

# **AC 2010-2283: DEVELOPING NETWORK INFRASTRUCTURE FOR CLASSROOM TECHNOLOGIES**

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# DEVELOPING NETWORK INFRASTRUCTURE FOR CLASSROOM TECHNOLOGIES

## Abstract

In order for classroom technologies to be useful in engineering education, appropriate infrastructures must be planned, implemented and tested so that they are sufficiently robust to serve the needs of the target usage. Usage will vary depending on size of the class, complexity of the teaching technology being used, and the amount of interactivity that the instructor attempts to utilize. This paper describes an infrastructure planned to be used in large and medium sized classrooms with the reasonably complex tool, Classroom Presenter, in a mode where four different levels of interactions are used in the classroom. The hardware infrastructure is designed for a nominal class size of 250 students with a medium amount of network traffic.

Testing of the infrastructure was performed using 80 student volunteers. The audience was requested to complete individual timed operations including: downloading graphic slides, receiving electronic ink strokes at each student station, students responding to polls, and students submitting graphical information back to the instructor's computer. All of these activities are generally included in a typical highly interactive and engaging classroom.

The infrastructure design will be described. Data will be presented on the outcomes of the testing including the timing of the data and graphical transmissions. Finally, suggested improvements to the infrastructure will be made in order to facilitate its use for larger student populations.

## Introduction

Designing classroom network infrastructures involves determining the expected bandwidth needed and the amount of interaction latency that can be tolerated while still maintaining an effective learning environment. The network implementation that will satisfy these two parameters depends on the number of students in the classroom, the amount of data transmitted by the courseware application, the network communications protocol implementation, and the amount of interaction the students and instructor attempt to have during typical classroom sessions.

A number of different classroom courseware tools are available on the market these days. Many of them endeavor to support rich real-time classroom interaction by sending data back and forth between student and faculty machines. Designing a network infrastructure to satisfy the needs of

these software packages is best performed by planning for situations that produce the heaviest network usage and then assuming that any less demanding operations will work fine if the most demanding needs are satisfied. Two highly interactive programs built to operate most effectively on Tablet PCs are Classroom Presenter and DyKnow. In their most network intensive modes, both programs send data between students and faculty members in the form of graphical screen data. Both use network unicast mode to send the data meaning that each client receives/sends an individual message from/to a server containing full graphical screen data. The upshot of this communication process is that for a faculty-students interaction in a classroom of size  $N$ , where information of size  $M$  must be transmitted,  $N \times M$  data must be transmitted through the network for each such interaction.

Classroom Presenter 3 (CP3) was chosen as the courseware tool to be used to benchmark the network infrastructure design. CP3 has several modes of interaction that can take place in typical classroom sessions. These include:

1. Transmit presentation slides from instructor to students
2. Students receive electronic ink (e-ink) from instructor in real-time
3. Instructor receives student poll information from each of the students
4. Instructor receives student submissions consisting of full student screen shots

Each of these modes has specific performance expectations in terms of network response time. If the technology operates too slowly, the learning environment will not be fluid enough to allow for natural and timely interactions that are typical in good learning practices. Instructor presentation slides must be delivered to students at the beginning of a presentation in less than two to three minutes. The lag time for an e-ink stroke to appear on a student machine must be less than one or two seconds. A quick poll must be able to be completely received from all student machines in less than five seconds. Student screen submissions must arrive at the instructor machine within one or two minutes. A sufficiently powerful network infrastructure must be designed with these bounds in mind.

### **Network Infrastructure**

The network infrastructure developed at Virginia Tech is based on a scheme where a sufficient number of access points are placed in classrooms so that the number of students expected to reside in the room during class times are satisfactorily served by the network. Using typical and worst-case network traffic from applications such as CP3 allows the network design to be sufficiently rich while not overdesigned. Of course the design always considers an appropriate overdesign factor to allow for future increases in demand by more intense applications.

At Virginia Tech, a typical network implementation for a classroom whose capacity is 150 students consists of four Cisco 1240 Wireless Access Points (WAPs). Each wireless access point

has a 2.4 GHz (802.11 b and g) and 5 GHz (802.11a) radio. Each access point in the classroom is connected to a 100 Mbps Ethernet edge switch. The switch has a 1000 Mbps connection to the building distribution switch.

