app in the Windows 8 Start screen that allows users to watch videos. We used both this player and the Windows Media Player to see whether the effect on network traffic differed.

As Figure 4 shows, performing these tasks on the Chromebook created much more network traffic—77.4 times more—than on the Windows notebook. Because the files on the Chromebook are stored in the Google Drive cloud, both the videos conversion and viewing tasks must be done over the network. Watching a video from the Google cloud is similar to watching a video online, and requires a good network connection to stream the data for viewing. The video files stored locally on the Windows notebook's hard drive required no network connection for editing or viewing.

We observed many long pauses and faltering playback on the Chromebook, making the video nearly unwatchable. As Figure 3 also shows, to

play a 1-minute video in its entirety took over 6 minutes on the Chromebook due to the pauses.

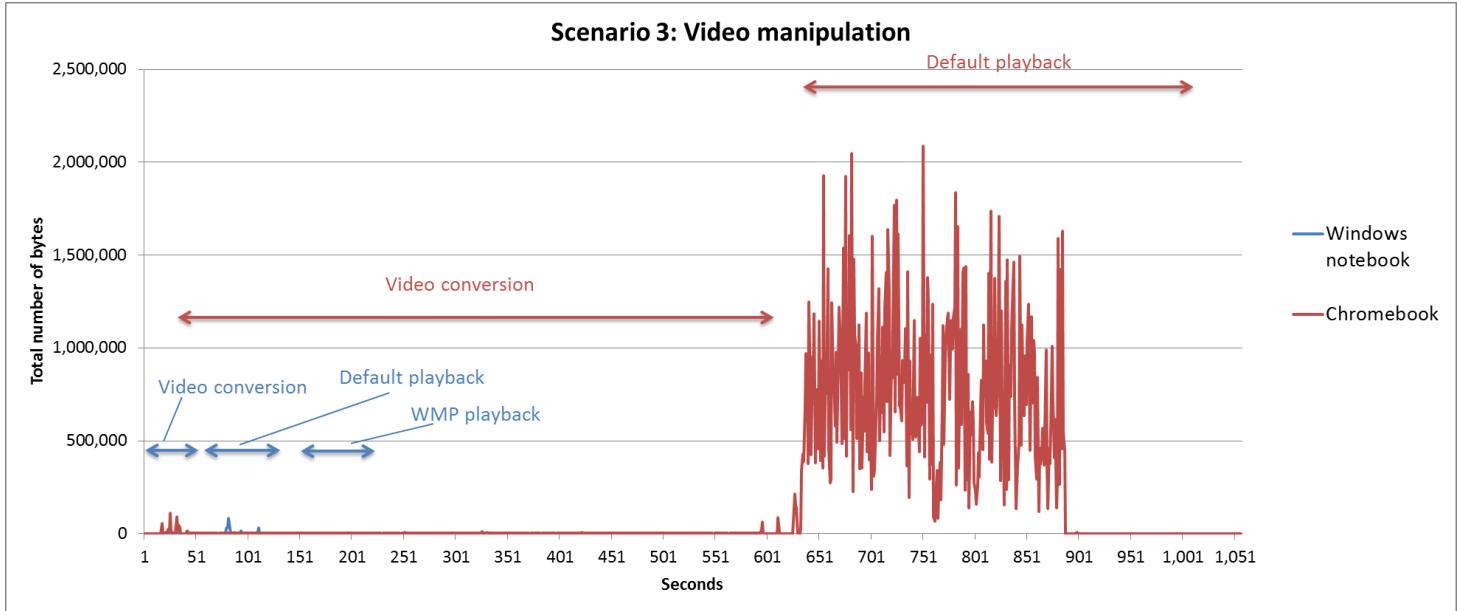


Figure 4: Network traffic for the two systems during the video manipulation scenario.

Scenario 4: Music manipulation

This scenario simulated a student manipulating music, as they might do for band or choir. We converted one 22.3 MB WAV file to MP3 format. On the Chromebook, we used the Google app CloudConvert, which allows users to convert various audio formats into other formats. On the Windows devices, we used Smart Converter from the Microsoft store.

We also played a music file while monitoring network traffic using the default music playing software on each device. The Chromebook has Google Play Music installed as the default music-listening software. Windows 8 uses a default Music app in the start page that allows users to listen to music. We used both this player and the Windows Media Player to see whether the effect on network traffic differed.

As Figure 5 shows, performing these tasks on the Chromebook created much more network traffic—692.2 times more—than on the Windows notebook. As with the photo and video tasks, the music files are stored on the Google Drive cloud, and require network streaming to edit and listen to the files, generating a great deal of network traffic, similar to listening to music on sites like Pandora® or Spotify®. The music files stored locally on the Windows notebook's hard drive required no network connection for editing or playing.

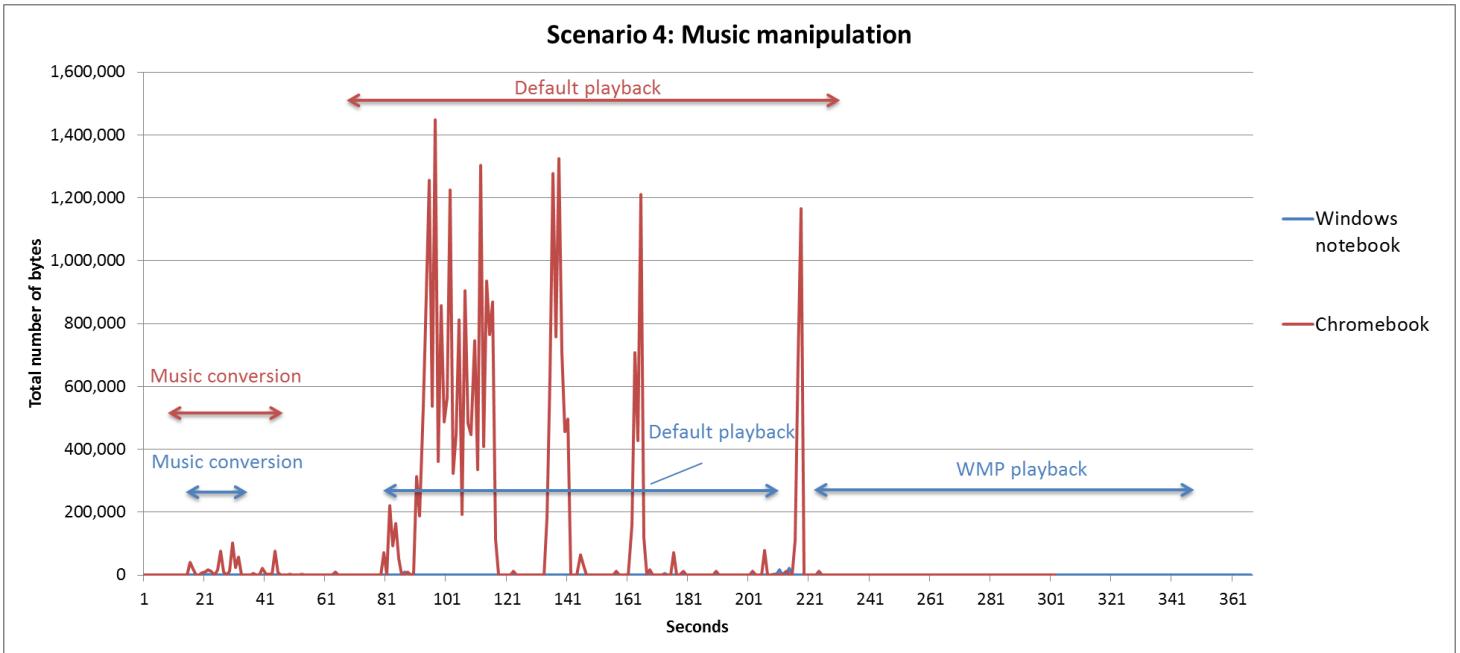


Figure 5: Network traffic for the two systems during the music manipulation scenario.

Scenario 5: Web browsing

This scenario simulated a student performing research for various papers and projects. We browsed to a set of different education-based Web sites on each device while monitoring network traffic to see whether there was an additional network impact on the Chromebook. We used Google Chrome™ on the Chromebook and Internet Explorer® 10, Modern UI version on the Windows system.

As Figure 6 shows, performing these tasks generated comparable network traffic on the two systems. This shows that the Chromebook does not generate an excessive amount of network traffic and puts the findings from the other scenarios into context: by design, the Chromebook simply requires more network activity than a Windows system that performs most tasks locally.

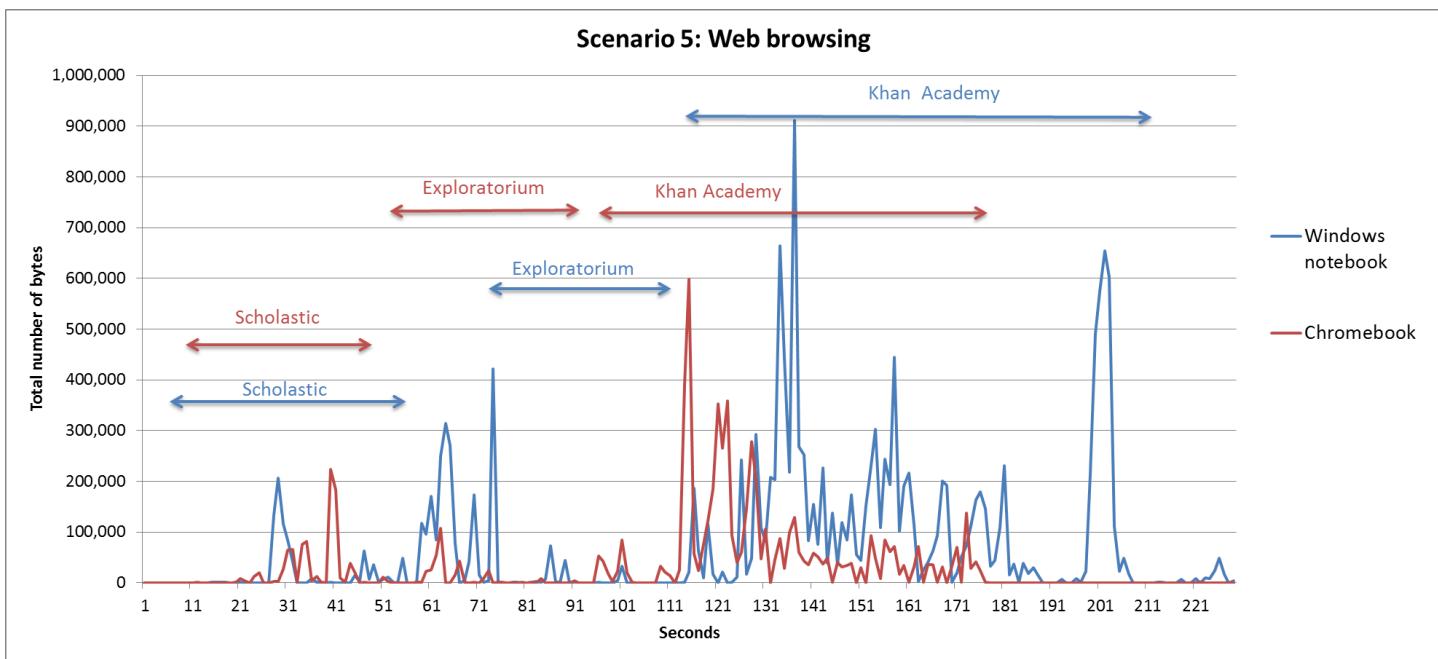


Figure 6: Network traffic for the two systems during the Web browsing scenario.

