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MPLS Traffic Engineering -- DiffServ Aware (DS-TE)

Dillon Czerny
Purdue University, dczerny@purdue.edu

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Dillon Czerny

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ABSTRACT

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The purpose of this thesis is to measure the performance effects in a Differentiated Service aware MPLS network. This thesis is split into four chapters. The first chapter goes into detail on the scope of the thesis, the questions asked, the significance, and the constraints of the experiment. The second chapter is a literature review of the technologies used, how they function separately and then research into how they have functioned together in other studies and experiments. The third chapter describes the process of the experiment and the steps to finding and answering the question asked in the first chapter. Finally, the last chapter contains a conclusion of the findings and my interpretations. The different networks of MPLS, MPLS TE, and DS-TE all have their uses depending on the situation and are not necessarily direct improvements/upgrades from the previous technology.

CHAPTER 1. INTRODUCTION

This chapter introduces the research by presenting the problem statement and associated research questions. Also, a look at the constraints of the study, defining terms used throughout the study, and the reason for conducting the study and its impact was done.

1.1. Statement of Problem

The question that is being asked is how well do MPLS and Diffserv work together in the same network environment? By combining these two technologies together a better guarantee for services in a network can be established, while still allowing other network resources to be utilized effectively. The following details the reasons for asking this research question and the attempt to answer that same question.

Computer networks in any scenario are constantly changing whether they are in business, academic, or any field that uses computer networks. As these networks continue to change and adapt more types of traffic are being added, such as voice and video, and the question that arises is how does one effectively manage them all? This is where the concept of Quality of Service comes in; it allows certain types of traffic to be prioritized in the network. If some traffic, such as video, is more important than others in a network, by using the various QoS technologies a network administrator can prioritize that video traffic to ensure that the service remains un-interrupted while the other traffic may be slowed down or even dropped. This QoS is a very important concept for a network that relies on a certain type of data on a daily basis. A look at two technologies that can

implement QoS features are differentiated services (DiffServ) and multiprotocol label switching with traffic engineering (MPLS TE) was done.

The reason for choosing both DiffServ and MPLS is because both these technologies were created to manage resources within the network, but were not created together. This is an interesting point because, even though they were not created together, they compliment each other very well in how they work to better prioritize traffic in the network. MPLS uses label edge routers (LERs) to label packets as they enter the network so that the routing of the traffic is more efficient. The shortcoming of MPLS though is that it cannot provide service differentiation, and that is where DiffServ comes into the picture. By looking at both of these technologies and the advantages they provide in a network, it will help to create a network that allows some types of traffic to be more reliable than others.

1.2. Research Question

This thesis answers the primary question as well as secondary questions relevant to the study.

1.2.1. Primary

- How well do MPLS TE and Diffserv work together in the same network environment?

1.2.2. Secondary

- What additional technologies are required?
- How will emulation work with these technologies?

1.3. Scope

This research is limited to the technologies differentiated services (DiffServ) and multiprotocol label switching with traffic engineering (MPLS TE). A test environment in GNS3 with Cisco IOSs was created to simulate how DiffServ

and MPLS TE work together. Traffic was generated using hping, a packet injector, and measured with Jperf to determine performance under different circumstances.

1.4. Significance

QoS gives the ability to manage network traffic effectively through detecting changes in the network, limiting or prioritizing traffic, and measuring bandwidth. Each of the two technologies of DiffServ and MPLS TE let you manage how traffic is handled with QoS. This is an important feature because depending on the type of network in place some traffic may be more important than others. If a network relies heavily on Voice over Internet Protocol (VOIP) by implementing QoS technologies VOIP can be guaranteed to offer a continued level of service required by the organization.

Both DiffServ and MPLS TE offer the ability to manipulate traffic in a network. MPLS uses label edge routers (LERs) to label packets as they enter the network so that the routing of the traffic becomes more efficient (Anjali, Scoglio, & Cavalcante de Oliveira, 2005). Instead of looking at the packets at each router as the packet traverses the network with an MPLS label the packet can be directly sent to its destination without the need for all the routing. MPLS does not have the ability to differentiate services in the network and that is why DiffServ is being introduced. DiffServ gives the ability for the MPLS traffic to be prioritized based on the network service such as prioritizing VOIP.

1.5. Definitions

A list of terms and their definitions that are used within this document.

- differentiated services (DiffServ) – allows specific traffic to be flagged which can then be used to determine how it’s going to be handled within a network (Meggelen, Smith, & Madsen, 2007).

- label edge routers (LERs) – the ingress routers within an MPLS cloud that tags the traffic before it is assigned a stream based on that tag (Anjali, Scoglio, & Cavalcante de Oliveira, 2005).

- label switch routers (LSRs) – the routers with an MPLS cloud (Anjali, Scoglio, & Cavalcante de Oliveira, 2005).

- multiprotocol label switching (MPLS) – a QoS technology that allows packets to be labeled at an ingress router into the MPLS cloud. Once labeled the packet is looked at once and assigned to a stream where it then traverses the cloud until it reaches its destination (Meggelen, Smith, & Madsen, 2007).

- quality of service (QoS) – technology that allows the managing of traffic in various ways including detecting changes in the network, limiting or prioritizing traffic, and measuring bandwidth (Donahue, 2007).

- jitter – the mean deviation of the difference in packet spacing at the receiver compared to the sender (Unreliable transport (UDP), 2011).

1.6. Assumptions

The assumptions for this project are:

- GNS3-emulated traffic is comparable to real traffic,

- GNS3-emulated hardware is equal in function (using same IOSs) to the real devices,

- Bandwidth constraints are known , and

- The path of the traffic does not change in the network

1.7. Limitations

The limitations for this project are:

- The study being done uses emulated hardware,

- The Dell Optiplex 755 specifications limits the amount of emulated devices,
- Cisco only devices are used environment,
- Jperf only provides results for transfer (bandwidth) and jitter, and
- Normal traffic flows are based on research.

1.8. Delimitations

The delimitations for this project are:

- The system developed is evaluated on performance and functionality,
- The study only covers one network configuration (IP),
- The study does not use every MPLS/DiffServ capable device available,
- Only the Russian Doll Model (RDM) is used, and
- Connection to the Internet in the modeled network is not relevant

1.9. Summary

This chapter introduced the problem being looked at during the study and the questions of the thesis. The constraints of the study were also defined as well as the significance and reasoning for performing the study.

CHAPTER 2. LITERATURE REVIEW

This literature review provides a summary of research into differentiated services (DiffServ) and multi-label protocol switching (MPLS). These technologies will be looked at to see how they can provide a guaranteed service for different types of traffic in a network.

2.1. Introduction

MPLS and DiffServ are two technologies that were created separately but compliment each other well in certain situations. MPLS has the ability to work on any type of network regardless if it is an ATM network, PSTN, or Broadcast TV. Normally these networks would be separated from each other making the management and cost that much more, but by having an MPLS platform all these networks can be done within one MPLS domain if desired reducing the management needed and overall cost of the network. Combining this technology of MPLS traffic engineering with DiffServ allows traffic to have guaranteed service with bandwidth requirements (Veil, 2000).

2.2. MPLS TE

MPLS is a technology that provides scalability, flexibility, and increased performance in a network and in this scenario is used as an infrastructure tool providing traffic engineering capabilities. (Lucek & Minei, 2008) MPLS functions in a network by attaching a label to a packet, an additional header between L2 and L3, at the ingress router of an MPLS domain. This simplifies the routing

process in a network because no longer do routers have to waste resources processing the packet at each hop since a label is attached at the ingress of the MPLS domain already specifying the path needed to be taken (Stephenson, 1998).

The MPLS domain is comprised of ingress routers at the border known as label edge routers (LER), routers within the domain not on the border known as label switching routers (LSR). When a packet enters the MPLS domain a label as mentioned earlier is attached. This label provides the information on how the packet is going to reach the egress LER of the MPLS domain through a path known as the label switched path (LSP) which can be dynamic. Packets that traverse the same path in the MPLS domain and have the same label are part of the same forwarding equivalent class (FEC) (Anjali, Scoglio, Oliveira, 2005; Awduche & Jabbari, 2002).

MPLS also has the ability to use traffic engineering to further enhance its capabilities. Traffic engineering (TE) gives the ability for MPLS to not only efficiently route traffic in an MPLS domain, but also influence how that traffic is processed. Hold priorities and setup priorities can be set for each LSP in the domain, which is a rating that specifies the importance of the LSP. If a new LSP is created that has a higher setup priority than an existing LSP with a lower hold priority then the new LSP will take precedence. This helps to control how the traffic navigates, as dictated by the network, through the MPLS domain and is one of the functions of MPLS TE (Lucek & Minei, 2008). This basically allows MPLS TE to enforce bandwidth requirements for each LSP in the domain and is one of the important factors that work well with DiffServ, but DiffServ adds additional pieces to further improve on MPLS TE as described in the next section.

2.3. DiffServ

DiffServ works by having different types of traffic grouped into different Classes of Service (CoS). Each of these groups is assigned to the classes by

editing the Differentiated Services (DS) field, formerly Type of Service (ToS), byte in the IP header. The bits that replace the old ToS field are called the Differentiated Services Codepoint (DSCP) which allows up to 64 different classes, of which only 32 are available (“Diffserv,” 2005). Packets in the network that are assigned to the same DSCP based on the service they are providing are called a Behavior Aggregate (BA). By having the ability to edit this new DS field the traffic can be prioritized based on the BA it belongs. This is done with per hop behaviors (PHB) “which refers to packet scheduling, queuing, policing, or shaping behavior of a node on any given packet belonging to a BA, and as configured by a Service Level Agreement (SLA) or policy” (“Diffserv,” 2005). In a DiffServ network there are currently four types of PHBs, which are:

Default PHB specifies that a packet marked with a DSCP value of '000000' gets the traditional best effort service from a DS-compliant node (a network node that complies to all the core DiffServ requirements). Also, if a packet arrives at a DS-compliant node and its DSCP value is not mapped to any other of the PHBs, it will get mapped to the default PHB...

Class-Selector PHB is used to preserve backward compatibility with the IP-precedence scheme, DSCP values of the form 'xxx000,' where x is either 0 or 1, are defined...

Expedited Forwarding PHB is the key ingredient in DiffServ for providing a low-loss, low-latency, low-jitter, and assured bandwidth service. Applications such as voice over IP (VoIP), video, and online trading programs require a robust network-treatment...

Assured Forwarding PHB defines a method by which BAs can be given different forwarding assurances. For example, traffic can be divided into gold, silver, and bronze classes, with gold being allocated 50 percent of the available link bandwidth, silver 30 percent, and bronze 20 percent... (“Diffserv – the scalable,” 2005, pp. 5-6)

In the above quoted block Cisco specifies the different types of PHBs encountered in a DiffServ environment. The most important being the Expedited Forwarding and Assured Forwarding PHB. These PHBs allow a customized priority of traffic within the DiffServ network which makes up for the shortcomings of MPLS not being able to provide service differentiation (Oliveira, Scoglio, Akyildiz, & Uhl, 2004). EF PHB and AF PHB also differ in the way they mark traffic. In Assured Forwarding PHB the reason for created the different classes are for assigning different types of traffic to those classes based on importance. If voice traffic is the most important then assigning it to the gold class would be the best choice.

2.4. MPLS TE and DiffServ (DS-TE)

Now that both MPLS TE and DiffServ have been discussed independently, a look at how they can function together will be done that combines the advantages of both to “achieve QoS in a scalable, flexible, and dynamic way” (Atzori & Onali, 2008). MPLS simplifies the network by not only allowing it to function on multiple network types, but also simplifies the network with its ability to attach labels to packets in the network. With the addition of traffic engineering to MPLS, the paths created in the domain can then have bandwidth requirements. DiffServ allows certain types of traffic to be prioritized within a network based on the class that it belongs. By combining these two technologies into DS-TE, you have the ability to enforce bandwidth constraints for different CoS. This is done by mapping a CoS to each LSP in an MPLS domain, which allows each service in the network to be managed separately. Atzori, and Onali (2008) state that a class type (CT) “is a set of traffic trunks with the same QoS requirements (no more than eight CTs can be set up).” This statement shows that there is a limit in the DS-TE network which only eight different services can be defined and used within the MPLS domain. RFC 3564 by F. Le Faucheur (2003) states in regards to the number of CT classes is “This is felt to be beyond current practical requirements. The current practical requirement is that the DS-TE solution MUST allow support for up to 8 TE-classes.” Nadeua (2002) states

that not all networks will benefit from a DS-TE implementation unless they are “networks where bandwidth is scarce, networks with significant amounts of delay sensitive traffic, and networks where the relative proportion of traffic across classes of service is not uniform.”

Several studies (Anjali et al., 2005; Lim, Yaacob, Phang, & Ling, 2004, Oliveira et al., 2004) have used DS-TE and expanded on this technology through improvements to its current functions. It is possible to build this network and have these two technologies work together, but how will they perform in the environment created?