Theoretically, the available bandwidth in the room is 54 Mbps per radio. Realistically, we can only achieve about half of that under perfect situations. This is because of the half duplex operation of the radios, overhead in packet headers and 802.11 control messages. Therefore, each radio (2 per WAP) can provide approximately 25 Mbps under ideal circumstances. This bandwidth is shared by all clients associated to the radio.

The goal of the classroom wireless design is to achieve an environment that provides the most efficient use of the wireless medium while adhering to strict radio and technological constraints. This is accomplished by striving to meet the following goals:

1. Create an isolated cell: Careful placement of the WAPs within the room and reducing the transmit power confines the wireless signals to the classroom while supporting high data rates within the cell. This reduces the probability that users outside of the room will connect to the “cell” and create more contention for the available radio spectrum. It also allows the flexibility to alter the radio environment within that classroom without affecting the service in adjacent areas.
2. Achieve client load balancing: In a high client density environment, it is important to balance the number of clients across all the available radios, not just across the access points within the room. Load balancing clients across the room to the closest access point is achieved by reducing the transmit power on the WAPs. Unfortunately, most clients will attempt to connect to the 802.11g radios first even if the contention for the 802.11a radio is less. By increasing the power of the 802.11a radios slightly we can convince more clients to prefer the 802.11a radio over the 802.11g radio effectively balancing clients between the two.
3. Deny low data rates: Low data rates have been disabled in the WAPs. Clients can connect to WAPs at low data rates for a number of reasons such as: clients that only support 802.11b; client is an extended distance from the WAP, and the client is running on legacy software drivers. All these scenarios lead to more contention on the WAP, lowering the aggregate performance for that access point affecting all the users.

Design calculations performed before implementation indicate that this network will support up to 150 users all performing typical operations with highly network demanding software tools such as CP3 and DyKnow. Testing of the infrastructure in typical working situations allows network engineers to fine tune the network, make significant adjustments if necessary, and to plan for the next generation network that will eventually be required to satisfy the needs of future, more intensive, applications. It is assumed that almost all network traffic will take place within the classroom.

## Infrastructure testing

The network infrastructure described above was tested with several objectives in mind:

- 1) Assess usability of tools such as CP3 in the classroom given the state of the network design.
- 2) Identify, if possible, any critical bottleneck that limits the number of participants in a CP3 (or other tools) session, or that degrades CP3 performance to an unusable level
- 3) Identify any adjustments instructors should use in order to take best advantage of the combination of the software tool and network infrastructure.
- 4) Plan network infrastructure adjustments.

The network/software test was performed with 80 student participants in the target classroom, a classroom with a wireless network infrastructure (802.11a, g) already shown to be capable of handling more than 250 simultaneous connections of users that are doing typical web browsing. The student participants were rising-freshmen taking part in a summer pre-college experience program. We used the Networking tool in Windows Task Manager to observe network utilization on the server. We also used a digital watch to measure elapsed time of student receptions of and responses to CP3 activities. Communication Network Services (CNS) monitored network traffic during the testing period and provided data that is discussed at the end of the report.

The software we used was CP3 version 1934. The instructor Tablet was a Fujitsu T5010 (build 9SEN2), with a 2.4 GHz Intel Core 2 Duo CPU, 2 GB RAM, and the 32-bit Windows Vista Business operating system. It used an Atheros AR928x wireless network adapter and Mobile Intel 4 Series display chipset. It is important to note that the student machines are dual band capable. The instructor machine acted as a TCP server when running CP3. The presentation test deck was loaded into the instructor machine before the students started CP3. Each student was using a Fujitsu T4210 Tablet, with a 1.83 GHz Centrino Duo CPU, 1 GB RAM, and Windows Vista Enterprise.

We distributed 80 index cards, each with a number written on it. Because one student had computer problems and could not participate in the pilot test, we will consider index card numbers 1 -79 in this report. The index cards would be used later in the testing to recognize and isolate any specific difficulties in operation. We also asked the students not to run any applications except CP3 during the tests. We required all the students to connect to VT\_WLAN, the network subnet for this classroom.

Once the setup was completed, specific tests to gauge the operation in each of the operating modes listed above were performed. The results are described below.