Scenario 6: Taking notes and clipping from the Web

This scenario simulated a student taking notes, as they might do during lectures, and using a tool to “clip” information from the Web, as they might do while conducting research. We used the Microsoft OneNote® application on the Windows device, and Evernote® Web on the Chromebook while measuring network traffic. We used a 1,940KB DOCX document for the attachment in this scenario.

As Figure 7 shows, the Chromebook created more traffic while the student was taking notes—3.0 times more—than on the Windows notebook. Although both devices created similar amounts of traffic while using Web browsers, as shown in the previous task, the Chromebook also created traffic in the note-taking application because it is Web based. Because the Windows device used a locally stored note-taking application, it did not create as much traffic in the combined task.

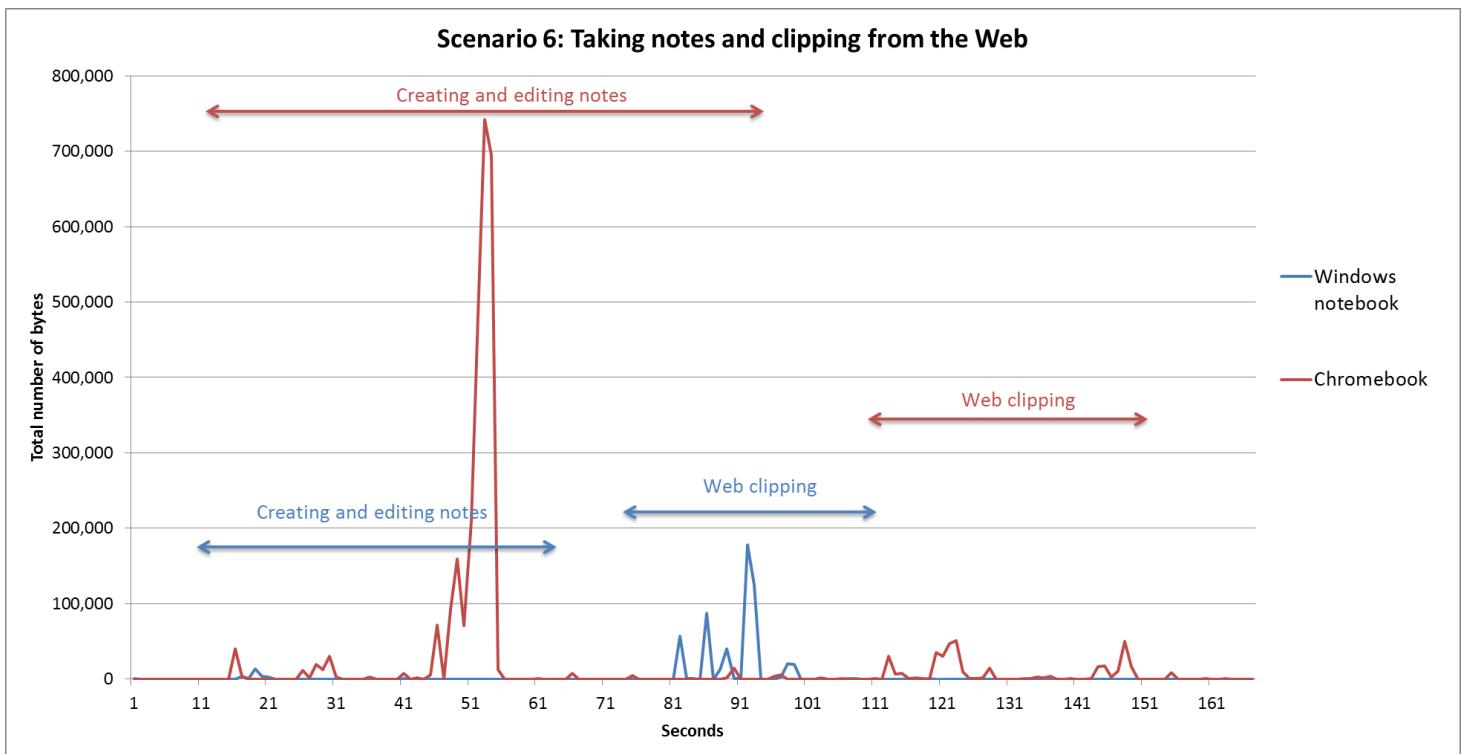


Figure 7: Network traffic for the two systems during the note-taking scenario.

Scenario 7: Test-taking

Many teachers utilize online test creation sites that allow students to take exams on their computers instead of in the traditional paper manner. This scenario simulated a student browsing to an online test and completing it on each device while capturing the network traffic.

As Figure 8 shows, performing this task generated slightly more network traffic on the Chromebook—1.7 times more—than on the Windows notebook. Similar to basic Web browsing, online tests generate a similar amount of traffic on both systems. However, the Windows system showed a more consistent, and lower overall average, network traffic generation making the Windows system a more reliable test-taking platform.

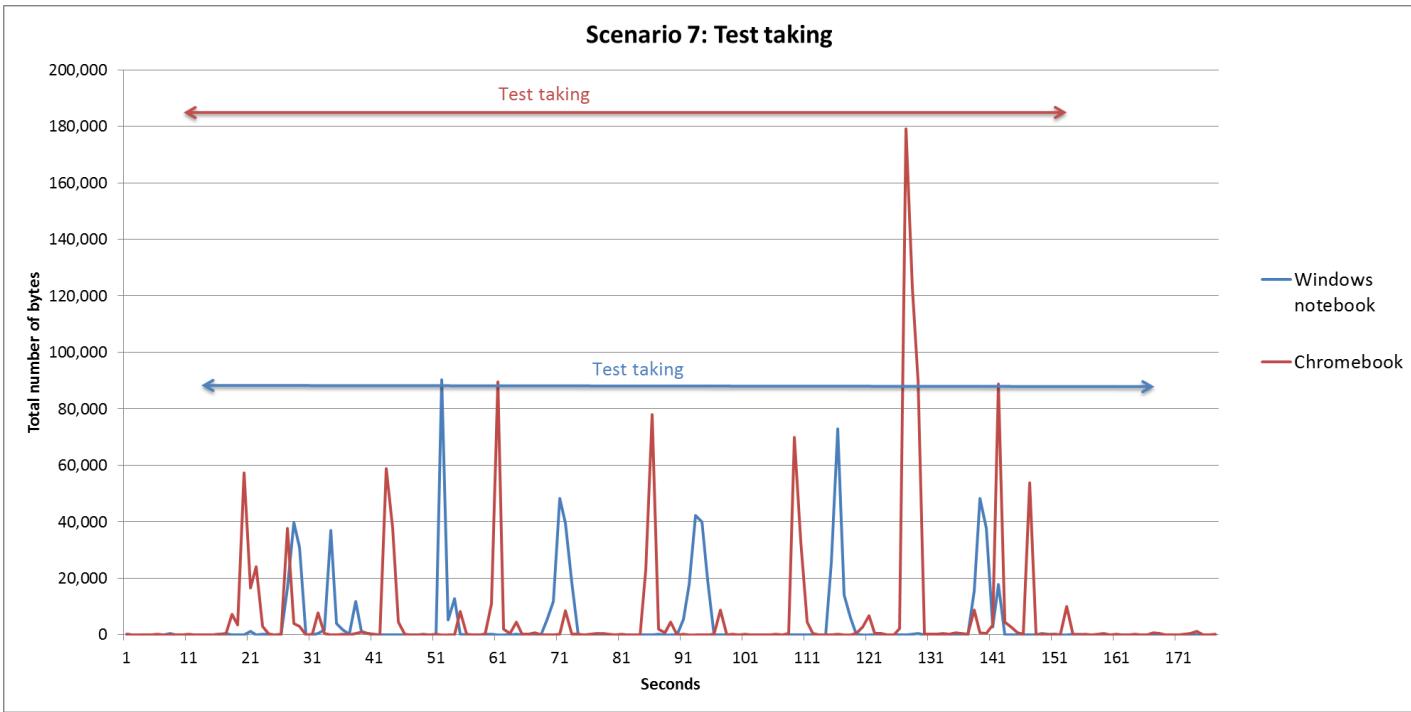


Figure 8: Network traffic for the two systems during the test-taking scenario.

IN CONCLUSION

As they seek the most cost-effective way to meet the computing needs of their students, many schools and school systems are considering Chromebooks. Our testing revealed a hidden cost to these inexpensive systems: they can create significantly more network traffic than notebooks running Windows—an average of 152.3 times more traffic across our seven scenarios and as much as 692.2 times more.

With roughly 80 percent of schools reporting that their broadband connections fell short of their current needs,² few schools would be able to absorb extra network traffic from Chromebooks without expanding their network infrastructure, and continuing to pay for this cost over time. The fact that all of the students in a class tend to do the same things at the same time of day can compound the problem of network traffic bottlenecks, lowering the quality of the educational experience and frustrating students.

It is clear that any school that decides to adopt Chromebooks for student use must plan for adequate network capabilities. The cost of increasing these capabilities could easily negate the savings of purchasing Chromebooks, making Windows devices an even more attractive choice.

² Federal Communications Commission survey of schools and libraries (http://transition.fcc.gov/010511_Eratereport.pdf).

APPENDIX A – DETAILED SYSTEM INFORMATION

Figure 9 presents detailed system information for the two systems we tested.

System	Asus VivoBook S200E	Chromebook
General		
Number of processor packages	1	1
Number of cores per processor	2	2
Number of hardware threads per core	2	N/A
Total number of Threads	4	N/A
System power management policy	Power4Gear High Performance	N/A
System dimensions (depth x width x height)	7.87" x 11.93" x 0.82"	8.09" x 11.4" x 0.69"
System weight	4.95 lbs.	2.43 lb.
CPU		
Vendor	Intel®	Samsung
Name	Core® i3	Exynos 5 Dual
Model number	3217U	N/A
Stepping	9	N/A
Socket type and number of pins	Socket 988B rPGA	N/A
Core frequency (GHz)	1.8	1.7
Bus frequency	99.78 MHz	N/A
L1 cache	32 KB + 32 KB (per core)	N/A
L2 cache	512 KB (256 KB per core)	N/A
L3 cache	3 MB	1 MB
Platform		
Vendor	ASUS	Samsung
Motherboard model number	X202E	N/A
Motherboard chipset	Intel HM76	N/A
BIOS name and version	American Megatrends Inc. X202E.205 (10/01/2012)	N/A
Memory module(s)		
Vendor and model number	Samsung M471B5273DH0-CK0	N/A
Type	DDR3	DDR3L
Speed (MHz)	1,333	N/A
Speed running in the system (MHz)	655	N/A
Timing/Latency (tCL-tRCD-tRP-tRASmin)	9-9-9-24	N/A
Size (MB)	3,982	2GB
Number of memory module(s)	1	N/A
Chip organization (single-sided/double-sided)	Double-sided	N/A
Channel (single/dual)	Single	N/A

System	Asus VivoBook S200E	Chromebook
Ethernet		
Vendor and model number	Qualcomm® Atheros AR8162/8166/8168 PCI-E Fast Ethernet Controller (NDIS 6.30)	N/A
Driver	Qualcomm Atheros 2.1.0.7 (07/19/2012)	N/A
Optical drive(s)		
Vendor and model number	Portable/USB	N/A
USB ports		
Number	3	1
Type	1 x USB 3.0 2 x USB 2.0	1 x USB 3.0 1 x USB 2.0
Other	HDMI, VGA port/Mini D-sub 15-pin, 2-in-1 card reader (SD/ SDHC/ SDXC/ MMC)	HDMI, VGA
Monitor		
LCD type	LED-backlit	LED HD
Screen size	11.6"	11.6"
Battery		
Type	2Cells 5136 mAh 38 Whrs Polymer Battery	2 cell/Li-Po
Rated capacity	5,136mAh / 38 Wh	4080mAh / 30 Wh

Figure 9: Detailed configuration information for the two systems.