2.5. Russian Doll Model (RDM)

A look at the RDM will be done when creating the DS-TE environment. This model defines a set of requirements of how the DS-TE environment should be created. There are two other models such as the Maximum Allocation Model (MAM) and Maximum Allocation with Reservation (MAR), but according to the Le Faucheur (2002) study the RDM model is the best choice for a DS-TE environment if preemption is used. The two most popular models in a Cisco environment are RDM and MAM with the differences between the two shown in table 2.1 below.

Table 2.1. Bandwidth Constraint Model Capabilities

MODEL	Achieves Bandwidth Efficiency	Ensures Isolation across Class Types		Protects against QoS Degradation...	
		When Preemption is Not Used	When Preemption is Used	...of the Premium Class Type	...of all other Class Types
Maximum Allocation	Yes	Yes	Yes	Yes	**No**
Russian Dolls	Yes	**No**	Yes	Yes	Yes

Several studies (Le Faucheur, 2002; Oliveira et al., 2004) states that the RDM is defined as "the maximum number of bandwidth constraints (BC) is equal to the maximum number of CTs = 8; all LSPs from CT_c must use no more than BC_b (with $b < c < 7$, and $BC_b < BC_{b-1}$, for $b = 1,...,7$)." This means that unused bandwidth can be shared between different tunnels on the same CT. If CT 0 is configured to use the link bandwidth of 10Mbps and a tunnel is created using CT 0 of 8Mpbs and a second tunnel is created on CT 0 of 1Mpbs then the second tunnel can use the remaining bandwidth and follow the most efficient path in the network. If a tunnel is created and bandwidth is not available then it will try and preempt the tunnels already created, but if the tunnel cannot preempt than bandwidth is not guaranteed. In a MAM network model this cannot be done because even though a tunnel is using only a portion of the resources on CT 0 if another CT such as a sub-pool is using those resources than no matter what even if they are not being used they cannot be assigned to another tunnel. This is the reason why in RDM preemption is required (Bhagat, 2010).

2.6. Graphical Network Simulator 3 (GNS3)

GNS3 is a tool that allows emulation of Cisco devices. It allows an emulated network to be built on a single computer and then configured for testing purposes. This tool will be used to build the DS-TE environment and emulate traffic in the network for performance testing. This emulation software is used because of limited resources and the ability for the software to generate traffic which would be significantly harder with physical equipment. It is assumed that the real physical devices would work just as well if not better than the emulated devices on GNS3. The only difference from the physical to the emulation being the physical device itself since the emulated device uses the same Internetwork Operating System (IOS) (Fuszner, 2009).

2.7. Chapter Summary

This chapter summarized literature on the topic of DS-TE. The tool used to perform the building and testing of the network was defined as GNS3 to provide the ability to build the network and create the traffic needed to take performance measurements. The proposed RDM will be followed to see what affect that has on the DS-TE environment.

CHAPTER 3. METHODOLOGY

This chapter covers the research framework, testing methodology, data sources, and data analysis.

3.1. Research Framework

This thesis presents a quantitative study on the best methods for DiffServ aware MPLS-TE. The research follows an experimental model that manipulates several independent variables:

- The technology implemented: MPLS, MPLS-TE, and DS-TE
- Priority and preemption on each MPLS-TE tunnel with CT mapping

The research focuses on testing several null form hypotheses on performance as shown below:

- Ho1 There is no performance difference (% increase or decrease) between an MPLS network, MPLS TE network, or DS-TE network
- Ha1 There is a performance difference (%increase or decrease) with prioritized traffic going from MPLS to MPLS TE to DS-TE

3.2. Testing Methodology

The experimental design involves implementing an emulated network environment of Cisco equipment. The emulation software (GNS3) runs on a Dell Optiplex 755 with the following technical specifications:

- 4GB of RAM
- Core 2 Duo E6750 @ 2.66GHz
- CentOS 5
- Seagate 250GB 7200RPM
- Intel Q35 Express Chipset

The emulated network environment is configured to have multiple LSR routers for the MPLS environment to create a fully mesh network as shown in Appendix A-Figure A.1. There are three LER routers for the network that are on the border of the MPLS network and provide connectivity within the MPLS network for the clients on each side connecting to the LERs. A comparison of three different experiment networks, MPLS only, MPLS TE, and DS-TE was done to evaluate the performance of the system under different circumstances. The physical configuration was used as the basis for the first experiment as shown in Appendix A-Figure A.1. For the second and third experiment the physical configuration as shown in Appendix A-Figure A.2 was used. BGP will be running in the network on the 7200 connected to the Internet and the 3600s connected to the customer sites. iBGP connections were established from the 3600s and the one 7200 connected to the Internet, and these same routers redistribute BGP into OSPF and from OSPF to BGP. The 7200s in the center of the network, excluding the one connected to the Internet, are configured to only run OSPF. eBGP connections were established from the 2600s to the 3600s and a separate OSPF area was configured on the customer client side of each 2600 with redistribution between OSPF and BGP on those same 2600s. VMware server was implemented on the CentOS machine as well to provide the virtual clients that connect to the GNS3 environment within the customer sites. Each customer site has a single Windows XP client with the exception of customer site one which also has a CentOS virtual machine for running hping. All IOS versions are 12.2.

The following was used in all the experiments. The common sizes of TCP traffic are 44, 552, 576, and 1500 bytes (Miller & Thompson, 1998). For the experiments 560 bytes was used as the average TCP packet size for the background traffic generated from Hping. For UDP traffic 137 bytes was used for the average traffic generated by Hping (Siemon, 2008). These UDP/TCP connections were done from customer site one to customer site two and customer site one to customer site three using the flood command in Hping. Jperf was used to simulate standard VOIP traffic of 160 bytes for G.711 codec (Voice over IP-Cisco, 2006). Jperf also measured the bandwidth and jitter, defined by Jperf's website as latency variation (IPERF, 2010), of the generated VOIP traffic from customer site one (client) to customer site two (server). This was done after Hping had been generating the UDP/TCP traffic for 30 seconds. The average readings for bandwidth and jitter was taken from Jperf over a 10 second period of 3 separate transmissions and entered into a table for easy comparison. A copy of the graphs of the results for each test run is shown in Appendix A, B, and C.

3.3. Experiments

Experiment 1

The first experiment was configured to use MPLS only as shown in Appendix A-Figure A.3. In this experiment MPLS was configured on the 3600s as being the LERs to the network and the 2600s as the customer edge routers. The 7200s were configured as the LSRs of the MPLS network. Hping was used to create both UDP and TCP background traffic as per the settings mentioned above.

Experiment 2

The second experiment was configured to use MPLS with Traffic Engineering as shown in Appendix A-Figure A.4. In this experiment MPLS TE was configured on the 3600s as being the LERs to the network and the 2600s as

the customer edge routers. The 7200s were configured as the LSRs of the MPLS TE network. An MPLS TE tunnel was created from customer site one to customer site two which was used by Jperf to send the VOIP traffic. Hping was used to create both UDP and TCP background traffic, with the same settings mentioned above and the same as the previous experiment, and did not go through the MPLS TE tunnels. RSVP bandwidths of 1000kbps were configured on all interfaces within the MPLS TE area excluding the eBGP connections. Dynamic pathing was chosen for the creation of the MPLS TE tunnels which relies on OSPF for the calculations/metrics used to create the tunnels. Static pathing could have been used, but reliance on the IGP and RSVP protocols were done so that the path of the TE tunnel was dynamic based on the best path in the network. The private address space at customer site 2 was split into two /25s so that the CentOS running Hping communicated with the 192.168.2.128/25 network space and the WinXP running Jperf communicated with the 192.168.2.0/25 network space. The reason for this is to separate the background traffic from the VOIP generated traffic for the MPLS TE tunnel since the traffic is sent over the tunnel using static routes based on destination.

Experiment 3

The third experiment was configured to use Differentiated Services aware MPLS with Traffic Engineering as shown in Appendix A-Figure A.5. In this experiment MPLS TE was configured on the 3600s as being the LERs to the network and the 2600s as the customer edge routers. The 7200s were configured as the LSRs of the MPLS TE network. Three tunnels were created on this network with two going from customer site one to customer site two and one going to customer site three from customer site one. The tunnel created for the VOIP traffic was configured with a higher priority and preemption than the other two tunnels. The other two tunnels were configured to half of the global pool resources. Hping was used to create both UDP and TCP background traffic and went through the tunnel with lesser priority and preemption as the VOIP traffic. RSVP sub-pool (CT 1) with a bandwidth of 1000kbps and global pool (CT 0) with

a bandwidth of 10000kbps was configured on all interfaces within the MPLS TE area excluding the eBGP connections. Dynamic pathing was chosen for the creation of the MPLS TE tunnels which relies on OSPF for the calculations/metrics used to create the tunnels. The private address space for this experiment on customer site two was split into two /25s so that the CentOS running Hping communicated with the 192.168.2.128/25 network space and the WinXP running Jperf communicated with the 192.168.2.0/25 network space. This separated the VOIP traffic to use the higher priority/preemption tunnel as opposed to the best effort traffic on a lower priority/preemption tunnel. The default CTs for DS-TE are shown below in table 3.1.

Table 3.1. Default TE-Class Definition in Cisco IOS

TE-Class	Class-Type	Priority
0	0	7
1	1	7
2	Unused	Unused
3	Unused	Unused
4	0	0
5	1	0
6	Unused	Unused
7	Unused	Unused

Two traffic engineered classes were used so that CT 0 will contain the bandwidth of the entire link with the lowest priority and CT 1 was configured to be a sub-pool of CT 0 with a bandwidth constraint of 1000 but with a higher priority/preemption than CT 0.

3.4. Data Sources

From the testing methodology several data sources are generated:

- Bandwidth measurements (quantitative tabulated numerical data)
- Jitter (quantitative tabulated numerical data)

The client for Jperf used in experiment one is shown in Appendix B-Table B.1 as well as the graph of the transmission in Appendix B-Figure B.1. The results for experiment one are shown in Appendix B-Table B.2 to Table B.8 with the last row calculating the average for the columns. The graphs generated by Jperf are also shown in Appendix B-Figure B.2 to Figure B.8. The configurations used on all the routers are shown in the last part of Appendix B.

The client for Jperf used in experiment two is shown in Appendix C-Table C.1 as well as the graph of the transmission in Appendix C-Figure C.1. The results for experiment two are shown in Appendix C-Table C.2 to Table C.8 with the last row calculating the average for the columns. The graphs generated by Jperf are also shown in Appendix C-Figure C.2 to Figure C.8. The configurations used on all the routers are shown in the last part of Appendix C.

The client for Jperf used in experiment three is shown in Appendix D-Table D.1 as well as the graph of the transmission in Appendix D-Figure D.1. The results for experiment three are shown in Appendix D-Table D.2 to Table D.8 with the last row calculating the average for the columns. The graphs generated by Jperf are also shown in Appendix D-Figure D.2 to Figure D.8. The configurations used on all the routers are shown in the last part of Appendix D.

3.5. Data Analysis

Once seven identical testing routines are done for each experiment in the network, completed independently from each other, a look at the difference in performance from the same traffic type in differing situations will be compared and analyzed for establishing the correlation between the key independent and dependent variables. Transfer and jitter were analyzed based on the quantitative results to determine the best network (MPLS, MPLS TE, or DS-TE) for prioritizing and guaranteeing traffic.

3.6. Chapter Summary

This chapter covers the key variables in the experiment, and the hypotheses

that need to be tested. It also describes the data to be used and the how the testing framework is setup.

CHAPTER 4. FINDINGS AND CONCLUSIONS

This chapter goes over the results, findings and thoughts, and conclusions of this thesis.

4.1. Results

Below are three tables 4.1 – 4.3 that show the average results for each run from each experiment respectively.