## Test 1 – Bulk slide transmission to students. Transmission

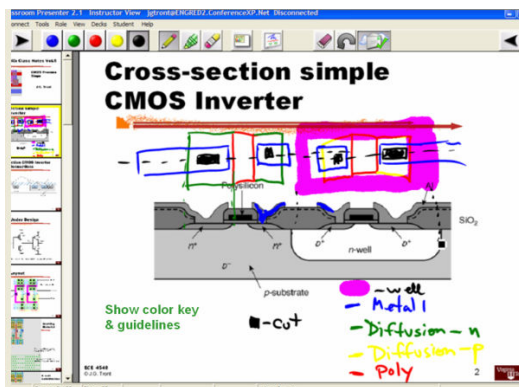
This test measured the typical operation that would occur at the beginning of a presentation where all of the slides on the instructor machine are transmitted to each of the student client machines at the beginning of class. In this test we measured the elapsed time between the start of the slide deck transmission from the instructor (server) machine to the point where all students received the last slide as indicated by them lowering their index card (previously raised at the start of transmission verbal test command).

We used a test file named *CP3-Test-Deck3-Tablet.cp3* (1028 KB) and displayed the last of five slides on the server. Students were to indicate that their machines were displaying this same slide by lowering their index card. At the start, students launched CP3, selected “Student” role, and selected the presentation radio button. This is the typical client start up sequence for CP3. The whole operation took about two minutes. Partial results for Test 1 are shown in Table 1 of the Appendix.

## Test 2 - Change of Slide

This test measured the elapsed time between the selection of a new slide by the instructor and receipt of the change as indicated by lowering of the index cards of all students.

The test deck used was *CP3-Test-Deck3-Tablet.cp3* (1028 KB). Starting at the last slide of the deck, we timed how long it took for all students to see the change from one slide to another. See Figure 2 for the two slides used in this measurement. It took roughly the same time to change in either direction for these two slides. Measurement results for Test 2 are shown in Table 1 of the Appendix.



(a)



(b)

Figure 2 Test 2 - Transition from slide (a) to slide (b)

### **Test 3A/3B - Real-Time Annotation**

Two different tests were used to determine how quickly the instructor's e-ink annotations arrived at all of the student machines. First, a sequence of individual ink strokes was tested to determine if the number of strokes increased the e-ink delivery latency. Next, a single long and continuous e-ink stroke was used to understand whether or not there is a significant difference for this type of e-ink stroke. In each test, a small circle was drawn to signify the end of the e-ink strokes.

Test 3A: Measured how long it took for all students to see the last e-ink stroke at the end of a series of short, vertical e-ink strokes. The vertical lines were drawn as quickly as possible for 30 seconds. Each student lowered their hand when the last of the strokes appeared on their screen.

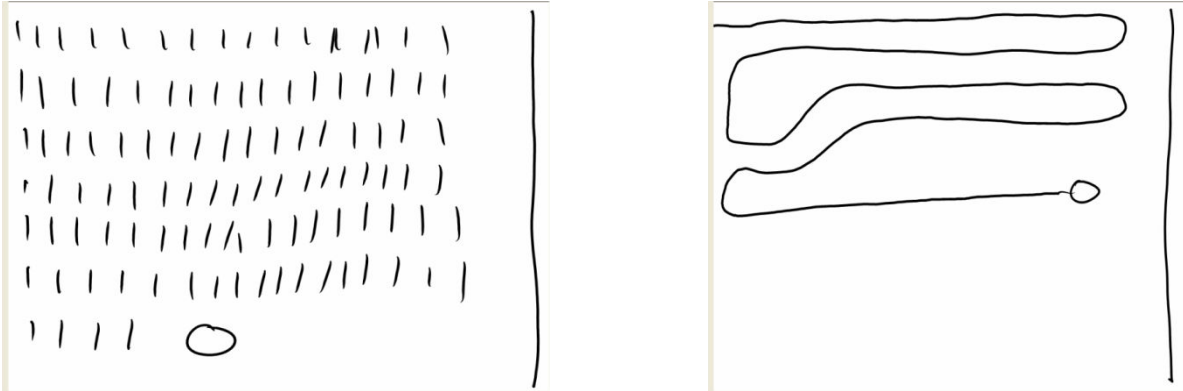
Test 3B: Measured how long it took for all students to see a circle at the end of a continuous line stroke. The single e-ink stroke line-circle was drawn for 30 seconds. Students lowered their hands when the circle appeared. End-of-test was marked when all student index cards were down.