APPENDIX B – DETAILED TEST METHODOLOGY

Note: All test files were original material created in the PT lab.

Scenario 1: Document manipulation

We used the following test files:

- Word document – size: 205 KB (210,188 bytes)
- Excel® workbook – size: 176 KB (180,955 bytes)
- PowerPoint presentation – size: 2.23 MB (2,351,104 bytes)

The document conversion test resulted in a PDF that was roughly 578 KB on the windows notebook and roughly 686 KB on the Chromebook (the file size fluctuated).

Performing this task on the Chromebook

1. Word processing
 - a. Open WordDOCX1.docx in Google Docs.
 - b. Scroll through the entire document, then return to the top.
 - c. Type a new paragraph into the introduction section.
 - i. We will simply re-type the original first paragraph, which takes roughly 75 seconds at a rate of 70 wpm.
 - d. Change the font of the Table of Contents to Calibri, size 11.
 - e. Close the document.
2. Slide show
 - a. Open PowerPointPPTX.pptx in Google Slides.
 - b. Switch slide 5 with slide 6.
 - c. Change the animation type to Cube.
 - d. Click Play to make sure the change went through, then click Stop.
 - e. Close the file.
3. Spreadsheet
 - a. Open ExcelXLSX2.xlsx in Google Sheets.
 - b. Click in column K, and choose Insert → Column right to create column L.
 - c. In cell L13, type =sum(F13:K13) and press Enter.
 - d. Highlight cell L13, and click and drag the bottom right corner to copy the formula. Continue dragging until you reach the end of the filled cells.
 - e. Release the mouse and allow the data to fill in.
 - f. Once the calculations have finished, close the file.
4. Document conversion
 - a. Open WordDOCX1.docx in Google Docs.
 - b. Click File→Download as→PDF Document (.pdf)
 - c. Click the PDF file on the bottom of the browser to open it.
 - d. After you have confirmed that it loads fully, close all windows and return to idle mode.

Performing this task on the Windows notebook

1. Word processing
 - a. Open WordDOCX1.docx in Microsoft Word 2013.
 - b. Scroll through the entire document, then return to the top.
 - c. Highlight the Introduction text, and leave a comment.
 - d. Save the file, and close it.

2. Slideshow
 - a. Open PowerPointPPTX.pptx in Microsoft PowerPoint 2013.
 - b. Switch slide 5 with slide 6.
 - c. Change the animation type to Cube.
 - d. Save the file, and close it.
3. Spreadsheet
 - a. Open ExcelXLSX2.xlsx in Microsoft Excel 2013.
 - b. In cell L13, type =sum(F13:K13) and press Enter.
 - c. Highlight cell L13, and click and drag the bottom right corner to copy the formula. Continue dragging until you reach the end of the filled cells.
 - d. Release the mouse and allow the data to fill in.
 - e. Once the calculations have finished, close the file.
4. Document conversion
 - a. Open WordDOCX1.docx in Microsoft Word.
 - b. Click File→Save As
 - c. Choose the location on the local drive where you want to save the file.
 - d. In the drop-down menu for Save as type, choose PDF (*.pdf), and click Save.
 - e. The new file should automatically open in the default Modern PDF viewer. Once you have determined that it opened correctly, close all windows and return to an idle state.

Scenario 2: Photo manipulation

We used three JPG-format images with the following file sizes:

- 4.70 MB (4,937,006 bytes)
- 4.38 MB (4,595,496 bytes)
- 6.29 MB (6,604,836 bytes)

Performing this task on the Chromebook

1. Photo conversion
 - a. Open the Web-based Google Drive by clicking the icon on the toolbar, and choose the JPEG files.
 - b. Click More→Open with, and choose CloudConvert.
 - c. Choose .png from the Convert to drop-down menu for each file.
 - d. Click Start Conversion.
 - e. When the conversion is finished, close all applications to return the system to an idle state.
2. Photo editing
 - a. Navigate Files→Google Drive.
 - b. Click the first JPEG, and wait for it to open.
 - c. On the bottom of the picture, click Edit.
 - d. Uncheck Overwrite original, and click Auto-fix.
 - e. When the auto-fix is finished, click the right side of the picture to pull up the next file.
 - f. Repeat steps d and e on the next two pictures.
 - g. Close everything and return to idle state.

Performing this task on the Windows notebook

1. Photo conversion
 - a. Navigate to the .jpg files.
 - b. Right click the first file, and choose Open with→Paint.
 - c. Click File→Save as→PNG picture
 - d. Click Save.

- e. Repeat steps b through d for each file.
 - f. Close everything down to return to an idle state.
2. Photo editing
 - a. Navigate to the JPEG files.
 - b. Right click the first file, and choose Open with→Photo Gallery.
 - c. Click Edit, Organize, Share in the top left corner.
 - d. Click Auto-adjust.
 - e. Click Next, and repeat step d for each file.
 - f. Close everything and return to idle state.

Scenario 3: Video manipulation

We used a 1-minute video file with a file size of 170 MB (179,150,606 bytes).

Performing this task on the Chromebook

1. Video conversion
 - a. Open the Web-based Google Drive by clicking the icon on the toolbar, and choose the MP4 video file.
 - b. Click More→Open with, and choose CloudConvert.
 - c. Choose .mov from the Convert to drop-down menu.
 - d. Click Start Conversion.
 - e. When the conversion is finished, close all applications to return the system to an idle state.
2. Video playback
 - a. Click Menu→Files, and click the MP4 video file.
 - b. Let the video play in the default player.
 - c. When the video is finished, close everything down to return to idle state.

Performing this task on the Windows notebook

1. Video conversion
 - a. Click to go to the desktop.
 - b. Double-click Smart Converter to open the program.
 - c. Click Select, and chose the file you want to convert.
 - d. Click Other→QuickTime.
 - e. Click Convert.
 - f. When the conversion finishes, close everything out and return to the desktop.
2. Video playback (Windows Media Player)
 - a. Browse to the MP4 file in the music directory in Windows explorer.
 - b. Right-click the MP4 file, click Open in..., and choose Windows Media Player to begin playing the song.
 - c. When the video has finished, close everything to return the system to an idle state.
3. Video playback (default player)
 - a. Click to go to the desktop.
 - b. Double-click the .mp4 file to start playing in the default video player.
 - c. When the video is finished, close everything down to return to idle state.

Scenario 4: Music manipulation

We used one music file, 2:02 in duration, with a file size of 22.3 MB (23,407,892 bytes).

Performing this task on the Chromebook

1. Music conversion
 - a. Open the Web-based Google Drive by clicking the icon on the toolbar, and choose the WAV music file.
 - b. Click More→Open in, and choose CloudConvert.
 - c. Choose mp3 from the Convert to drop-down menu.

- d. Click Start Conversion.
 - e. When the conversion is finished, close all applications to return the system to an idle state.
2. Music playback
 - a. Open the file system, and browse to the WAV file in Google Drive.
 - b. Left click the .wav file to begin playing.
 - c. When the song has finished, close everything to return the system to an idle state.

Performing this task on the Windows notebook

1. Music conversion
 - a. Click to go to the desktop.
 - b. Double-click Smart Converter to open the program.
 - c. Click Select, and chose the file(s) you want to convert.
 - d. Click Convert.
 - e. When the conversion finishes, close everything out to return to the desktop.
2. Music playback (Windows Media Player)
 - a. Browse to the .wav file in the music directory in Windows explorer.
 - b. Right-click the .wav file, click Open in..., and choose Windows Media Player to begin playing the song.
 - c. When the song has finished, close everything to return the system to an idle state.
3. Music playback (default device)
 - a. Browse to the .wav file in the music directory in Windows explorer.
 - b. Double-click the video file to start playing in the default video player.
 - c. When the video is finished, close everything down to return to idle state.

Scenario 5: Internet browsing

Performing this task on the Chromebook

1. Launch the Chrome browser.
2. Navigate to <http://www.scholastic.com/kids/stacks/?Inkid=stacks/nav/home/main>
3. Click Books & Authors → Inkheart → Excerpt.
4. Go back to the navigation bar, and go to <http://www.exploratorium.edu/>
5. Click Explore → Microscope Imaging Station, and let a few images scroll by.
6. Go back to the navigation bar, and go to <https://www.khanacademy.org/>
7. Play the top video on the main page.
8. When the video is finished, close the browser and return the system to an idle state.

Performing this task on the Windows notebook

1. Launch Internet Explorer Modern browser.
2. Navigate to <http://www.scholastic.com/kids/stacks/?Inkid=stacks/nav/home/main>
3. Click Books & Authors → Inkheart → Excerpt.
4. Go back to the navigation bar, and go to <http://www.exploratorium.edu/>
5. Click Explore → Microscope Imaging Station, and let a few images scroll by.
6. Go back to the navigation bar, and go to <https://www.khanacademy.org/>
7. Play the top video on the main page.
8. When the video is finished, close the browser and return the system to an idle state.

Scenario 6: Taking notes and clipping from the Web

We used a test document with a file size of 1.89 MB (1,985,994 bytes).

Performing this task on the Chromebook

1. Launch Evernote Web, and sign in.
2. Click New Note, and type a name in the Name field.

3. Click Attach, and choose WordDOCX2.docx to attach to the note.
4. Click Edit, and type some text into the note.
5. In a new browser tab, navigate to <http://en.wikipedia.org/wiki/Platypus>
6. Click the Evernote Web Clipper button in the browser window, and use the arrow keys to select the picture of the platypus.
7. Click Save Article.
8. Ensure that the note has been saved in the All Notes section, and close the program.
9. Return to the idle state.

Performing this task on the Windows notebook

1. Launch OneNote from the start screen.
2. Click the + to make a new tab, and name it.
3. Name the new page, and click Insert→File Attachment.
4. Choose WordDOCX2.docx, and click insert attachment.
5. Click elsewhere on the screen, and add some text.
6. Open Internet Explorer in the Modern start screen, and navigate to <http://en.wikipedia.org/wiki/Platypus>
7. Hold down the Windows key, and type S to activate the OneNote clipping application.
8. Click and drag around the platypus picture, and choose the new page you created in OneNote.
9. Click Send.
10. Close OneNote, and let the system return to an idle state.

Scenario 7: Taking tests

Performing this task on the Chromebook

1. Launch Google Chrome by clicking on the icon on the taskbar.
2. Navigate to the following Web site: <http://www.cambridgeenglish.org/test-your-english/>
3. Click on the link for the Student English test.
4. Answer each question, clicking Next as necessary to advance the test.
5. When you are finished and have received the score, close Chrome and return to an idle state.

Performing this task on the Windows notebook

6. Launch Internet Explorer Modern by clicking on the tile on the Home screen.
7. Navigate to the following website: <http://www.cambridgeenglish.org/test-your-english/>
8. Click on the link for the Student English test.
9. Answer each question, clicking Next as necessary to advance the test.
10. When you are finished and have received the score, close Internet Explorer and return to an idle state.