Table 4.1. Experiment One Results

Experiment Run	Transfer (Kbytes)	Jitter (ms)
One	0.08	189.100
Two	0.08	269.540
Three	0.10	168.29
Four	0.08	259.090
Five	0.09	136.990
Six	0.07	251.118
Seven	0.07	371.549
Average	0.08	235.097
Std. Dev.	0.01	78.36

Table 4.2. Experiment Two Results

Experiment Run	Transfer (Kbytes)	Jitter (ms)
One	0.07	155.578
Two	0.07	172.560
Three	0.08	221.780
Four	0.09	186.830
Five	0.08	189.317
Six	0.07	163.590
Seven	0.08	189.751
Average	0.08	182.772
Std. Dev.	0.01	21.76

Table 4.3. Experiment Three Results

Experiment Run	Transfer (Kbytes)	Jitter (ms)
One	0.08	79.613
Two	0.10	80.054
Three	0.08	49.020
Four	0.10	94.110
Five	0.09	85.550
Six	0.09	52.790
Seven	0.09	68.452
Average	0.09	72.80
Std. Dev.	0.01	16.835

4.2. Findings and Thoughts

From the tables in section 4.1. it can be seen from MPLS to MPLS TE to DS-TE that the average jitter decreases proving my hypothesis correct in that there is a change from each implementation. From MPLS to MPLS TE the decrease in average jitter is 22% and from MPLS TE to DS-TE, a 60% decrease. The average differences between transfers in each experiment are not

substantial. In the first experiment with MPLS, data is packaged using labels defined by MPLS and sent on its way in the network. The queuing and prioritization of data does not occur in this network so that is why a high standard deviation is shown. The standard deviations for the second and third experiment were lower than the first experiment because of the reserved bandwidth from RSVP and the tunnels used for the prioritized traffic. The average jitter is improved going from MPLS to MPLS TE to DS-TE because MPLS TE and DS-TE use tunnels with bandwidth reservation to ensure that even when all the resources are used in the network the tunnels will always be created with the bandwidth specified. The difference between MPLS TE and DS-TE is that when traffic is sent in an MPLS TE network the type of traffic does not matter. The only thing that matters is that RSVP can allocate the desired resources for the tunnel, which is created using OSPF to calculate the shortest path. More control can be done to choose the path through the network, instead of using the dynamic option, but requires more planning and is not as scalable with a technology that is already poor in scaling. This is similar in a DS-TE environment in which CTs are needed to be configured with each addition of a new CT adding more complexity to the network. A global pool (CT 0) is usually configured to use the bandwidth of the link and sub-pools can be created for different tunnels with differing priorities and preemptions. A lower number priority/preemption means it’s higher on the priority list when setting up tunnels or able to preempt another tunnel that is already created when resources are scarce.

In all three environments a lot of configurations need to be done from a low level interface setting which makes them not very scalable. This was not a problem in the small network that was used, but in a large ISP network this can be a nightmare to manage each individual interface. If a sub-pool in DS-TE needs to be changed or an RSVP setting in MPLS-TE then each interface will need to be looked at and possibly reconfigured to make sure the allocated bandwidth is enough for the change. There is also no measure to check whether or not the RSVP bandwidth reservations are over the capabilities of a link. A lot of preparation and planning needs to be done before configuration to verify that

tunnels are not using more than a link can provide especially since there is no measure to notify that this can occur.

As each experiment was run it was seen that improvements were made to the capabilities of the network. Going from MPLS to MPLS-TE showed that tunnels can be created in the network with bandwidth reservations so that whenever important traffic needs to traverse the network especially at high traffic times the tunnel can be created because of those reservations. This enables those high priority traffic to always be available, but the problem being that the tunnel creation is not very granular and has limited if any QoS capabilities. When going from an MPLS-TE to a DS-TE environment a lot of the problems mentioned before are remedied. In this environment more tunnels can be created based on CT pairings and when used in conjunction with RDM the tunnels will be more efficient in how they use bandwidth. Typically CT 0 is the global pool which is configured as the link bandwidth. More CTs can be added up to CT 7, total of eight, which use a portion of CT 0. Each of these CTs can be configured with a priority setting from 0 to 7 with 0 having the highest priority. This allows in each CT to have eight additional configurations with a total of 64 different variations. With these variations tunnel creation and preemption can be controlled at a very granular level with different CTs tied to different types of traffic. In the experiment two CTs were used so that CT 0 had a lower priority than CT 1. In this network during high congestion if the traffic assigned to CT 1 needed to be sent a tunnel would be created regardless of how many resources are currently in use because the rest of the traffic is using CT 0 with a lower priority to CT 1. The required resources would then be diverted to the tunnel creation tied to CT 1. Further enhancements can be done though the use of QoS mechanisms. These were not looked into for the experiment because they were not needed. If done though policing or a similar implementation can be done to conform the data to a specific setting and then sent with a modified EXP or DSCP value as discussed in the literature review. At each hop/interface within the network different settings can be adjusted for those types of traffic depending on the EXP or DSCP value

set in the packet. This is similar to tagging traffic within a network and doing a specific action based on a certain tag.

4.3. Conclusions

Based on the results of the experiments it can be seen that the different technologies of MPLS, MPLS TE, and DS-TE do have an impact on the jitter for the VOIP traffic used in the network. They do also, depending on the situation, provide required bandwidth reservations. The changes are not significant enough for the costs of the implementation. If the planning and execution are not done correctly then the entire network will not prioritize traffic correctly or may not work at all. If further changes are done to the network as well, more time will need to be spent planning integration of new devices, or updates to the topology because so many parts of the network will need to be changed and tested. As the network grows the management of DS-TE and MPLS TE grows as well making the scalability of these technologies harder to manage.

Emulation of this type of network is not recommended unless used for testing purposes. Since the same configuration on an emulated Cisco device can be used on a non-emulated device, ease of testing and implementation to production can be done, but latency issues will need to be considered since significant resources of the emulated devices are shared on one machine as opposed to non-emulated devices having dedicated resources to that sole device.

4.4. Chapter Summary

This chapter reviewed the results of the experiments and detailed the findings and thoughts of the paper.