We started both tests with a blank white slide. A vertical line was drawn to define a border on the blank slide to prevent inadvertent changes of the slide. (Running the e-ink over the right margin of the white page caused the slide to advance to open more drawing space). Figure 3 shows what the students saw during each test. Timing results are shown in Appendix 1.

### **Test 4 - Quick Poll**

This test measured how long it took the server to receive poll responses from all students. The quick poll in CP3 was set up to allow four different responses to the poll, the letters A through D. We asked all students to click the "A" button on a starting signal.

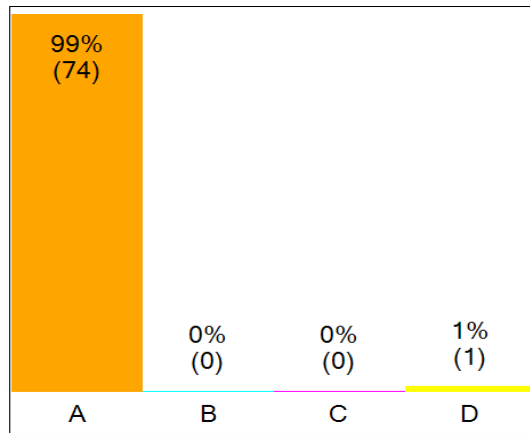
Most students responded with the intended letter, though one student signaled D and some students did not participate in this test as indicated afterward. See Figure 4 for the results of the poll. Measurements are shown in the Appendix. The network utilization and activity time were not recorded. The results may have taken longer to receive than actual networking would have allowed since some of the students were not paying good attention and did not click on the button immediately when the start signal was given. Overall, this test produced a satisfactory result for typical classroom situations and the seemingly higher than expected timing was judged to be primarily due to student latency.



(a)

(b)

**Figure 3 (a) Vertical lines in Test 3A and (b) continuous line in Test 3B**



**Figure 4 Quick poll results**

### Test 5 - Student Submission

This test is perhaps the most critical in that it measured how long it took the server to receive submissions from all students. The submissions consisted of screen information developed on the student machine and sent to the instructor machine on the testers start signal. A typical classroom scenario for this type of operation is when an instructor asks the class to graphically respond to a question posed in the flow of a discussion. The test performed here is certainly a worst-case situation since it asks all students to submit their data starting at the same time. In a more typical classroom situation, students are very unlikely to complete an assignment and submit their data at exactly the same instant.



There were three trials in this test. In two trials, students wrote their assigned number (remember the number on the index card) on a blank slide. On the third trial, students submitted complex content. Sample outputs of complex submissions are shown in Figure 5 below.

### Trial 1

Filename of saved deck: *Student Submissions.cp3*

Total submitted slides = 101 (some students submitted more than once)

Duplicates (of index card numbers) = 24

Missing index card numbers: 11,15,16,25,30,33,36,43,51,52,63,72; total = 12

Slides with no number written (including Test 3B slides) = 10

Slides with numbers (and no duplicates) = 67

Partial submissions are shown in Figure 5(a) below. One can see that rising-freshmen are not yet conditioned to follow exact direction. We counted 67 slides with non-duplicated numbers and, therefore know that we had at least 67 participants in Trial 1. We also know that the numbers from 12 index cards were not written on any of the submitted slides. When asked, 12 students admitted to not clicking the submission buttons thus relieving the software and/or the network of any culpability. Finally, we have 10 slides that were submitted without numbers. The 10 slides without numbers consist of 2 identical slides with Test 3B drawings, 1 slide with Test 3B drawing and scribble, 2 identical slides with “lol noob”, 1 blank slide, and 4 unique slides with various artworks. It’s possible that we had 9 students submit the 10 slides without numbers and those same students were assigned the missing index card numbers. If so, we would have 76 participants and 4 non-participants. Note that the number of ink strokes in these submissions was a lot more than we had expected since the students decided on their own to stylize their number drawings.

### Trial 2

Filename of saved deck: *Student Submissions-2.cp3*

Total submitted slides = 85

Duplicates (of index card numbers) = 8

Missing index card numbers: 13,52,76,78; total = 4

Slides with no number written = 2

Slides with numbers (and no duplicates) = 75

In this test we asked the students to draw their index card number with the fewest strokes. Because we are missing 4 index card numbers, it is reasonable to conclude that we most likely had no more than 75 participants in trial 2. Sample submissions for trial 2 are shown in Figure 5(b).