APPENDIX C – DETAILED RESULTS

Scenario 1: Document manipulation

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Word processing			
Total time (seconds)	159	168	
Total packets	4,606	219	95.2%
Total bytes	1,438,111	40,991	97.1%
Total bandwidth	72,358	1,952	97.3%
Packets per second	29.0	1.3	95.5%
Outgoing packets	2,294	122	94.7%
Outgoing bytes	836,811	14,369	98.3%
Outgoing bandwidth	42,104	684	98.4%
Outgoing packets/sec	14.4	0.7	95.0%
Incoming packets	2,312	97	95.8%
Incoming bytes	601,300	26,622	95.6%
Incoming bandwidth	30,254	1,268	95.8%
Incoming packets/sec	14.5	0.6	96.0%
Slideshow			
Total time (seconds)	75	52	
Total packets	2,850	22	99.2%
Total bytes	2,153,781	2,387	99.9%
Total bandwidth	229,737	367	99.8%
Packets per second	38.0	0.4	98.9%
Outgoing packets	1,181	14	98.8%
Outgoing bytes	180,632	1,237	99.3%
Outgoing bandwidth	19,267	190	99.0%
Outgoing packets/sec	15.7	0.3	98.3%
Incoming packets	1,669	8	99.5%
Incoming bytes	1,973,149	1,150	99.9%
Incoming bandwidth	210,469	177	99.9%
Incoming packets/sec	22.3	0.2	99.3%
Spreadsheet			
Total time (seconds)	223	66	
Total packets	1,619	34	97.9%
Total bytes	931,566	3,532	99.6%
Total bandwidth	33,419	428	98.7%
Packets per second	7.3	0.5	92.9%
Outgoing packets	678	22	96.8%

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Outgoing bytes	148,665	2,004	98.7%
Outgoing bandwidth	5,333	243	95.4%
Outgoing packets/sec	3.0	0.3	89.0%
Incoming packets	941	12	98.7%
Incoming bytes	782,901	1,528	99.8%
Incoming bandwidth	28,086	185	99.3%
Incoming packets/sec	4.2	0.2	95.7%
PDF conversion			
Total time (seconds)	58	59	
Total packets	1,760	25	98.6%
Total bytes	1,173,497	2,964	99.7%
Total bandwidth	161,862	402	99.8%
Packets per second	30.3	0.4	98.6%
Outgoing packets	761	19	97.5%
Outgoing bytes	138,092	2,181	98.4%
Outgoing bandwidth	19,047	296	98.4%
Outgoing packets/sec	13.1	0.3	97.5%
Incoming packets	999	6	99.4%
Incoming bytes	1,035,405	783	99.9%
Incoming bandwidth	142,814	106	99.9%
Incoming packets/sec	17.2	0.1	99.4%

Figure 10: Network traffic for the two systems during the document manipulation scenario.

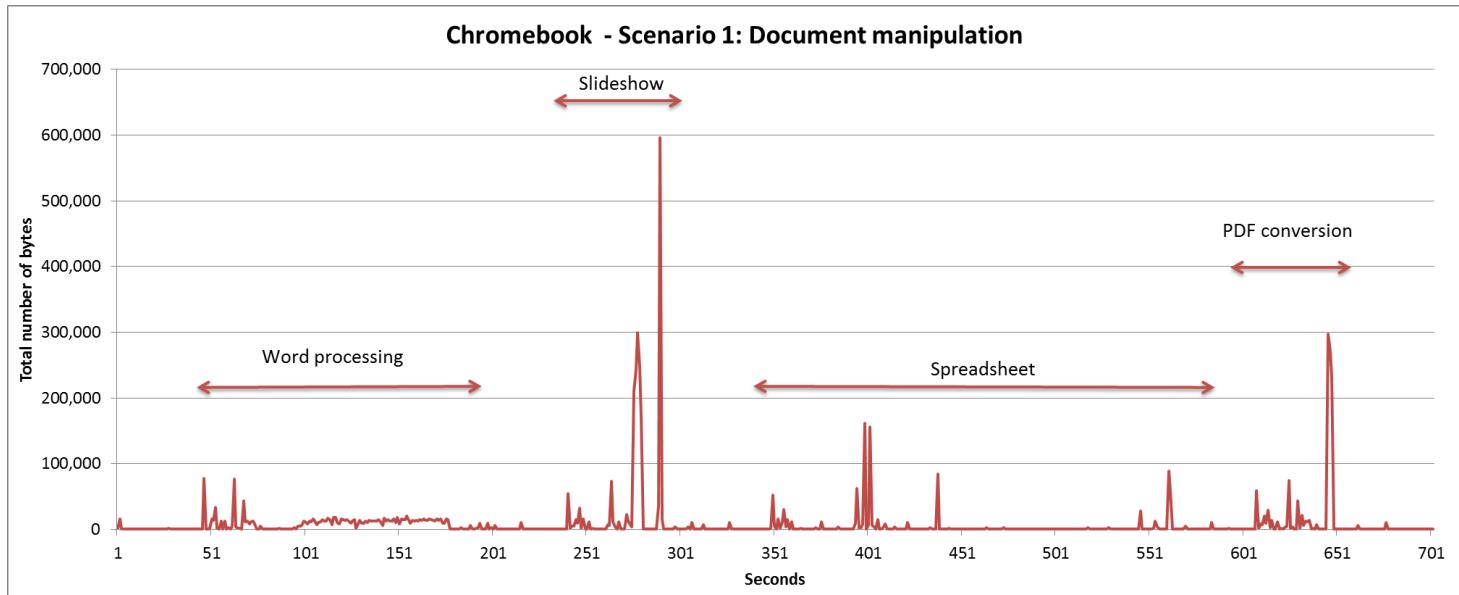


Figure 11: Network traffic for the Chromebook during the document manipulation scenario.

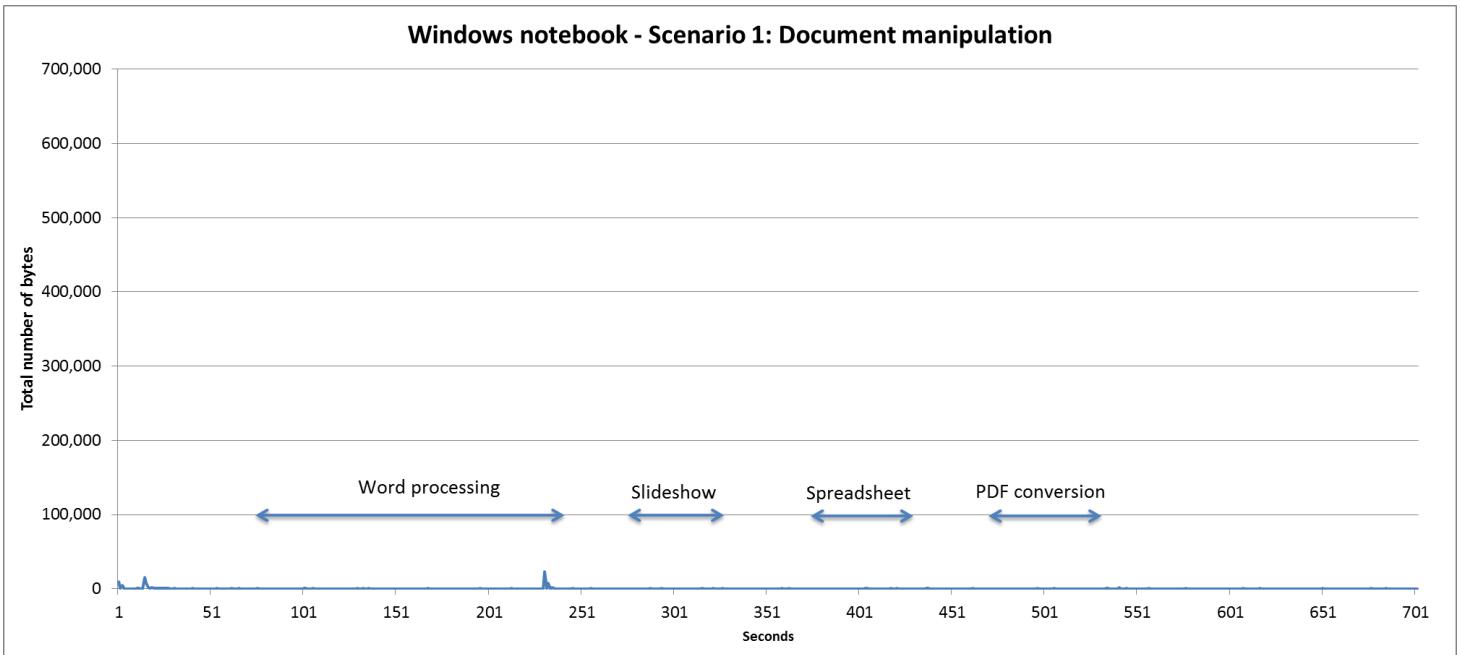


Figure 12: Network traffic for the two systems during the document manipulation scenario.

Scenario 2: Photo manipulation

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Photo conversion			
Total time (seconds)	121	74	
Total packets	2,209	38	98.3%
Total bytes	1,202,676	4,013	99.7%
Total bandwidth	79,516	434	99.5%
Packets per second	18.3	0.5	97.2%
Outgoing packets	1,130	28	97.5%
Outgoing bytes	328,055	3,160	99.0%
Outgoing bandwidth	21,690	342	98.4%
Outgoing packets/sec	9.3	0.4	95.9%
Incoming packets	1,079	853	20.9%
Incoming bytes	874,621	10	100.0%
Incoming bandwidth	57,826	92	99.8%
Incoming packets/sec	8.9	0.1	98.5%
Photo editing			
Total time (seconds)	94	66	
Total packets	12,893	122	99.1%
Total bytes	11,531,091	34,577	99.7%
Total bandwidth	981,369	4,191	99.6%
Packets per second	137.2	1.8	98.7%
Outgoing packets	7,029	70	99.0%
Outgoing bytes	6,670,505	16,403	99.8%
Outgoing bandwidth	567,703	1,988	99.6%
Outgoing packets/sec	74.8	1.1	98.6%
Incoming packets	4,860,586	52	100.0%
Incoming bytes	5,864	18,174	-209.9%
Incoming bandwidth	413,667	2,203	99.5%
Incoming packets/sec	62.4	0.8	98.7%

Figure 13: Network traffic for the two systems during the photo-manipulation scenario.