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APPENDICES

Appendix A

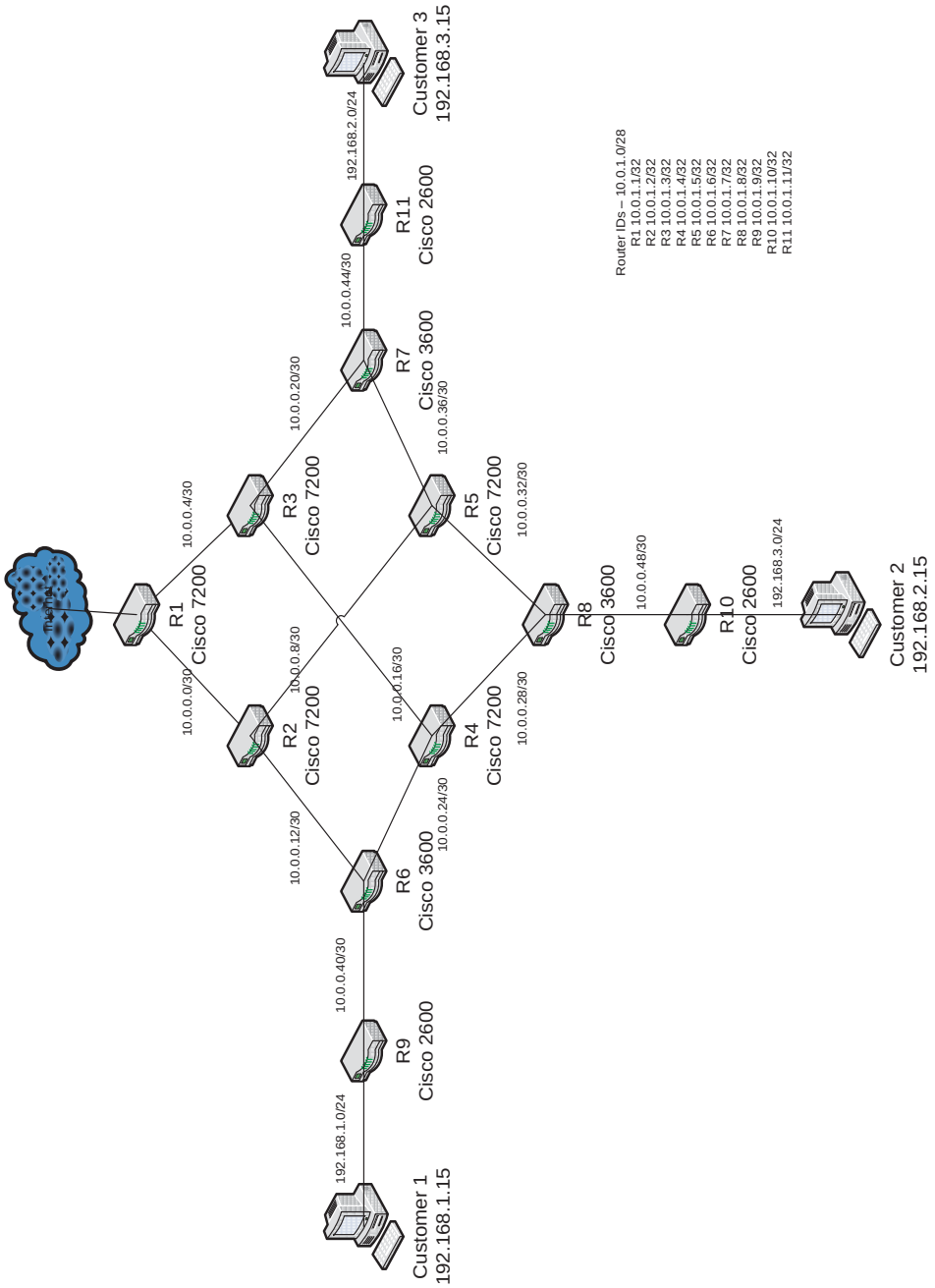

Figure A.1. Physical Network Diagram Experiment One

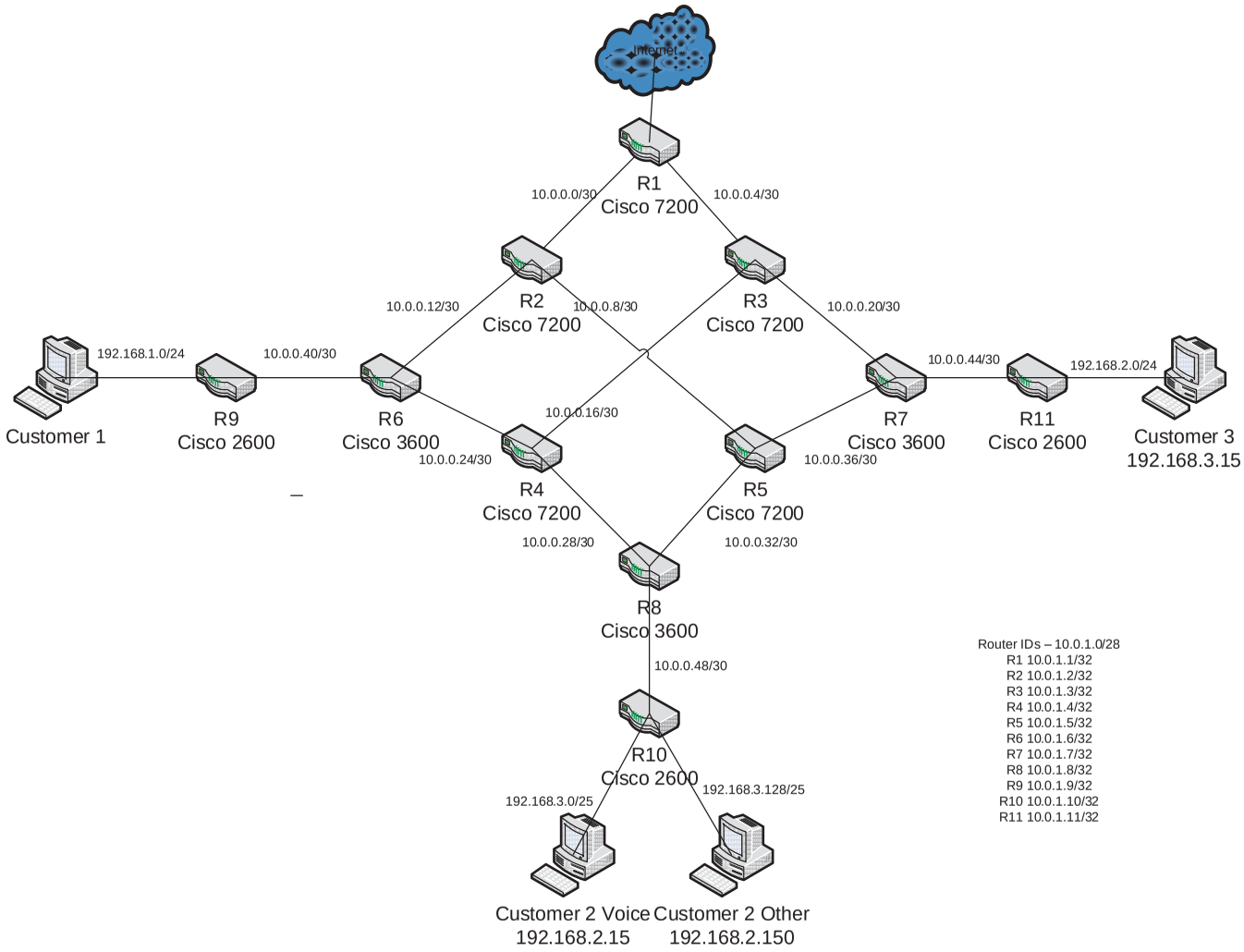

Figure A.2. Physical Network Diagram Experiment Two and Three

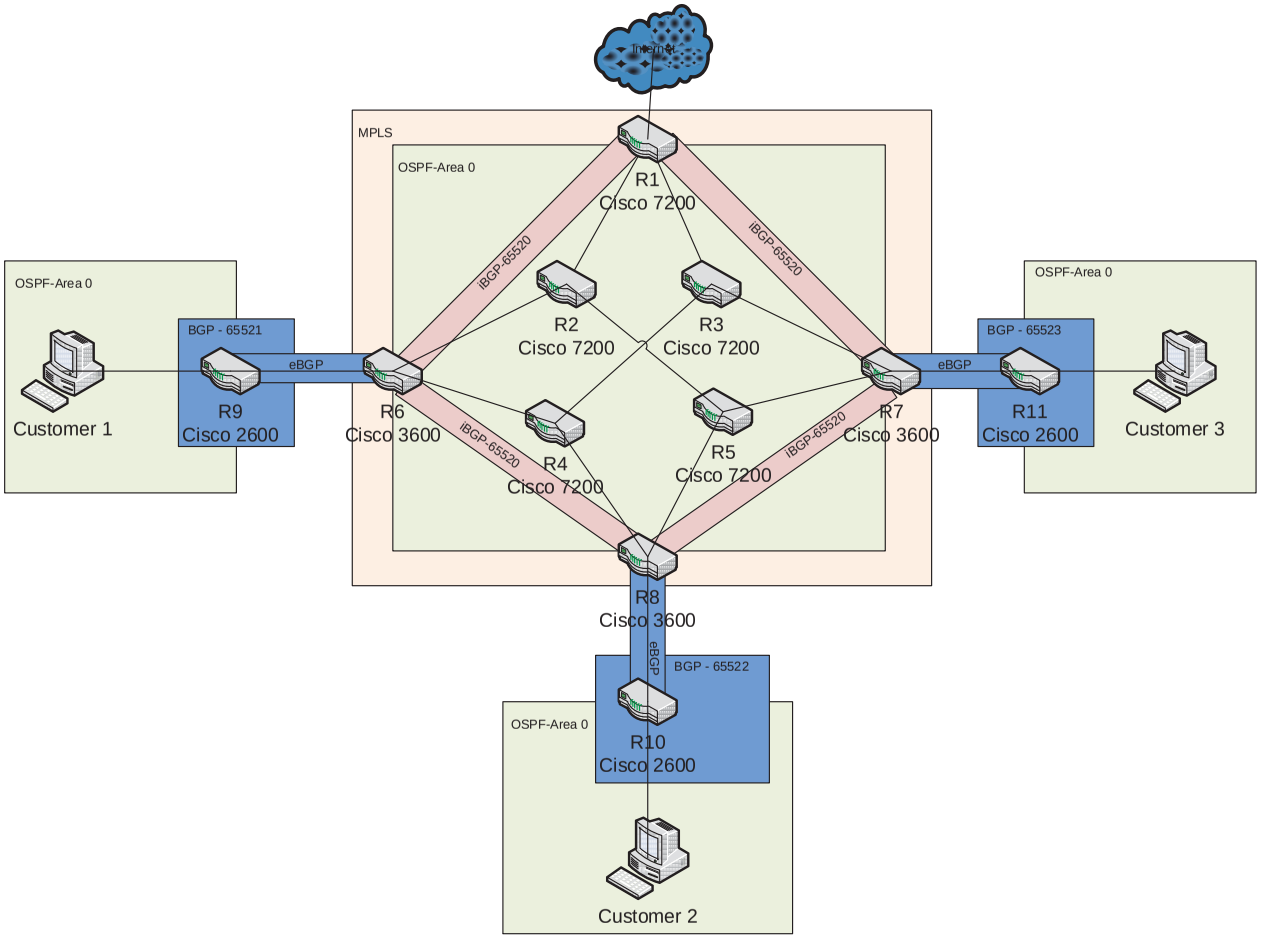

Figure A.3. Logical Network Diagram-Experiment 1

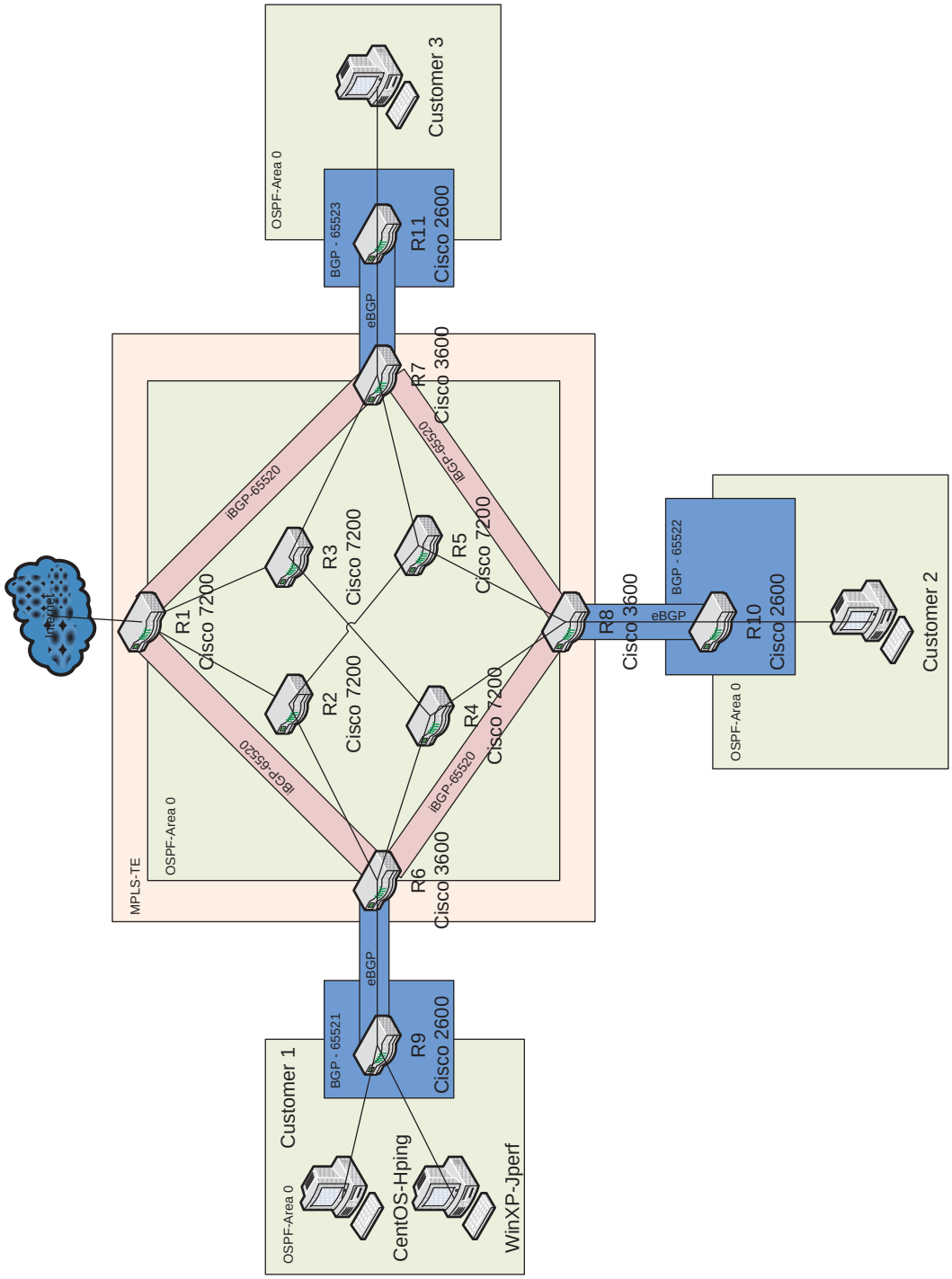

Figure A.4. Logical Network Diagram-Experiment 2

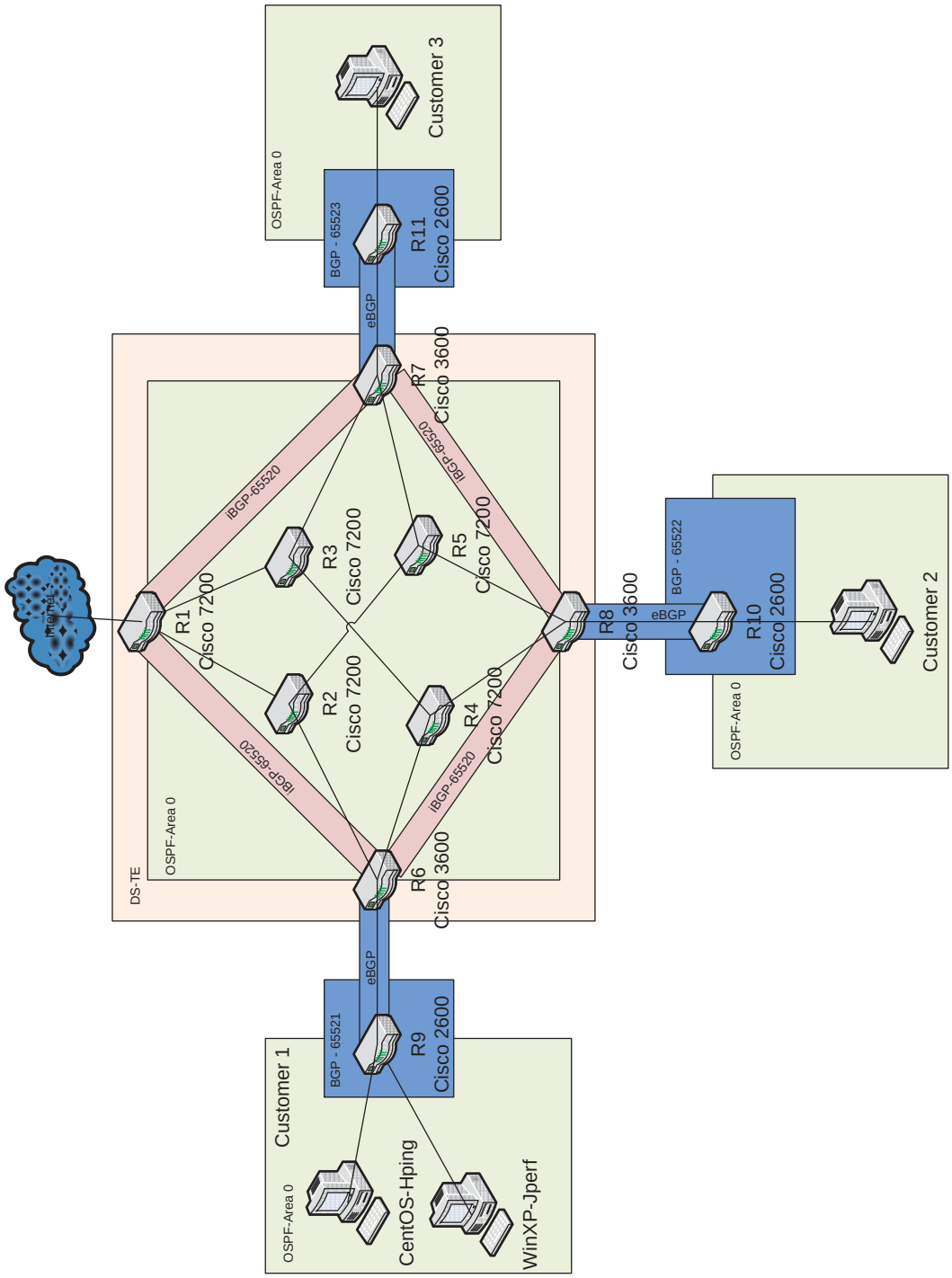

Figure A.5. Logical Network Diagram-Experiment 3

Appendix B

B.1. Experiment One Data

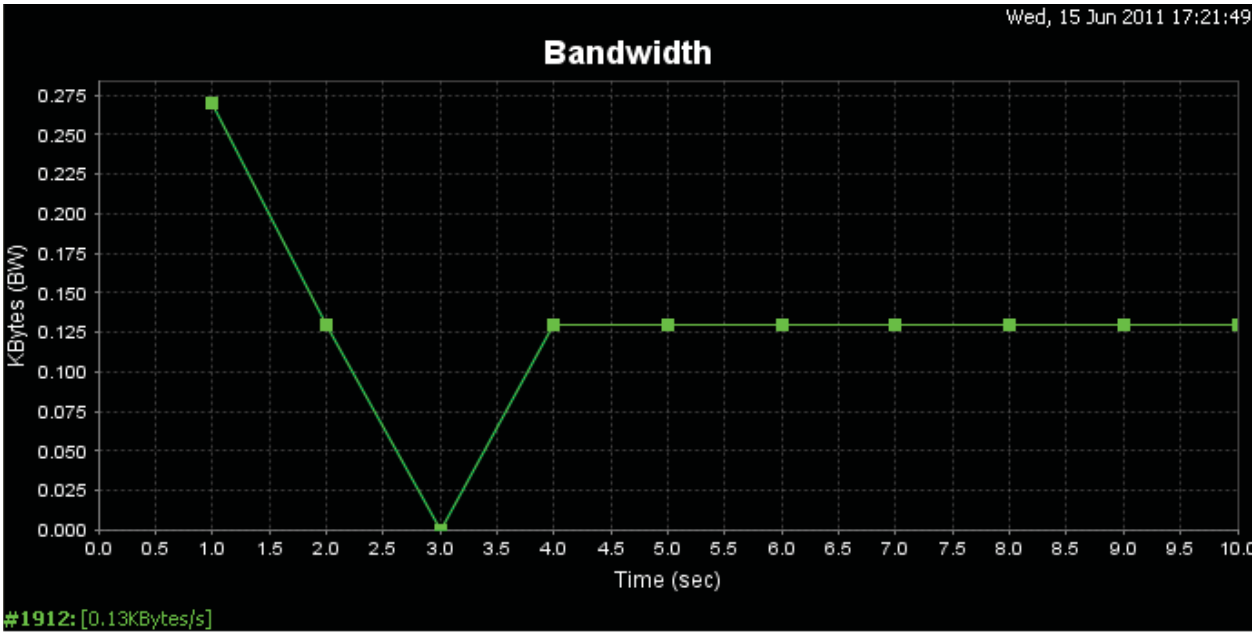

Figure B.1. All Experiments One Jperf Client Graph

Table B.1. All Experiments One Jperf Client

Interval (sec)	Transfer (Kbytes)
0.0-1.0	0.27
1.0-2.0	0.13
2.0-3.0	0.00
3.0-4.0	0.13
4.0-5.0	0.13
5.0-6.0	0.13
6.0-7.0	0.13
7.0-8.0	0.13
8.0-9.0	0.13
9.0-10.0	0.13