### Trial 3 (Complex slides)

Students were told to draw whatever comes to mind and to submit their work. We gave them two minutes to generate their submission. Samples are shown in Figure 5(c).

Filename of result saved deck: *Student Submissions-3.cp3*

Slides with content = 55

Blank slides = 2

Total submitted slides = 57

### **Network Performance Capture**

Communications Network Services (CNS) captured data during the testing period utilizing a commercial wireless network management tool called Airwave Management Platform. Based on the data, Figure 6 gives us the bandwidth usage and Figure 7 provides the number of users during the tests. Both the usage graph and the "number of users" graph are averaged aggregates; each graph is scaled to allow easier viewing. The *bits per second in* refers to aggregate traffic that arrives from client machines to the WAPs, and *bits per second out* refers to aggregate traffic that is sent from WAPs to client machines. The capture software polled the WAPs and averaged the data every 5 minutes.

From about 13:50 pm to 14:30 pm, the *bits per second in* and the *bits per second out* are similar in shape (mirrored on x axis in Figure 6). This somewhat symmetrical behavior is in agreement with what is expected during Tests 1A through 4. Throughout the tests, "out" traffic is greater than the "in" traffic. The reason could be because of student downloads from the Internet or because of differences in overhead in inbound vs. outbound network packets. We are continuing to explore this difference. Test 5 illustrates this clearly. Between 14:35 pm and 14:50 pm, note the greater bandwidth utilization out (to student computers) compared to utilization in (from student computers).

61	4	
79	75	
VT BOYS 39	19	5
17	56	
40	34	44
74	VT BOYS *3%	45
58	7	49
38	68	10
42	50	22
	13	26
54	71 DOPE! VT	14
29	28	53
18	20	27

(a) Trial 1

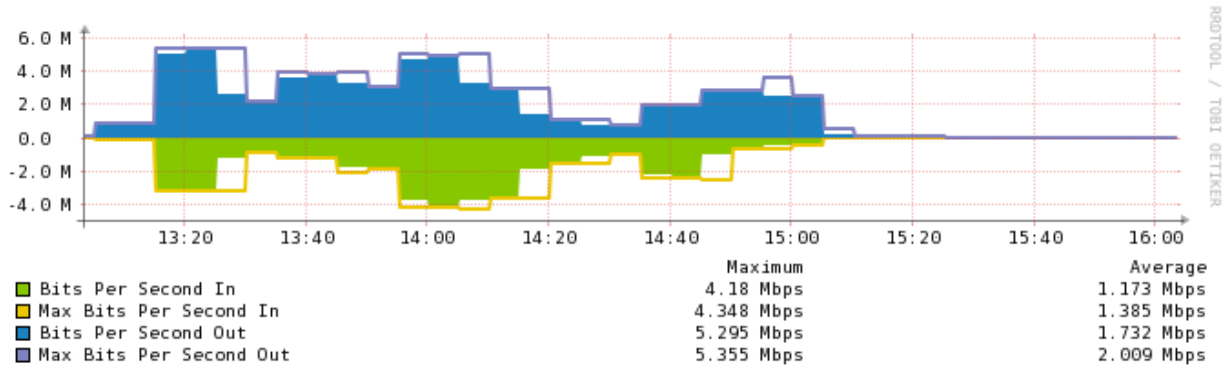
67		67
EPICAM SANDY	59 59	61
23	26	16
17	24	12
5	36	1
21	56	22
11	31	8
69	35	2
68	32	43
3	65	46
39	63	40
79	58	73
19	71	9