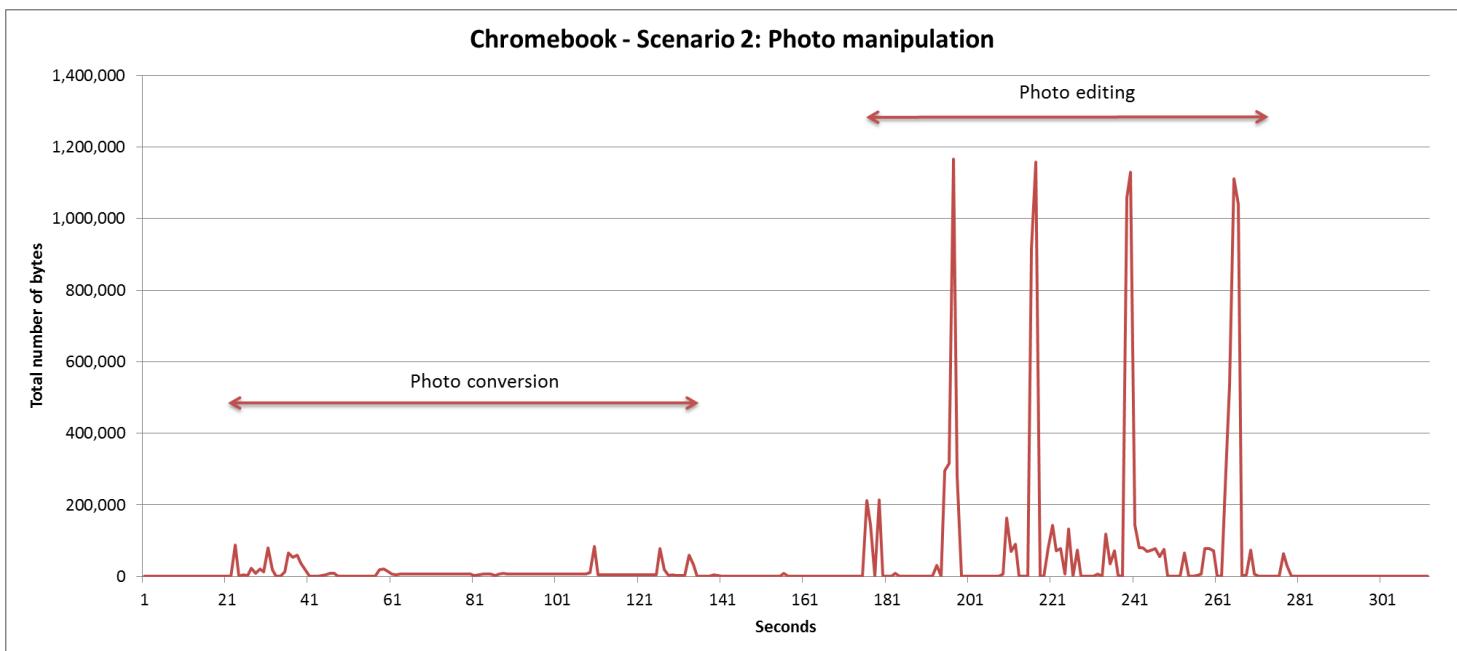


Figure 14: Network traffic for the Chromebook during the photo-manipulation scenario.

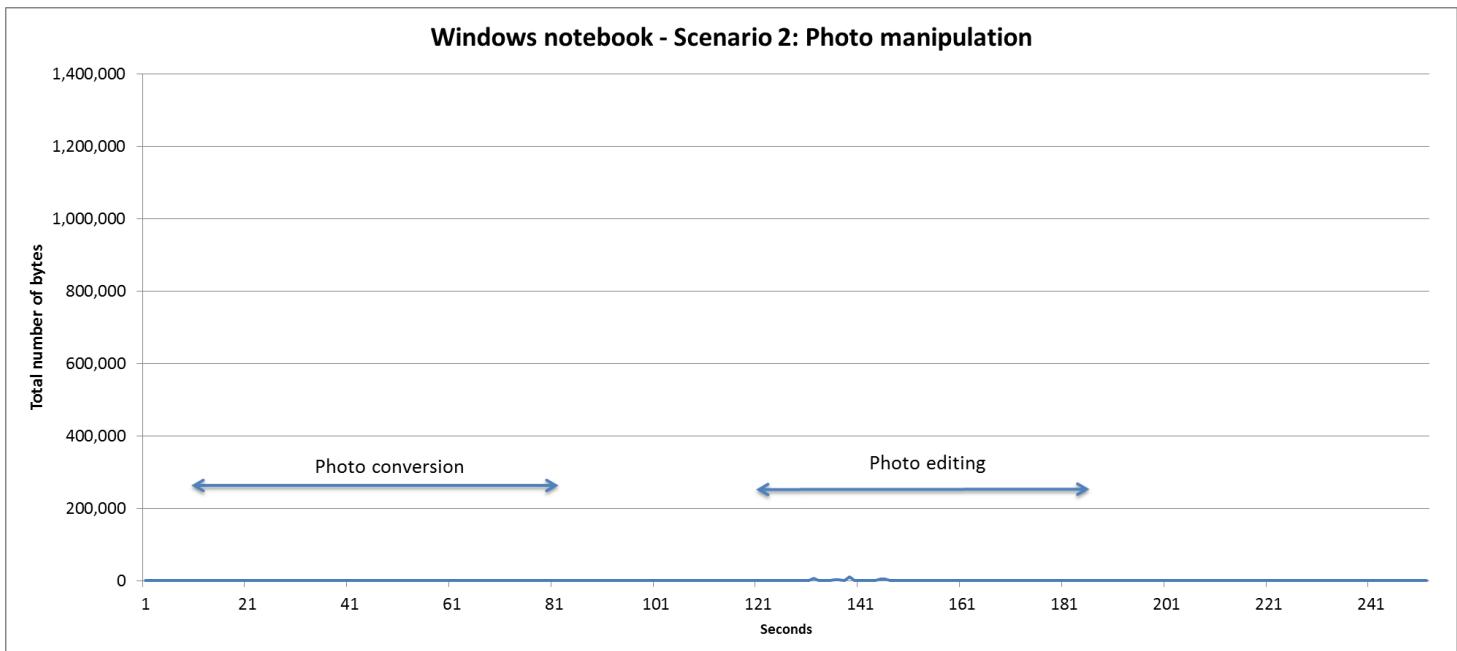


Figure 15: Network traffic for the two systems during the photo-manipulation scenario.

Scenario 3: Video manipulation

	Chromebook	Windows notebook Modern	Windows notebook Windows Media Player	% decrease Modern	% decrease WMP
Video conversion					
Total time (seconds)	568	31			
Total packets	4,375	47		98.9%	
Total bytes	2,653,007	7,679		99.7%	
Total bandwidth	37,366	1,982		94.7%	
Packets per second	7.7	1.5		80.3%	
Outgoing packets	2,275	28		98.8%	
Outgoing bytes	613,215	3,670		99.4%	
Outgoing bandwidth	8,637	947		89.0%	
Outgoing packets/sec	4.0	0.9		77.4%	
Incoming packets	2,100	19		99.1%	
Incoming bytes	2,039,792	4,009		99.8%	
Incoming bandwidth	28,730	1,035		96.4%	
Incoming packets/sec	3.7	0.6		83.4%	
Video playback					
Total time (seconds)	372	67	63		
Total packets	206,199	473	25	99.8%	100.0%
Total bytes	200,727,938	266,316	2,901	99.9%	100.0%
Total bandwidth	4,316,730	31,799	368	99.3%	100.0%
Packets per second	554.3	7.1	0.4	98.7%	99.9%
Outgoing packets	69,675	252	16	99.6%	100.0%
Outgoing bytes	4,866,397	128,414	2,076	97.4%	100.0%
Outgoing bandwidth	104,654	15,333	264	85.3%	99.7%
Outgoing packets/sec	187.3	3.8	0.3	98.0%	99.9%
Incoming packets	136,524	221	9	99.8%	100.0%
Incoming bytes	195,861,541	137,902	825	99.9%	100.0%
Incoming bandwidth	4,212,080	16,466	105	99.6%	100.0%
Incoming packets/sec	367.0	3.3	0.1	99.1%	100.0%

Figure 16: Network traffic for the two systems during the video-manipulation scenario.

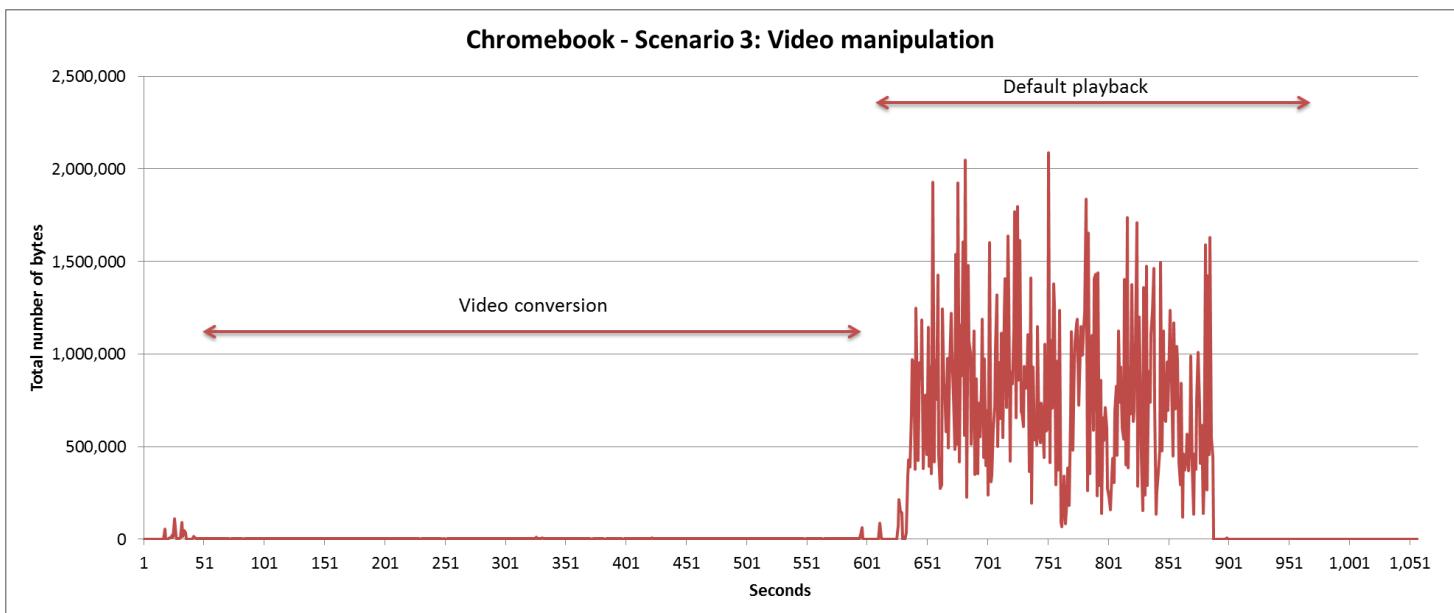


Figure 17: Network traffic for the Chromebook during the video-manipulation scenario.