B.1.1. Run One

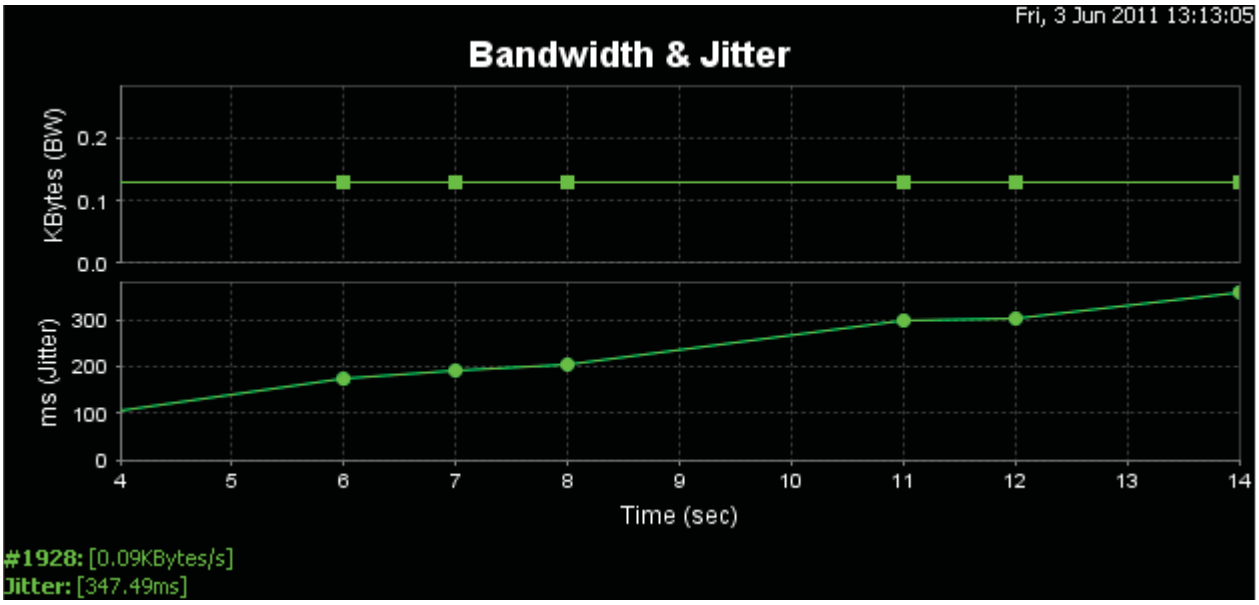

Figure B.2. Experiment One-One Graph

Table B.2. Experiment One-One Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	13.672
1.0-2.0	0.00	13.672
2.0-3.0	0.13	70.435
3.0-4.0	0.00	70.435
4.0-5.0	0.00	70.435
5.0-6.0	0.13	172.478
6.0-7.0	0.13	191.971
7.0-8.0	0.13	204.387
8.0-9.0	0.00	204.387
9.0-10.0	0.00	204.387
10.0-11.0	0.13	298.058
11.0-12.0	0.13	301.891
12.0-13.0	0.00	301.891
13.0-14.0	0.13	359.194
14.0-15.0	0.00	359.194
	0.08	189.10

B.1.2. Run Two

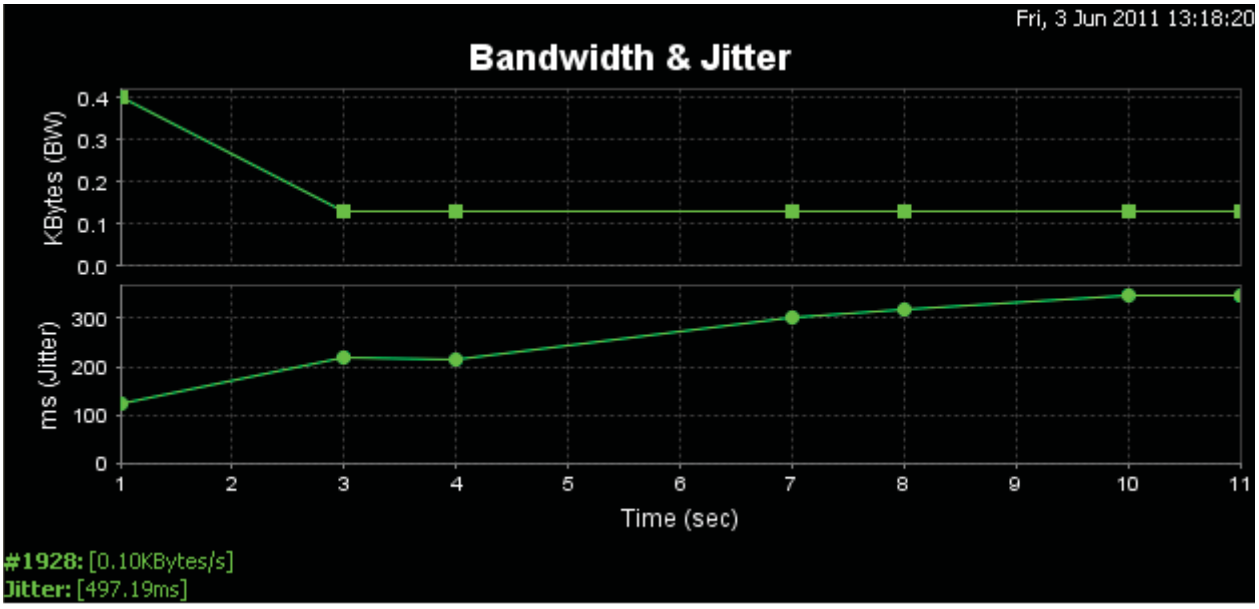

Figure B.3. Experiment One-Two Graph

Table B.3. Experiment One-Two Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.40	123.047
1.0-2.0	0.00	123.047
2.0-3.0	0.13	219.849
3.0-4.0	0.13	213.921
4.0-5.0	0.00	213.921
5.0-6.0	0.00	213.921
6.0-7.0	0.13	302.113
7.0-8.0	0.13	317.411
8.0-9.0	0.00	317.411
9.0-10.0	0.13	348.354
10.0-11.0	0.13	345.136
11.0-12.0	0.00	345.136
12.0-13.0	0.00	345.136
13.0-14.0	0.00	345.136
	0.08	269.54

B.1.3. Run Three

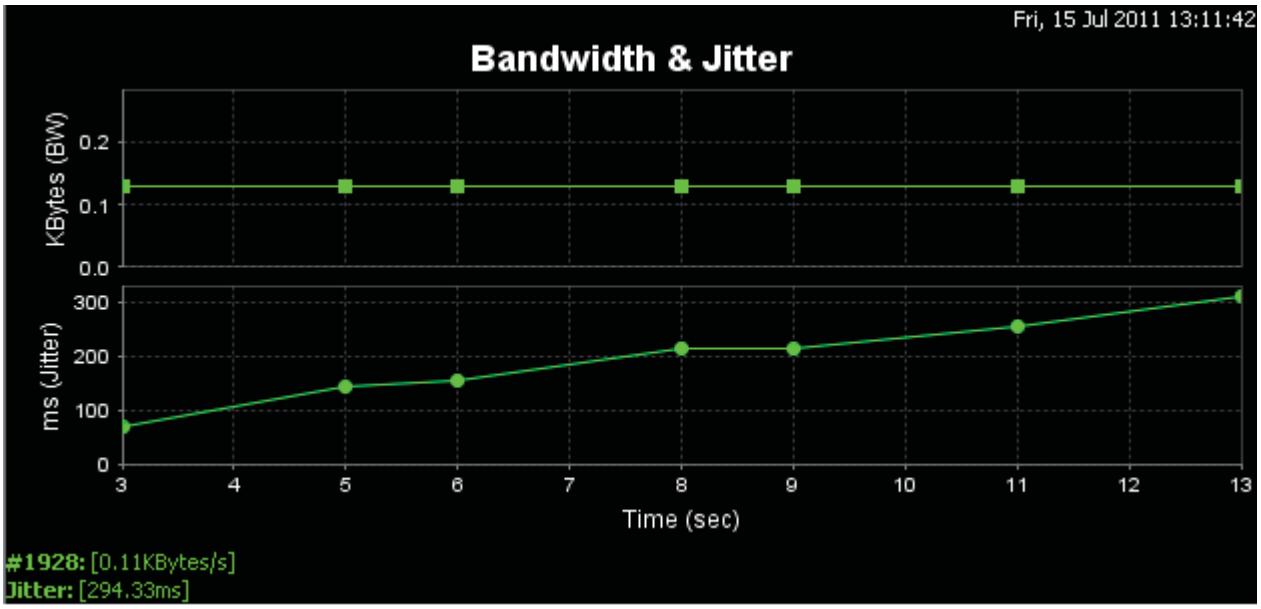

Figure B.4. Experiment One-Three Graph

Table B.4. Experiment One-Three Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	62.5
1.0-2.0	0.13	64.453
2.0-3.0	0.13	68.237
3.0-4.0	0.00	68.237
4.0-5.0	0.13	144.051
5.0-6.0	0.13	155.555
6.0-7.0	0.00	155.555
7.0-8.0	0.13	216.146
8.0-9.0	0.13	213.379
9.0-10.0	0.00	213.379
10.0-11.0	0.13	256.683
11.0-12.0	0.00	256.683
12.0-13.0	0.13	312.906
	0.10	168.29

B.1.4. Run Four

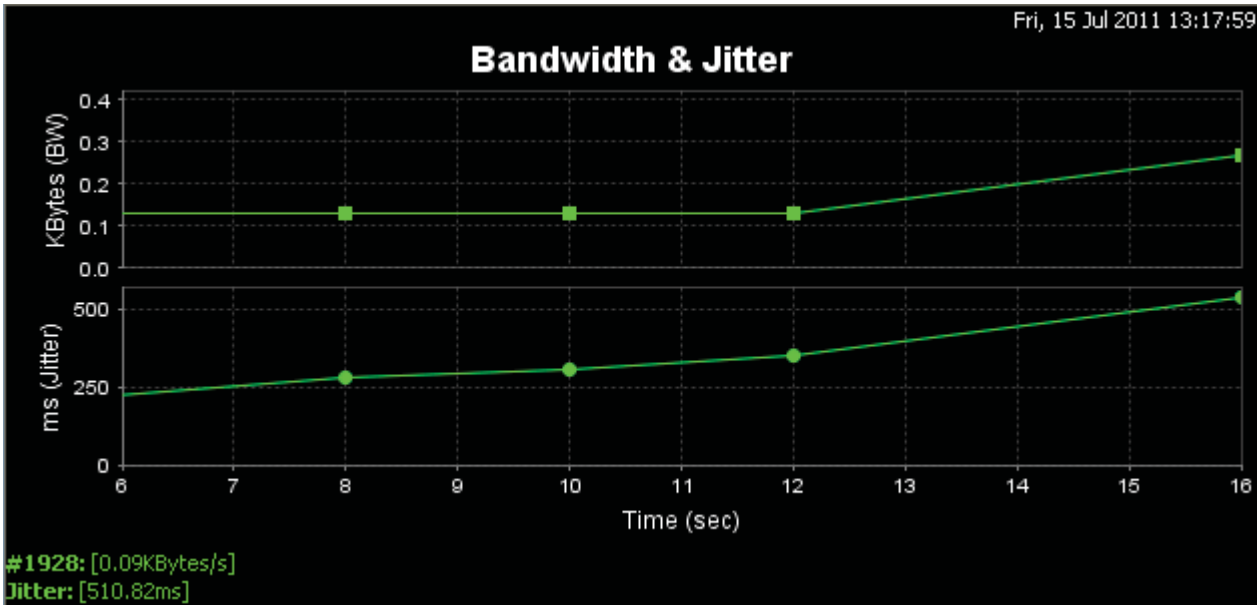

Figure B.5. Experiment One-Four Graph

Table B.5. Experiment One-Four Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.40	76.172
1.0-2.0	0.00	76.172
2.0-3.0	0.13	136.841
3.0-4.0	0.00	136.841
4.0-5.0	0.13	199.577
5.0-6.0	0.00	199.577
6.0-7.0	0.00	199.577
7.0-8.0	0.13	281.83
8.0-9.0	0.00	281.83
9.0-10.0	0.13	307.185
10.0-11.0	0.00	307.185
11.0-12.0	0.13	350.486
12.0-13.0	0.00	350.486
13.0-14.0	0.00	350.486
14.0-15.0	0.00	350.486
15.0-16.0	0.27	540.71
	0.08	259.09