(b) Trial 2

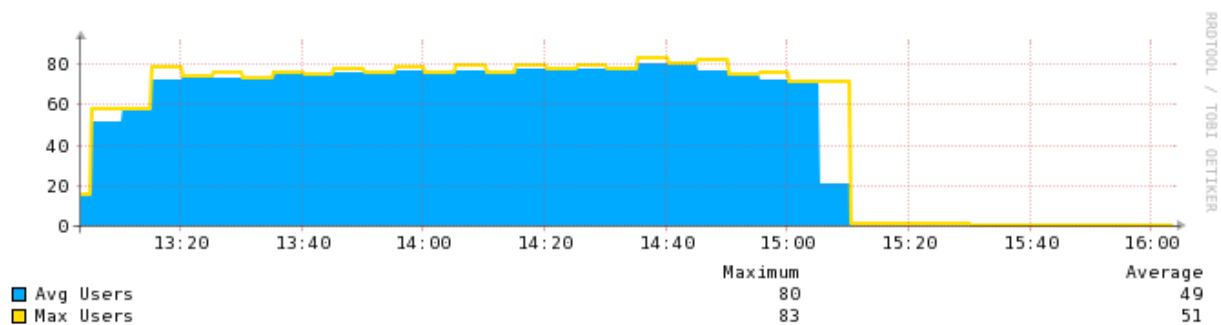
	VT BOYS	SO HUNGRY
VT BOYS		
BBT		78
	VT	
		VT BOYS
78	VT	
VT	BBT	
	55	
78		
		Ian is a dog

(c) Trial 3

Figure 5 Sample output from Test 5



**Figure 6 Average aggregate bandwidth usage**



**Figure 7 Aggregate number of users**

### Concluding Remarks

*Classroom Presenter Viability.* Readers should keep in mind that several of these tests were conducted in worst-case situations. For example, it is highly unlikely that all student machines would download or upload slides simultaneously, as in Test 1 and 5. Test 3 provided worst case scenarios of CP3’s real-time broadcast implementation. From Table 1 in the Appendix, we see that the students’ machines took four additional seconds to display all vertical ink strokes during Test 3A, and three additional seconds to display a continuous line during Test 3B. Feedback from students indicated that this was a very much worst-case situation which only occurred on less than 5% of the student client machines. Most students had received the strokes almost instantaneously leading us to believe that there was some anomaly on certain machine. Again, lack of discipline by the student test user may have been the culprit since it was noticed that some students were occasionally distracted.

We conclude that CP3 is a viable tool for lecture presentation and significant student-teacher interaction in classrooms of size 80. By extension, other classroom tools such as DyKnow are also likely to work well in this same environment. The basic premise, however, is that the classroom needs to be outfitted with sufficient wireless network infrastructure as described in

this paper. Extrapolating the result to larger numbers of students in this classroom is possible. Given the network infrastructure of the pilot test location, and the measured network activity, it is expected that the traffic from at least twice as many student (160) machines can be satisfactorily supported in classrooms. This extrapolation is based on the reasonable assumption that increases in delay will be linearly proportional to the increase in numbers of users. It is also based on the fact that the current measured delays are very tolerable and that a doubling of the delays is still within the student and instructor tolerance ranges.

### **Acknowledgement**

Thanks to Trey Waller for coordinating and supplying students to act as participants for the tests. Kashyap Sridhar performed the timing operations and helped collect the data. Dr. Glenda Scales provided support for performing the testing as well as the Ben and Jerry's rewards for all student participants.

Appendix

**Table 1 Test Measurements**

Test	TOD	N Students	Deck filename	File size (KB)	Elapsed time (min:sec) <sup>1</sup>	Net Utilization <sup>2</sup>	Net Activity Time (sec) <sup>3</sup>	Note
1	14:13	79	CP3-Test-Deck3-Tablet	1028	<2:30	n/a	n/a	Second attempt. Server locked up.
2	14:18	79	<i>CP3-Test-Deck3-Tablet</i>	1028	00:02	~25%	4	
3A	14:25	79	<i>CP3-Test-Deck3-Tablet</i>	1028	00:34	~40%	48	Blank slide added to deck
3B	14:28	79	<i>CP3-Test-Deck3-Tablet</i>	1028	00:33	~30%	28	Blank slide added to deck
4	14:32	75	n/a	n/a	00:11	n/a	n/a	Net utilization and activity not recorded
5 T1	14:38	67	Student Submissions	1287	01:19	30-35%	n/a	Trial 1; net utilization near end of test
5 T2	14:45	75	Student Submissions-2	175	00:28	~40%	28	Trial 2
5 T3	14:47	57	Student Submissions-3	1494	01:02	~40%	n/a	Trial 3 with complex slides; net utilization near end of test

<sup>1</sup> By stop watch. Time rounded to nearest second.

<sup>2</sup> Peak value as shown on Networking tab of the Windows Task Manager.

<sup>3</sup> Value measured from start of network activity to end of network activity shown on Networking tab of the Windows Task Manager.