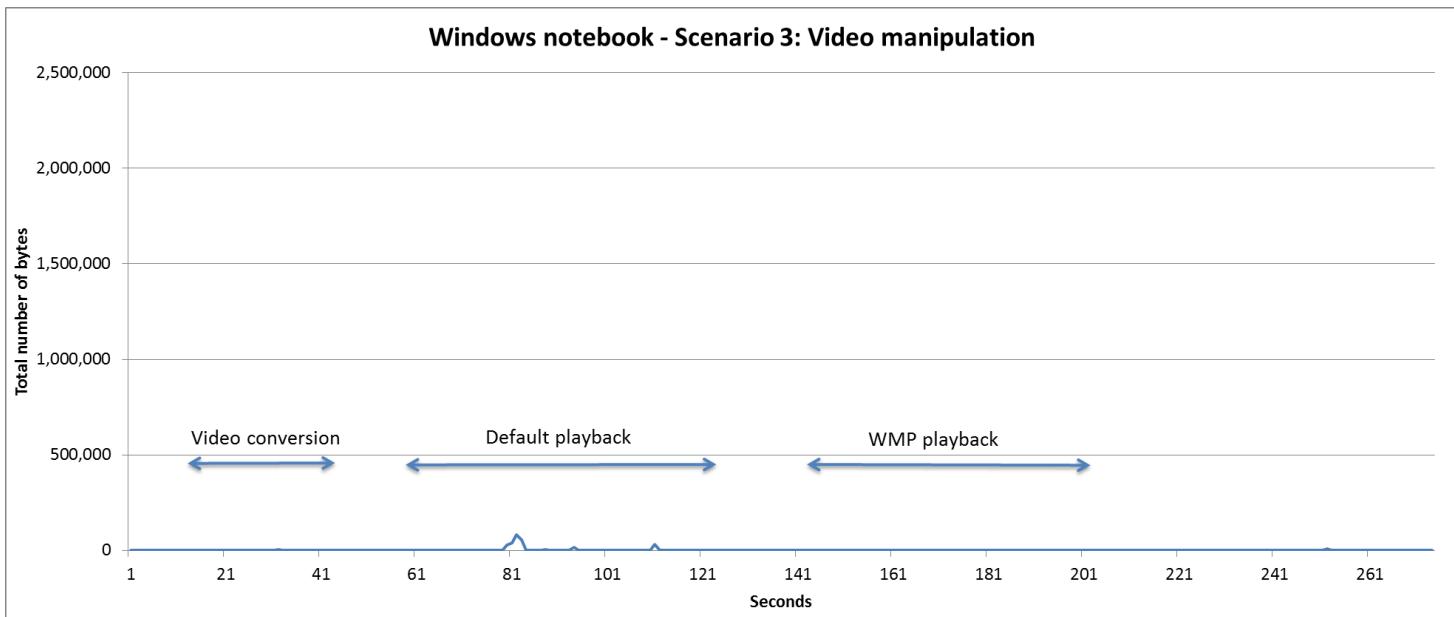


Figure 18: Network traffic for the two systems during the video-manipulation scenario.

Scenario 4: Music manipulation

	Chromebook	Windows notebook Modern	Windows notebook Windows Media Player	% decrease Modern	% decrease WMP
Music conversion					
Total time (seconds)	39	17			
Total packets	1,067	26		97.6%	
Total bytes	538,106	4,405		99.2%	
Total bandwidth	110,381	2,073		98.1%	
Packets per second	27.4	1.5		94.4%	
Outgoing packets	490	16		96.7%	
Outgoing bytes	111,721	1,696		98.5%	
Outgoing bandwidth	22,917	798		96.5%	
Outgoing packets/sec	12.6	0.9		92.5%	
Incoming packets	577	10		98.3%	
Incoming bytes	426,385	2,709		99.4%	
Incoming bandwidth	87,464	1,275		98.5%	
Incoming packets/sec	14.8	0.6		96.0%	
Music playback					
Total time (seconds)	160	129	124		
Total packets	29,819	118	49	99.6%	99.8%
Total bytes	29,123,459	27,033	5,565	99.9%	100.0%
Total bandwidth	1,574,240	1,676	359	99.9%	100.0%
Packets per second	201.5	0.9	0.4	99.5%	99.8%
Outgoing packets	9,890	68	36	99.3%	99.6%
Outgoing bytes	757,620	11,379	4,171	98.5%	99.4%
Outgoing bandwidth	40,952	706	269	98.3%	99.3%
Outgoing packets/sec	66.8	0.5	0.3	99.2%	99.6%
Incoming packets	19,929	50	13	99.7%	99.9%
Incoming bytes	28,365,839	15,654	1,394	99.9%	100.0%
Incoming bandwidth	1,533,290	971	90	99.9%	100.0%
Incoming packets/sec	134.7	0.4	0.1	99.7%	99.9%

Figure 19: Network traffic for the two systems during the music-manipulation scenario.

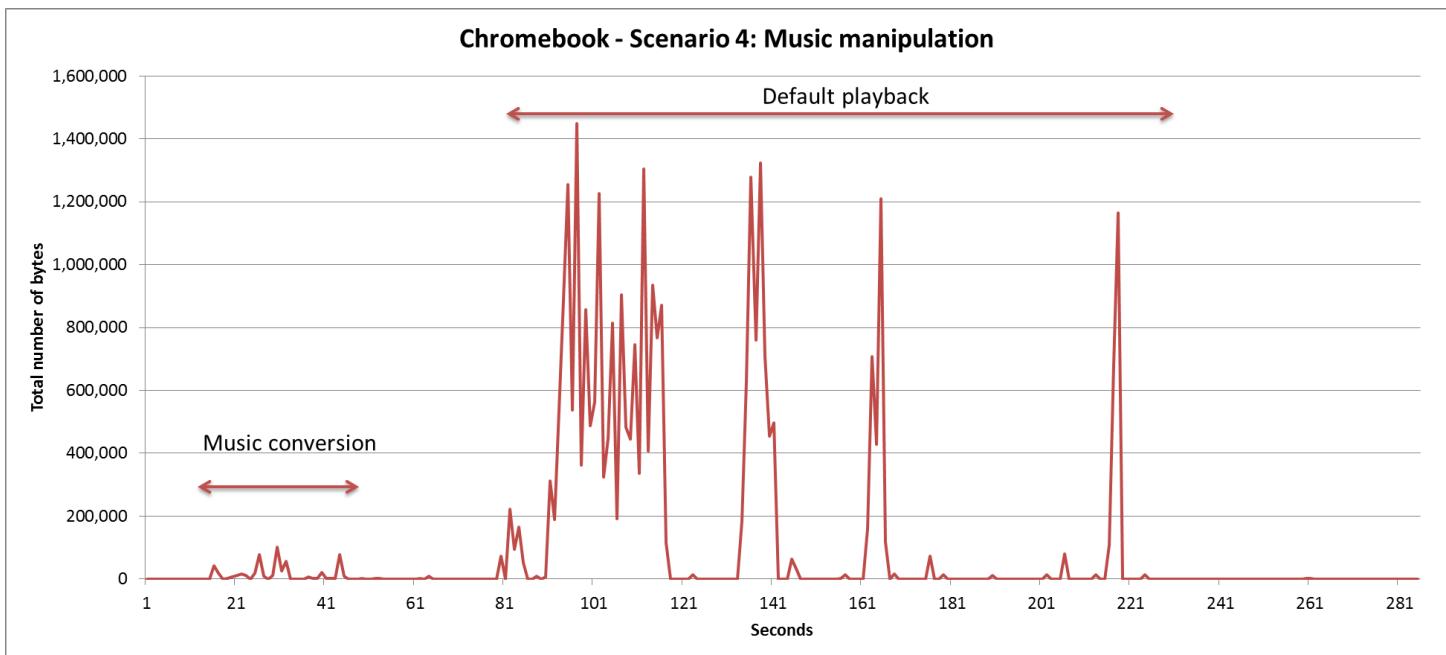


Figure 20: Network traffic for the Chromebook during the music-manipulation scenario.

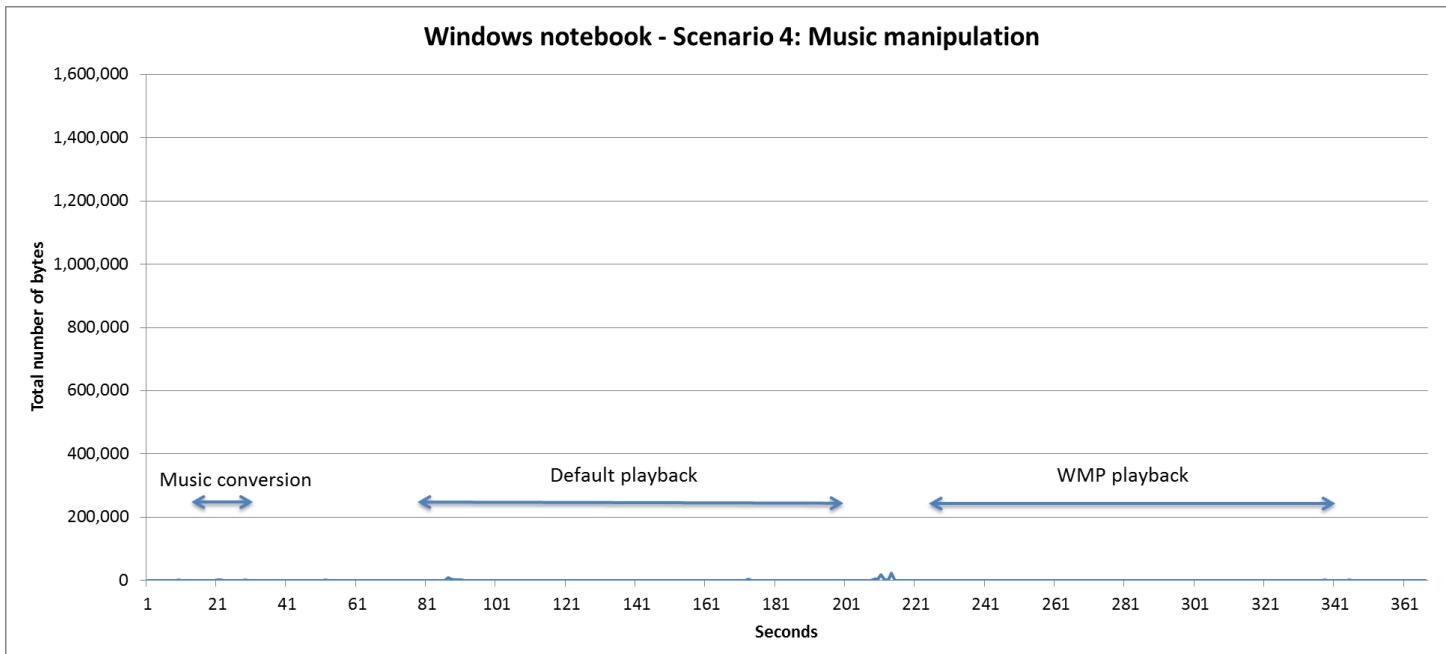


Figure 21: Network traffic for the two systems during the music-manipulation scenario.

Scenario 5: Web browsing

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Combined sites			
Total time (seconds)	161	197	
Total packets	9,169	16,973	-85.1%
Total bytes	6,814,348	15,611,463	-129.1%
Total bandwidth	338,601	633,968	-87.2%
Packets per second	57.0	86.2	-51.3%
Outgoing packets	3,787	5,757	-52.0%
Outgoing bytes	428,892	770,060	-79.5%
Outgoing bandwidth	21,311	31,272	-46.7%
Outgoing packets/sec	23.5	29.2	-24.2%
Incoming packets	5,382	11,216	-108.4%
Incoming bytes	6,385,456	14,841,403	-132.4%
Incoming bandwidth	317,290	602,697	-90.0%
Incoming packets/sec	33.4	56.9	-70.3%
Scholastic			
Total packets	1,667	1,488	10.7%
Total bytes	880,018	936,087	-6.4%
Total bandwidth	185,267	146,837	20.7%
Packets per second	43.9	29.2	33.5%
Outgoing packets	868	704	18.9%
Outgoing bytes	147,444	139,011	5.7%
Outgoing bandwidth	31,041	21,806	29.8%
Outgoing packets/sec	22.8	13.8	39.6%
Incoming packets	799	784	1.9%
Incoming bytes	732,574	797,076	-8.8%
Incoming bandwidth	154,226	125,032	18.9%
Incoming packets/sec	21.0	15.4	26.9%
Exploratorium			
Total packets	857	603	29.6%
Total bytes	329,038	243,274	26.1%
Total bandwidth	69,271	51,216	26.1%
Packets per second	22.6	15.9	29.6%
Outgoing packets	463	324	30.0%
Outgoing bytes	55,668	36,819	33.9%
Outgoing bandwidth	11,720	7,751	33.9%
Outgoing packets/sec	12.2	8.5	30.0%
Incoming packets	394	279	29.2%

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Incoming bytes	273,370	206,455	24.5%
Incoming bandwidth	57,552	43,464	24.5%
Incoming packets/sec	10.4	7.3	29.2%
Khan Academy			
Total packets	6,365	12,965	-103.7%
Total bytes	5,513,126	12,590,583	-128.4%
Total bandwidth	544,506	1,094,830	-101.1%
Packets per second	78.6	140.9	-79.3%
Outgoing packets	2,294	4,152	-81.0%
Outgoing bytes	199,883	534,258	-167.3%
Outgoing bandwidth	19,742	46,457	-135.3%
Outgoing packets/sec	28.3	45.1	-59.4%
Incoming packets	4,071	8,813	-116.5%
Incoming bytes	5,313,243	12,056,325	-126.9%
Incoming bandwidth	524,765	1,048,380	-99.8%
Incoming packets/sec	50.3	95.8	-90.6%

Figure 22: Network traffic for the two systems during the Web-browsing scenario.