B.1.5. Run Five

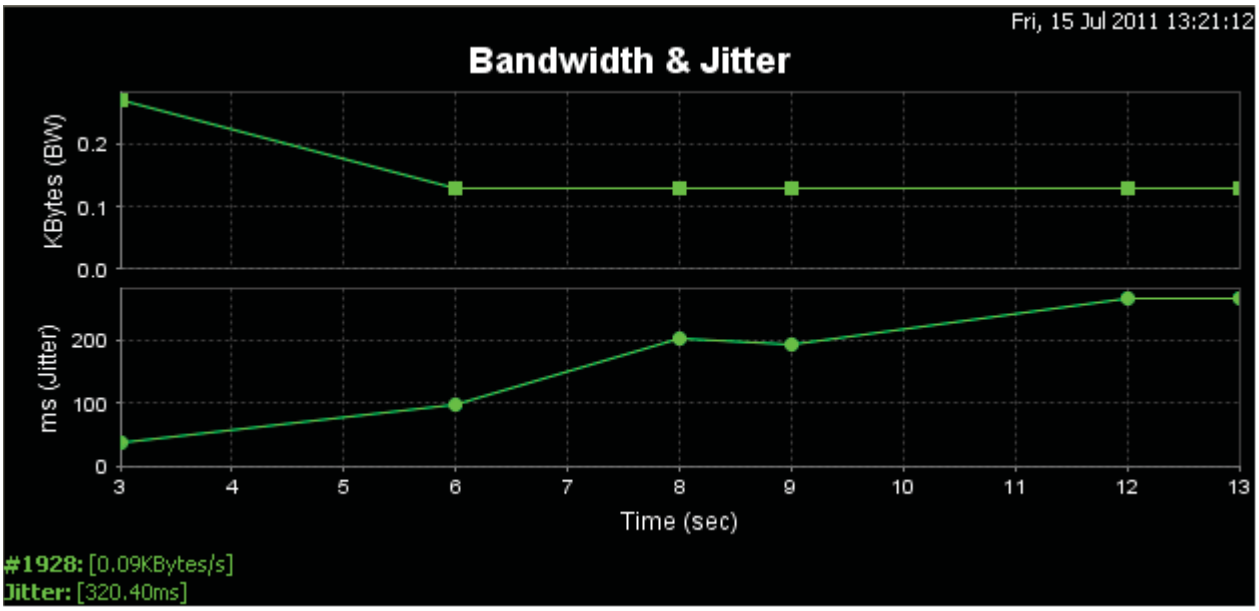

Figure B.6. Experiment One-Five Graph

Table B.6. Experiment One-Five Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	13.672
1.0-2.0	0.00	13.672
2.0-3.0	0.27	38.261
3.0-4.0	0.00	38.261
4.0-5.0	0.00	38.261
5.0-6.0	0.13	97.394
6.0-7.0	0.00	97.394
7.0-8.0	0.13	201.658
8.0-9.0	0.13	192.961
9.0-10.0	0.00	192.961
10.0-11.0	0.00	192.961
11.0-12.0	0.13	266.838
12.0-13.0	0.13	266.762
13.0-14.0	0.00	266.762
	0.09	136.99

B.1.6. Run Six

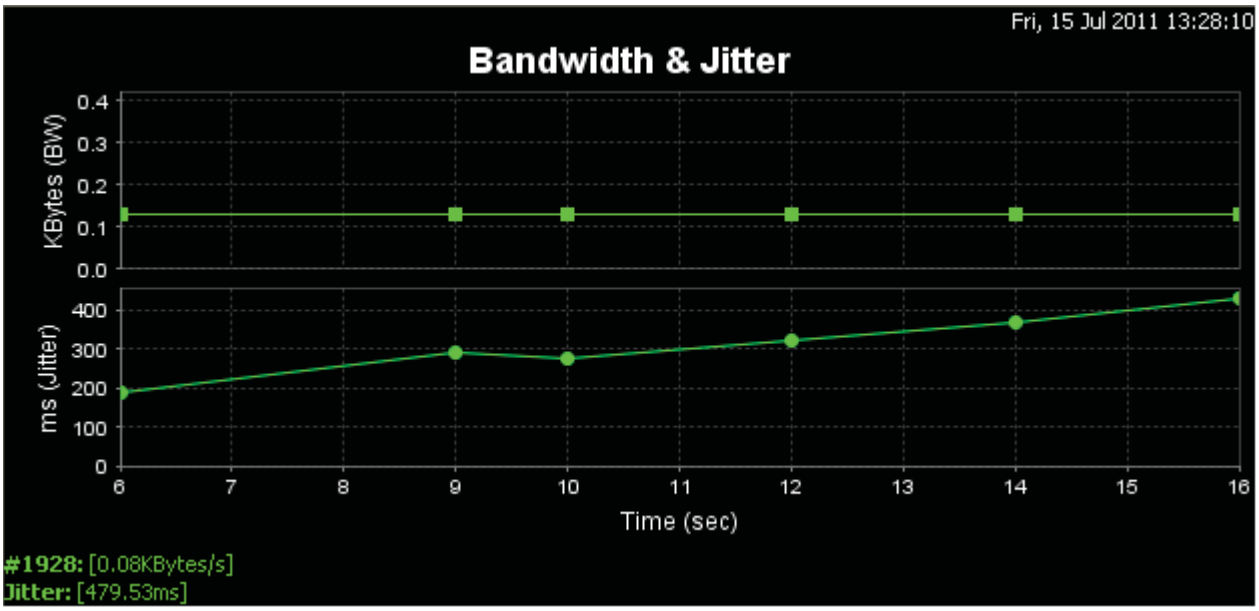

Figure B.7. Experiment One-Six Graph

Table B.7. Experiment One-Six Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.00	0
1.0-2.0	0.40	96.741
2.0-3.0	0.00	96.741
3.0-4.0	0.13	117.062
4.0-5.0	0.00	117.062
5.0-6.0	0.13	189.823
6.0-7.0	0.00	189.823
7.0-8.0	0.00	189.823
8.0-9.0	0.13	290.264
9.0-10.0	0.13	275.052
10.0-11.0	0.00	275.052
11.0-12.0	0.13	322.315
12.0-13.0	0.00	322.315
13.0-14.0	0.13	370.529
14.0-15.0	0.00	370.529
15.0-16.0	0.13	432.332
16.0-17.0	0.00	432.332
17.0-18.0	0.00	432.332
	0.07	251.118

B.1.7. Run Seven

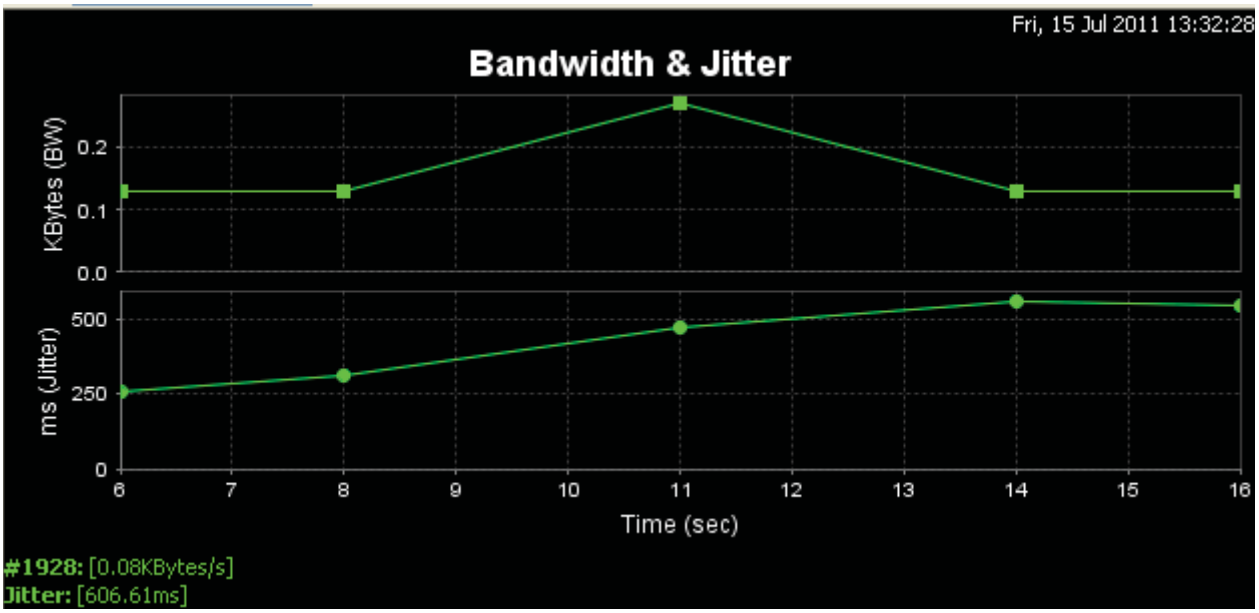

Figure B.8. Experiment One-Seven Graph

Table B.8. Experiment One-Seven Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	63.477
1.0-2.0	0.00	63.477
2.0-3.0	0.00	63.477
3.0-4.0	0.13	182.556
4.0-5.0	0.00	182.556
5.0-6.0	0.13	255.131
6.0-7.0	0.00	255.131
7.0-8.0	0.13	313.404
8.0-9.0	0.00	313.404
9.0-10.0	0.00	313.404
10.0-11.0	0.27	471.498
11.0-12.0	0.00	471.498
12.0-13.0	0.00	471.498
13.0-14.0	0.13	559.216
14.0-15.0	0.00	559.216
15.0-16.0	0.13	541.844
	0.07	317.549

B.2. Router Configurations

B.2.1. Router 1

```
Current configuration : 1287 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R1
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R1_Router_ID
 ip address 10.0.1.1 255.255.255.255
!
interface Ethernet1/0
 description R1_e1/0-R2_e2/2
 ip address 10.0.0.1 255.255.255.252
 full-duplex
!
interface Ethernet1/1
 description R1_f1/1-R3_f1/1
 ip address 10.0.0.5 255.255.255.252
 full-duplex
!
router ospf 1
 router-id 10.0.1.1
 log-adjacency-changes
 network 10.0.0.0 0.0.0.3 area 0
 network 10.0.0.4 0.0.0.3 area 0
 network 10.0.1.1 0.0.0.0 area 0
```

```
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.1
 bgp cluster-id 167772161
 bgp log-neighbor-changes
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 no auto-summary
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

B.2.2. Router 2

```
Current configuration : 1164 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R2
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 ip address 10.0.1.2 255.255.255.255
!
interface Ethernet2/2
 description R2_e2/2-R1_e1/0
 ip address 10.0.0.2 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/1
 description R2_e2/1-R5_e1/0
 ip address 10.0.0.9 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/0
 description R2_e2/0-R6_e2/0
 ip address 10.0.0.13 255.255.255.252
 full-duplex
 tag-switching ip
!
router ospf 1
```

```
 router-id 10.0.1.2
 log-adjacency-changes
 network 10.0.0.0 0.0.0.3 area 0
 network 10.0.0.8 0.0.0.3 area 0
 network 10.0.0.12 0.0.0.3 area 0
 network 10.0.1.2 0.0.0.0 area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