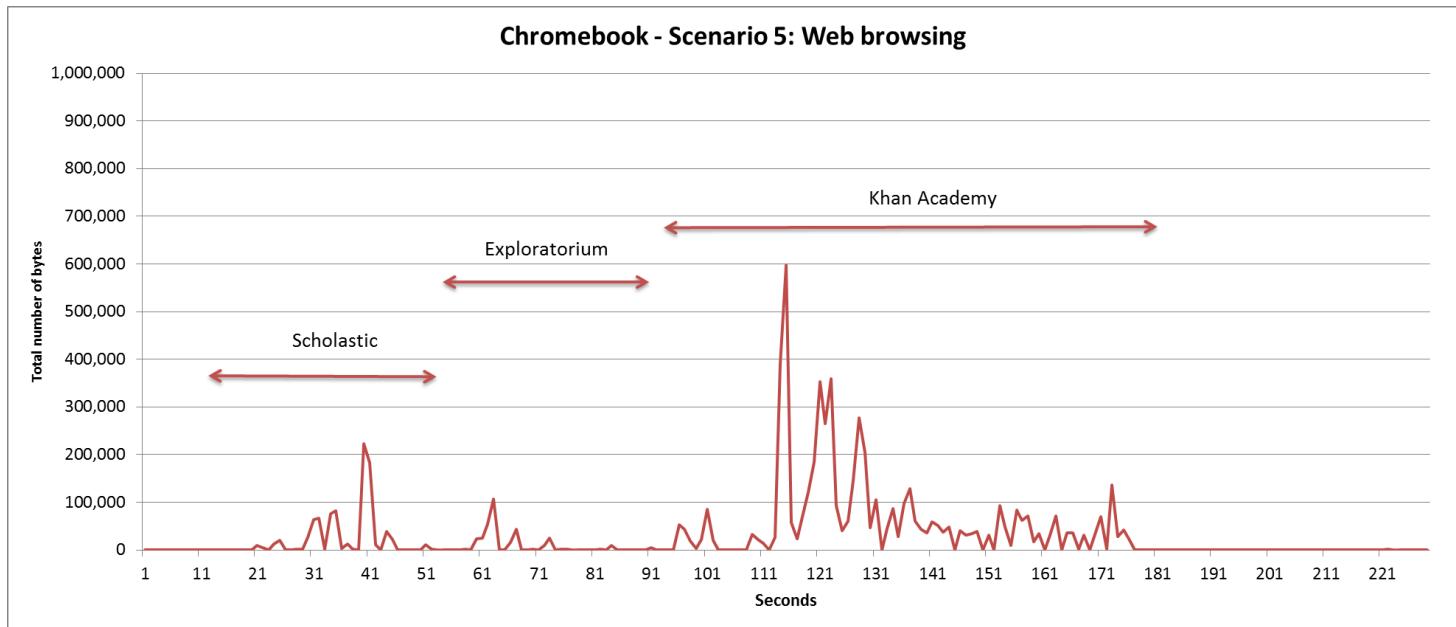


Figure 23: Network traffic for the Chromebook during the Web-browsing scenario.

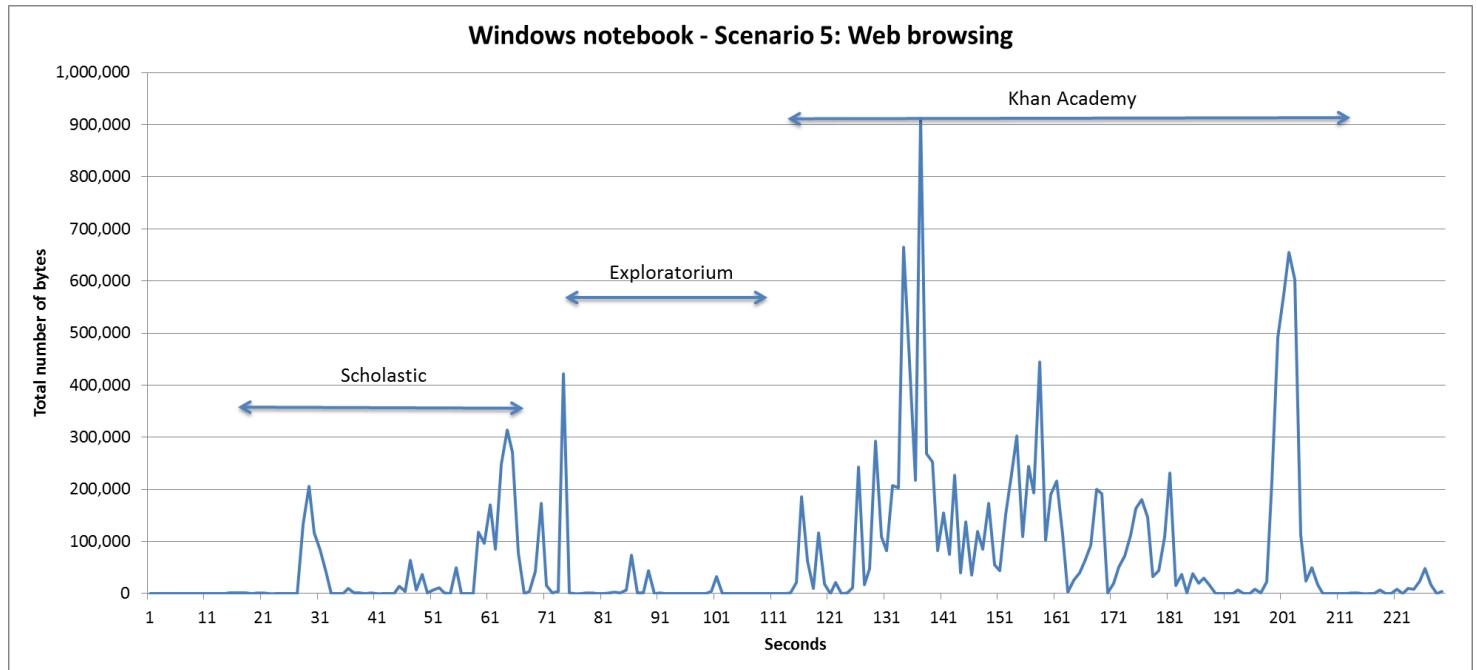


Figure 24: Network traffic for the two systems during the Web-browsing scenario.

Scenario 6: Taking notes and clipping from the Web

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Creating and editing notes			
Total time (seconds)	82	56	
Total packets	2,940	133	95.5%
Total bytes	2,710,892	25,324	99.1%
Total bandwidth	264,477	3,618	98.6%
Packets per second	35.9	2.4	93.4%
Outgoing packets	1,697	68	96.0%
Outgoing bytes	2,176,339	9,282	99.6%
Outgoing bandwidth	212,326	1,326	99.4%
Outgoing packets/sec	20.7	1.2	94.1%
Incoming packets	1,243	65	94.8%
Incoming bytes	534,553	16,042	97.0%
Incoming bandwidth	52,152	2,292	95.6%
Incoming packets/sec	15.2	1.2	92.3%
Web clipping task			
Total time (seconds)	82	36	
Total packets	875	656	25.0%
Total bytes	362,139	545,987	-50.8%
Total bandwidth	72,428	121,330	-67.5%
Packets per second	21.9	18.2	16.7%
Outgoing packets	478	294	38.5%
Outgoing bytes	112,140	192,442	-71.6%
Outgoing bandwidth	22,428	42,765	-90.7%
Outgoing packets/sec	12.0	8.2	31.7%
Incoming packets	397	362	8.8%
Incoming bytes	249,999	353,545	-41.4%
Incoming bandwidth	50,000	78,566	-57.1%
Incoming packets/sec	9.9	10.1	-1.3%

Figure 25: Network traffic for the two systems during the note-taking scenario.

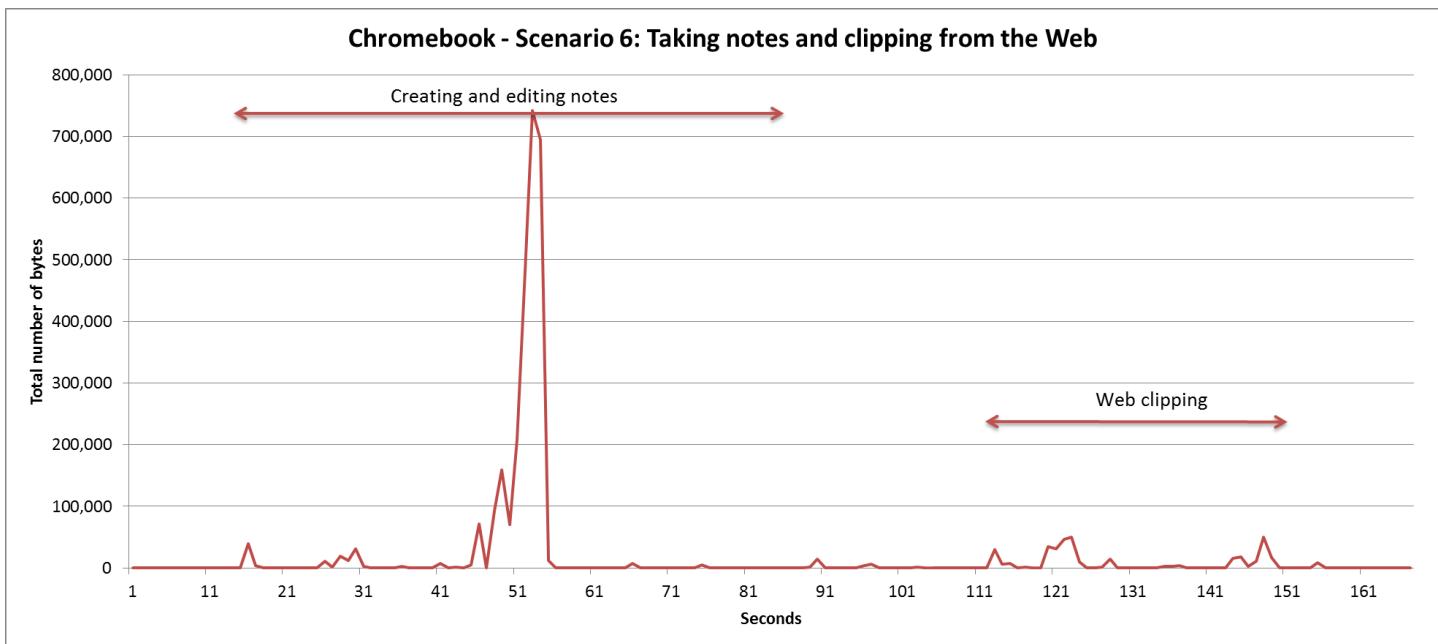


Figure 26: Network traffic for the Chromebook during the note-taking scenario.

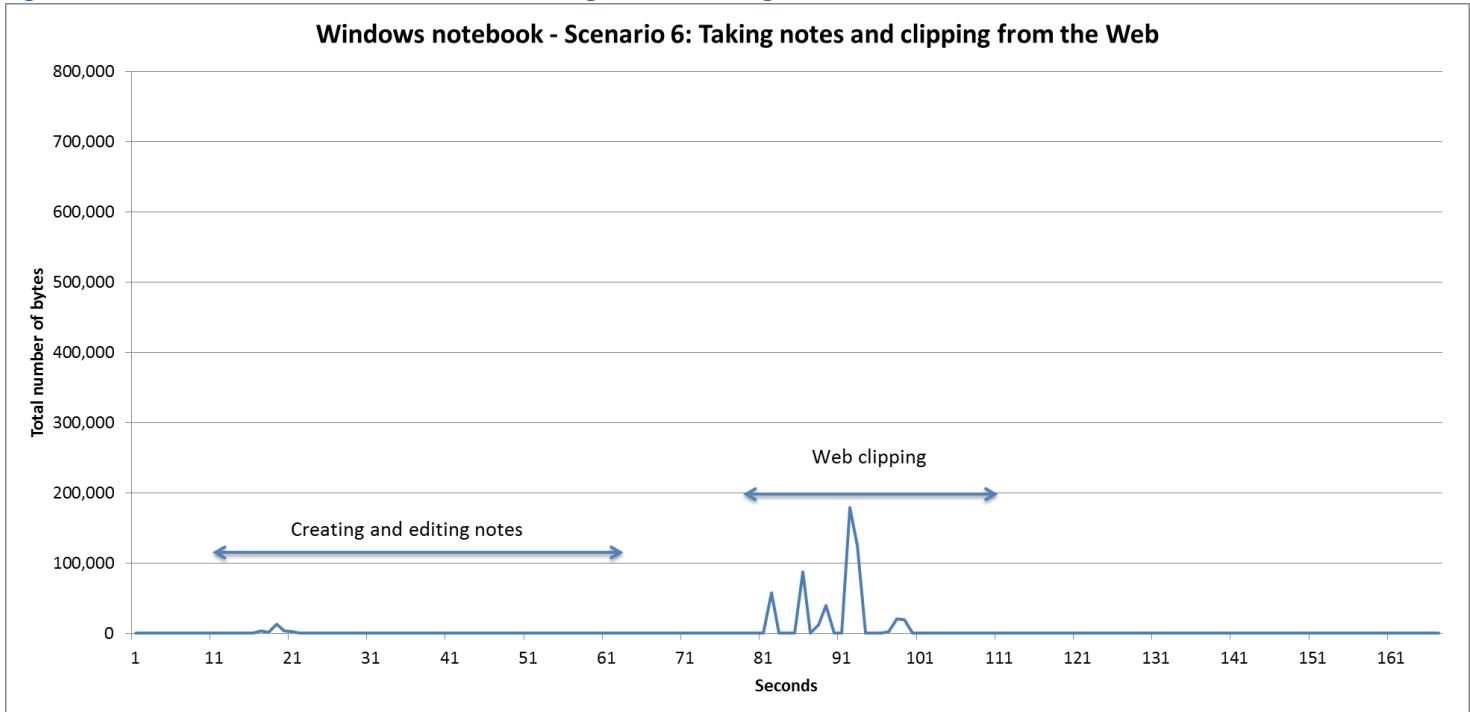


Figure 27: Network traffic for the two systems during the note-taking scenario.

Scenario 7: Test taking

	Chromebook	Windows notebook	Percentage decrease for Windows notebook
Online test taking			
Total time (seconds)	134	145	
Total packets	2,037	1,156	43.2%
Total bytes	1,187,491	742,428	37.5%
Total bandwidth	70,895	40,962	42.2%
Packets per second	15.2	8.0	47.6%
Outgoing packets	976	513	47.4%
Outgoing bytes	317,677	196,998	38.0%
Outgoing bandwidth	18,966	10,869	42.7%
Outgoing packets/sec	7.3	3.5	51.4%
Incoming packets	1,061	643	39.4%
Incoming bytes	869,814	545,430	37.3%
Incoming bandwidth	51,929	30,093	42.1%
Incoming packets/sec	7.9	4.4	44.0%

Figure 28: Network traffic for the two systems during the test-taking scenario.

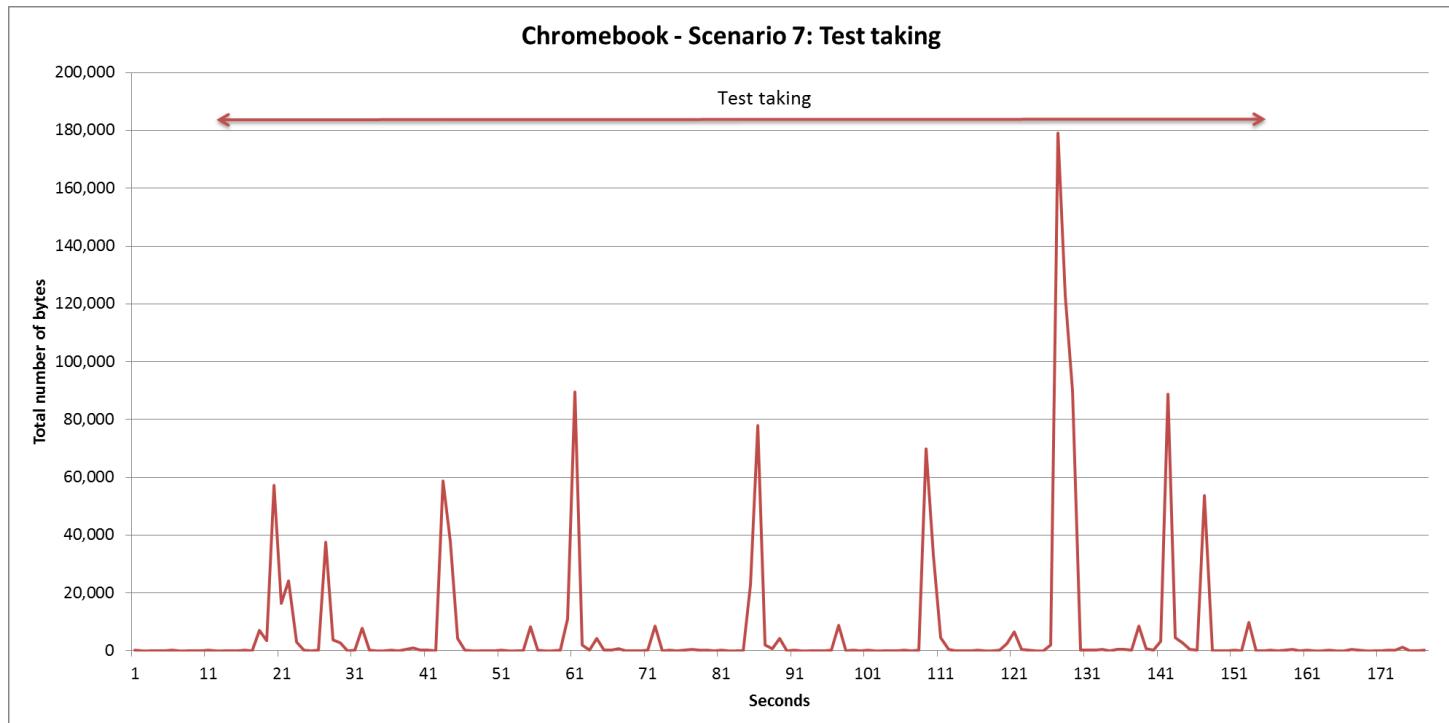


Figure 29: Network traffic for the Chromebook during the test-taking scenario.

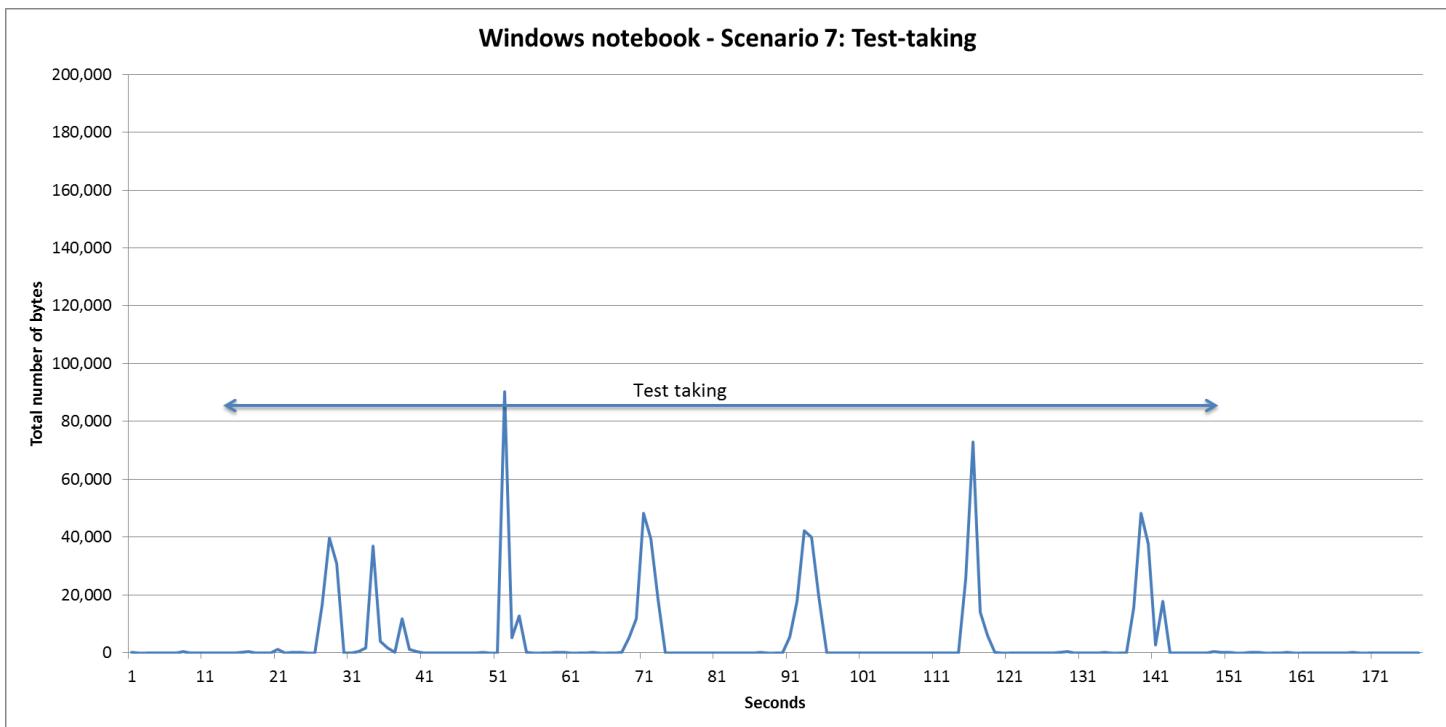


Figure 30: Network traffic for the two systems during the test-taking scenario.

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