B.2.3. Router 3

```
Current configuration : 1201 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R3
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R3_Router_ID
 ip address 10.0.1.3 255.255.255.255
!
interface Ethernet1/1
 description R3_e1/1-R1_e1/1
 ip address 10.0.0.6 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet1/0
 description R3_e1/0-R4_e1/1
 ip address 10.0.0.17 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet1/2
 description R3_e1/2-R7e2/0
 ip address 10.0.0.21 255.255.255.252
 full-duplex
 tag-switching ip
!
```

```
router ospf 1
 router-id 10.0.1.3
 log-adjacency-changes
 network 10.0.0.4 0.0.0.3 area 0
 network 10.0.0.16 0.0.0.3 area 0
 network 10.0.0.20 0.0.0.3 area 0
 network 10.0.1.3 0.0.0.0 area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

B.2.4. Router 4

```
Current configuration : 1204 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R4
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R4_Router_ID
 ip address 10.0.1.4 255.255.255.255
!
interface Ethernet1/1
 description R4_e1/1-R3_e1/0
 ip address 10.0.0.18 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet1/0
 description R4_e1/0-R6_e2/1
 ip address 10.0.0.25 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet1/2
 description R4_e1/2-R8_e2/1
 ip address 10.0.0.29 255.255.255.252
 full-duplex
 tag-switching ip
!
```

```
router ospf 1
 router-id 10.0.1.4
 log-adjacency-changes
 network 10.0.0.16 0.0.0.3 area 0
 network 10.0.0.24 0.0.0.3 area 0
 network 10.0.0.28 0.0.0.3 area 0
 network 10.0.1.4 0.0.0.0 area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

B.2.5. Router 5

```
Current configuration : 1203 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R5
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R5_Router_ID
 ip address 10.0.1.5 255.255.255.255
!
interface Ethernet1/0
 description R5_e1/0-R2_e2/1
 ip address 10.0.0.10 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet1/1
 description R5_e1/1-R7_e2/1
 ip address 10.0.0.37 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet1/2
 description R5_e1/2-R8_e2/0
 ip address 10.0.0.33 255.255.255.252
 full-duplex
 tag-switching ip
!
```

```
router ospf 1
 router-id 10.0.1.5
 log-adjacency-changes
 network 10.0.0.8 0.0.0.3 area 0
 network 10.0.0.32 0.0.0.3 area 0
 network 10.0.0.36 0.0.0.3 area 0
 network 10.0.1.5 0.0.0.0 area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

B.2.6. Router 6

```
Current configuration : 1724 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R6
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R6_Router_ID
 ip address 10.0.1.6 255.255.255.255
!
interface Ethernet2/0
 description R6_e2/0-R2_e2/0
 ip address 10.0.0.14 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/1
 description R6_e2/1-R4_e1/0
 ip address 10.0.0.26 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/2
 description R6_e2/2-R9_e1/0
 ip address 10.0.0.41 255.255.255.252
 full-duplex
```

```
!
interface Serial1/1
 no ip address
 shutdown
 serial restart-delay 0
!
interface Serial1/2
 no ip address
 shutdown
 serial restart-delay 0
!
interface Serial1/3
 no ip address
 shutdown
 serial restart-delay 0
!
router ospf 1
 router-id 10.0.1.6
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.12 0.0.0.3 area 0
 network 10.0.0.24 0.0.0.3 area 0
 network 10.0.1.6 0.0.0.0 area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.6
 bgp log-neighbor-changes
 neighbor 10.0.0.42 remote-as 65521
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.7 next-hop-self
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 neighbor 10.0.1.8 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
```

```
line aux 0
line vty 0 4
!
end
```

B.2.7. Router 7

```
Current configuration : 1725 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R7
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R7_Router_ID
 ip address 10.0.1.7 255.255.255.255
!
interface Ethernet2/0
 description R7_d2/0-R3_e1/2
 ip address 10.0.0.22 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/1
 description R7_e2/1-R5_e1/1
 ip address 10.0.0.38 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/2
 description R7_e2/2-R11_e1/0
 ip address 10.0.0.45 255.255.255.252
 full-duplex
```

```
!
interface Serial1/1
 no ip address
 shutdown
 serial restart-delay 0
!
interface Serial1/2
 no ip address
 shutdown
 serial restart-delay 0
!
interface Serial1/3
 no ip address
 shutdown
 serial restart-delay 0
!
router ospf 1
 router-id 10.0.1.7
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.20 0.0.0.3 area 0
 network 10.0.0.36 0.0.0.3 area 0
 network 10.0.1.7 0.0.0.0 area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.7
 bgp log-neighbor-changes
 neighbor 10.0.0.46 remote-as 65523
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.6 next-hop-self
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 neighbor 10.0.1.8 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
```

```
line aux 0
line vty 0 4
!
end
```

B.2.8. Router 8

```
Current configuration : 1725 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R8
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R8_Router_ID
 ip address 10.0.1.8 255.255.255.255
!
interface Ethernet2/0
 description R8_e2/0-R5_e1/2
 ip address 10.0.0.34 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/1
 description R8_e2/1-R4_e1/2
 ip address 10.0.0.30 255.255.255.252
 full-duplex
 tag-switching ip
!
interface Ethernet2/2
 description R8_e2/2-R10_e1/0
 ip address 10.0.0.49 255.255.255.252
 full-duplex
```

```
!
interface Serial1/1
 no ip address
 shutdown
 serial restart-delay 0
!
interface Serial1/2
 no ip address
 shutdown
 serial restart-delay 0
!
interface Serial1/3
 no ip address
 shutdown
 serial restart-delay 0
!
router ospf 1
 router-id 10.0.1.8
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.28 0.0.0.3 area 0
 network 10.0.0.32 0.0.0.3 area 0
 network 10.0.1.8 0.0.0.0 area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.8
 bgp log-neighbor-changes
 neighbor 10.0.0.50 remote-as 65522
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.6 next-hop-self
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.7 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
```

```
line aux 0
line vty 0 4
!
end
```

B.2.9. Router 9

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R9
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R9_Router_ID
 ip address 10.0.1.9 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.1.1 255.255.255.0
 full-duplex
!
interface Ethernet1/0
 description R9_e1/0-R6_e2/2
 ip address 10.0.0.42 255.255.255.252
 full-duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
 router-id 10.0.1.9
 log-adjacency-changes
 network 192.168.1.0 0.0.0.255 area 0
!
```

```
router bgp 65521
 no synchronization
 bgp router-id 10.0.1.9
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.41 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.41
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

B.2.10. Router 10

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R10
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R10_Router_ID
 ip address 10.0.1.10 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.2.1 255.255.255.0
 full-duplex
!
interface Ethernet1/0
 description R10_e1/0-R8_e2/2
 ip address 10.0.0.50 255.255.255.252
 full-duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
 router-id 10.0.1.10
 log-adjacency-changes
 network 192.168.2.0 0.0.0.255 area 0
!
```

```
router bgp 65522
 no synchronization
 bgp router-id 10.0.1.10
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.49 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.49
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

B.2.11. Router 11

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R11
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R11_Router_ID
 ip address 10.0.1.11 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.3.1 255.255.255.0
 full-duplex
!
interface Ethernet1/0
 description R11_e1/0-R7_e2/2
 ip address 10.0.0.46 255.255.255.252
 full duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
 router-id 10.0.1.11
 log-adjacency-changes
 network 192.168.3.0 0.0.0.255 area 0
!
```

```
router bgp 65523
 no synchronization
 bgp router-id 10.0.1.11
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.45 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.45
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

Appendix C

C.1. Experiment Two Data

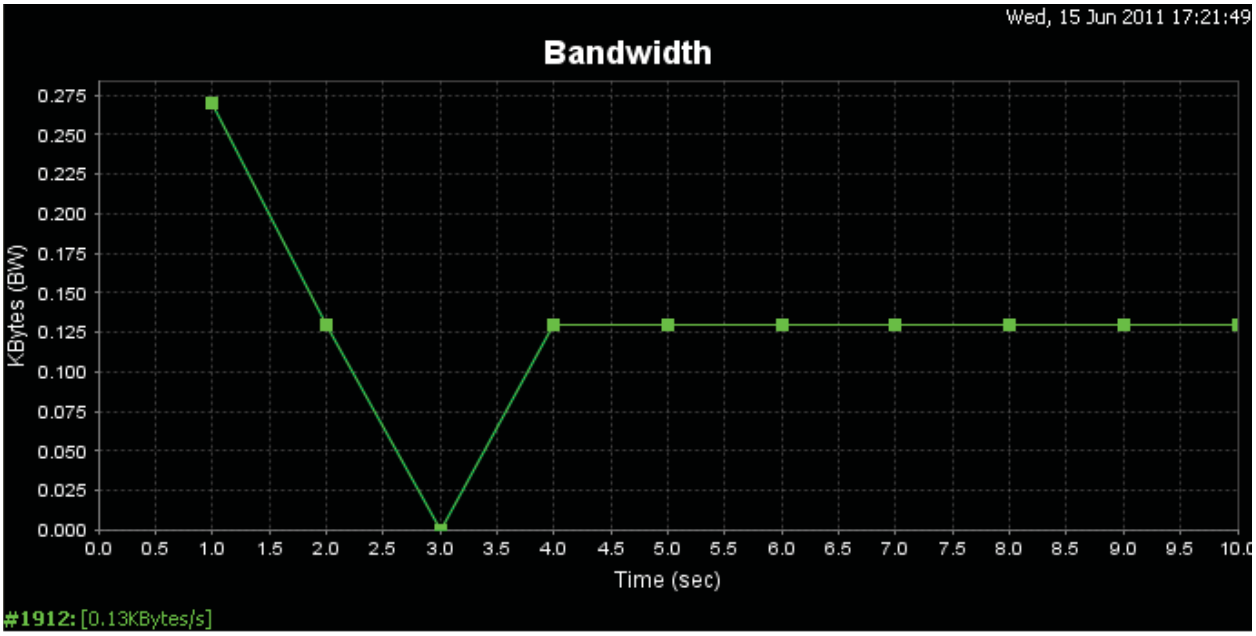

Figure C.1. All Experiments Two Jperf Client Graph

Table C.1. All Experiments Two Jperf Client

Interval (sec)	Transfer (Kbytes)
0.0-1.0	0.27
1.0-2.0	0.13
2.0-3.0	0.00
3.0-4.0	0.13
4.0-5.0	0.13
5.0-6.0	0.13
6.0-7.0	0.13
7.0-8.0	0.13
8.0-9.0	0.13
9.0-10.0	0.13

C.1.1. Run One

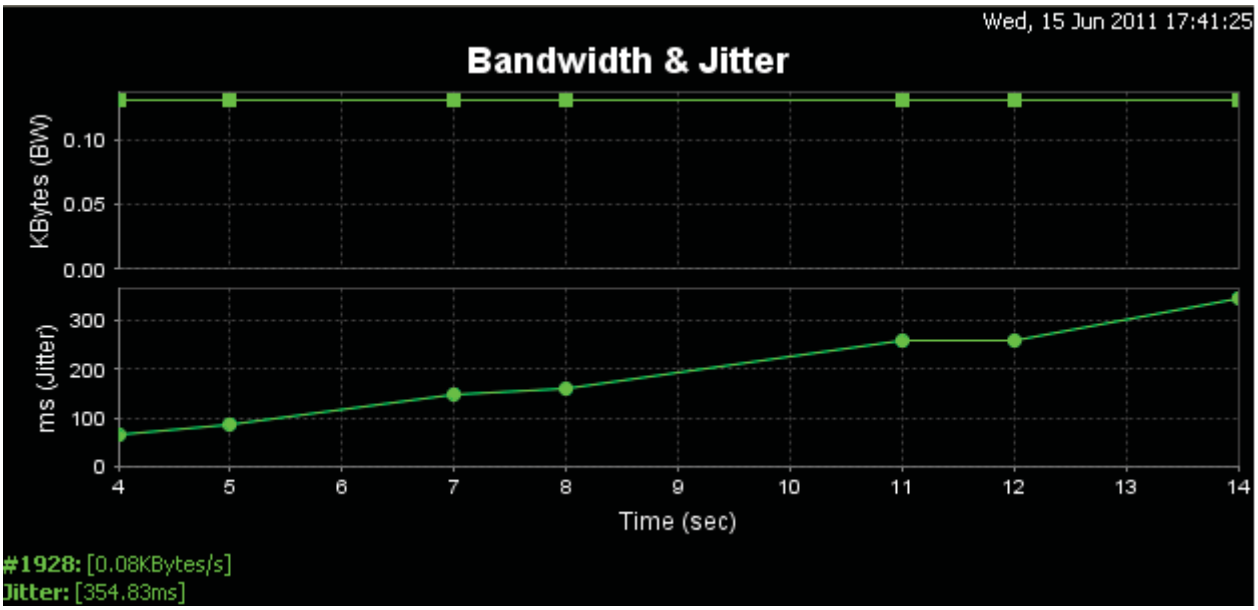

Figure C.2. Experiment Two-One Graph

Table C.2. Experiment Two-One Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.00	0.000
1.0-2.0	0.13	0.000
2.0-3.0	0.00	0.000
3.0-4.0	0.13	63.477
4.0-5.0	0.13	86.853
5.0-6.0	0.00	86.853
6.0-7.0	0.13	149.784
7.0-8.0	0.13	158.977
8.0-9.0	0.00	158.977
9.0-10.0	0.00	158.977
10.0-11.0	0.13	257.440
11.0-12.0	0.13	258.928
12.0-13.0	0.00	258.928
13.0-14.0	0.13	347.237
14.0-15.0	0.00	347.237
	0.07	155.578

C.1.2. Run Two

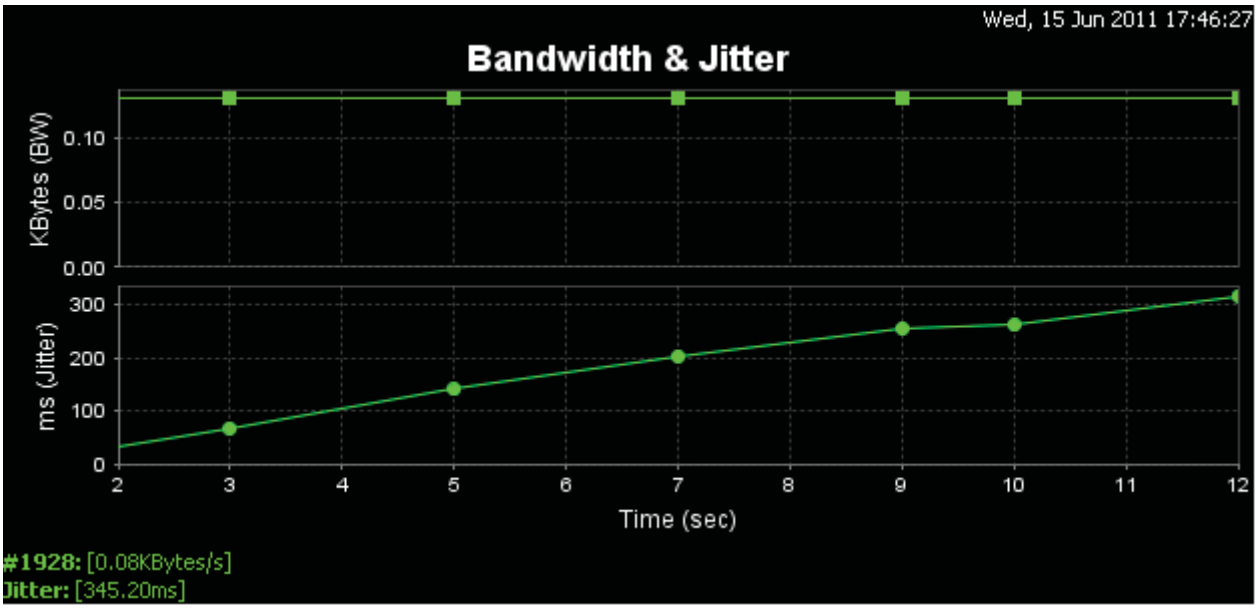

Figure C.3. Experiment Two-Two Graph

Table C.3. Experiment Two-Two Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.13	0.000
1.0-2.0	0.00	0.000
2.0-3.0	0.13	67.383
3.0-4.0	0.00	67.383
4.0-5.0	0.13	140.320
5.0-6.0	0.00	140.320
6.0-7.0	0.13	202.839
7.0-8.0	0.00	202.839
8.0-9.0	0.13	254.615
9.0-10.0	0.13	261.162
10.0-11.0	0.00	261.162
11.0-12.0	0.13	316.129
12.0-13.0	0.00	316.129
	0.07	171.56

C.1.3. Run Three

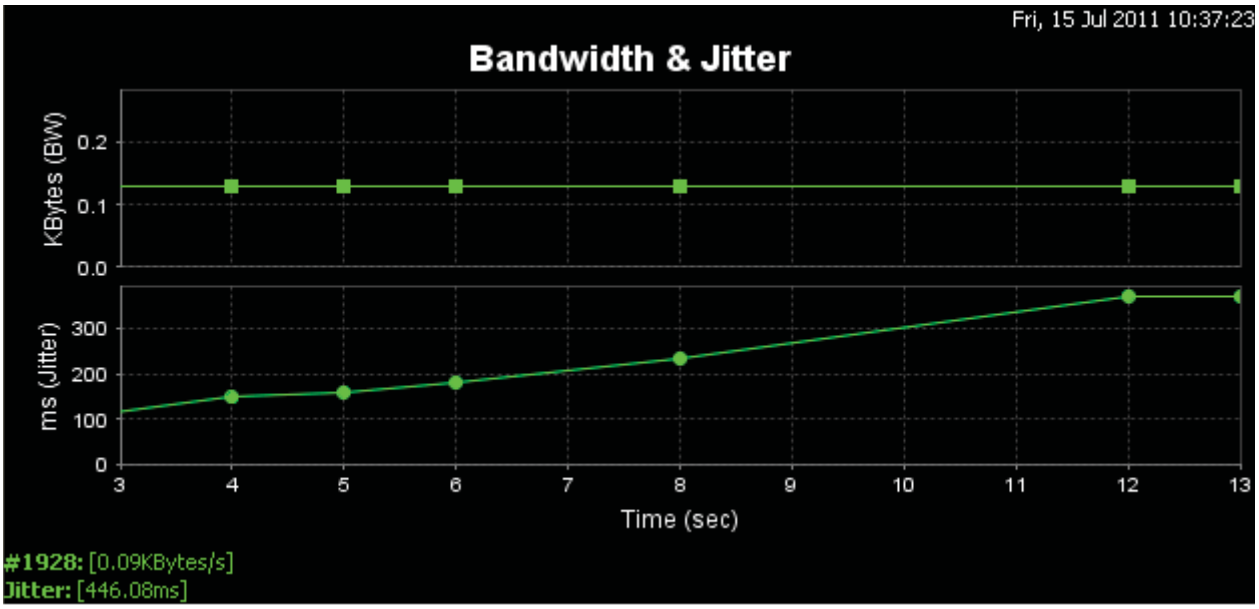

Figure C.4. Experiment Two-Three Graph

Table C.4. Experiment Two-Three Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	62.500
1.0-2.0	0.13	83.008
2.0-3.0	0.00	83.008
3.0-4.0	0.13	148.132
4.0-5.0	0.13	160.358
5.0-6.0	0.13	181.586
6.0-7.0	0.00	181.586
7.0-8.0	0.13	234.690
8.0-9.0	0.00	234.690
9.0-10.0	0.00	234.690
10.0-11.0	0.00	234.690
11.0-12.0	0.13	373.342
12.0-13.0	0.13	371.493
13.0-14.0	0.00	371.493
14.0-15.0	0.00	371.493
	0.08	221.78

C.1.4. Run Four

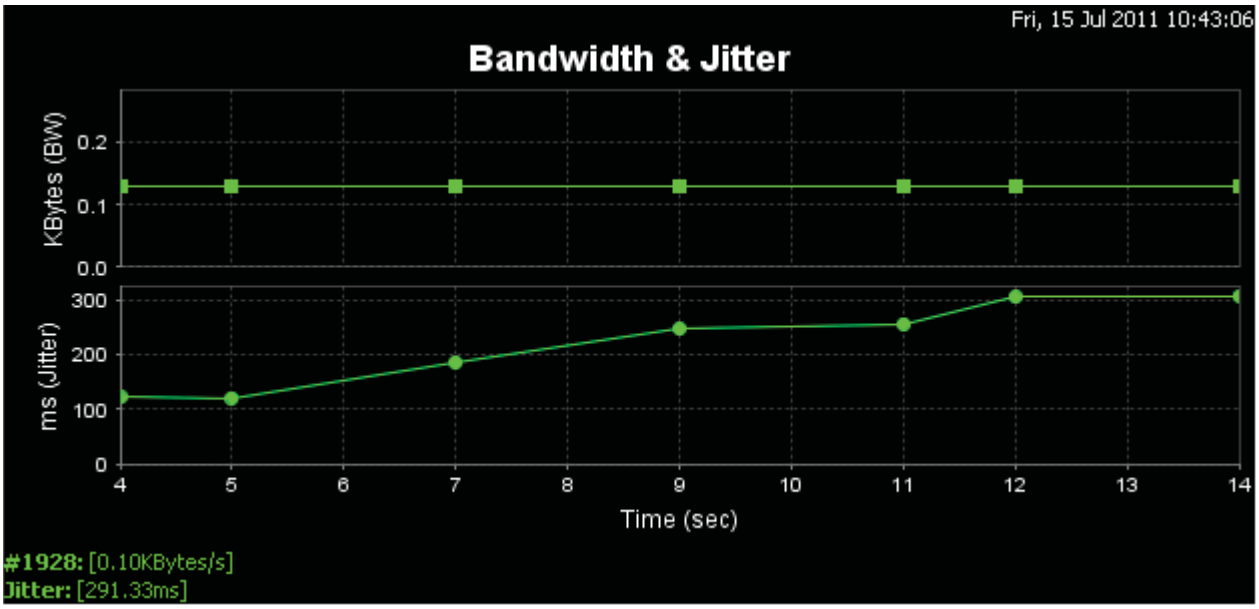

Figure C.5. Experiment Two-Four Graph

Table C.5. Experiment Two-Four Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	62.500
1.0-2.0	0.13	73.242
2.0-3.0	0.00	73.242
3.0-4.0	0.13	122.375
4.0-5.0	0.13	121.563
5.0-6.0	0.00	121.563
6.0-7.0	0.13	186.231
7.0-8.0	0.00	186.231
8.0-9.0	0.13	246.857
9.0-10.0	0.00	246.857
10.0-11.0	0.13	256.819
11.0-12.0	0.13	305.221
12.0-13.0	0.00	305.221
13.0-14.0	0.13	307.629
	0.09	186.83

C.1.5. Run Five

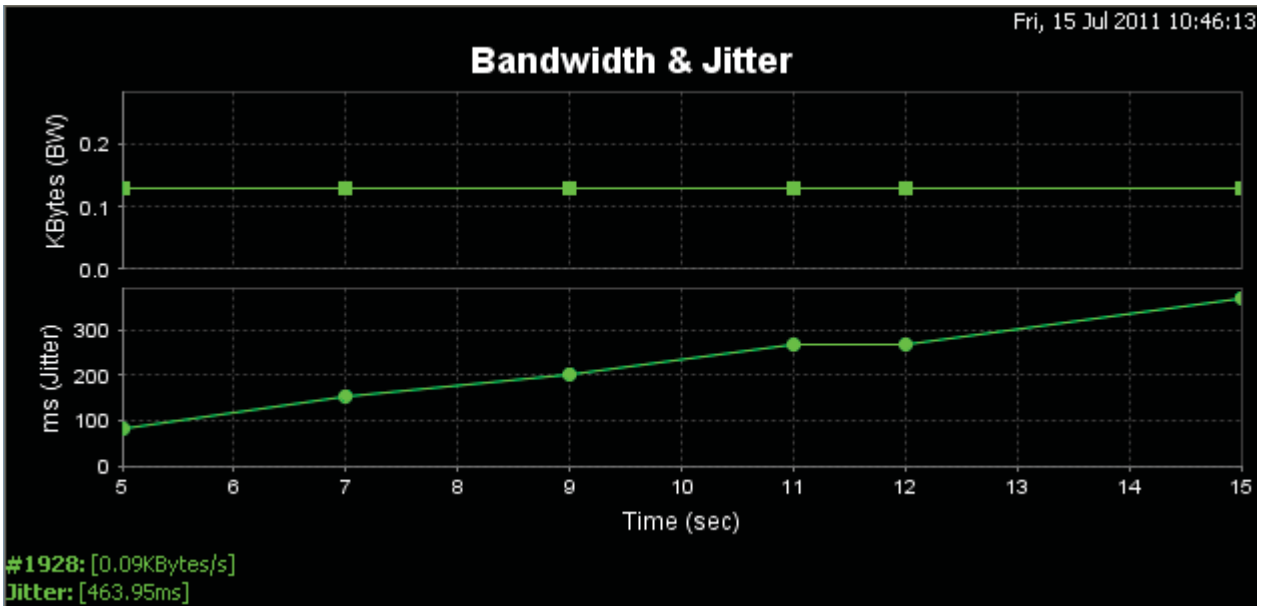

Figure C.6. Experiment Two-Five Graph

Table C.6. Experiment Two-Five Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	23.438
1.0-2.0	0.13	33.691
2.0-3.0	0.13	48.187
3.0-4.0	0.00	48.187
4.0-5.0	0.13	83.261
5.0-6.0	0.00	83.261
6.0-7.0	0.13	155.206
7.0-8.0	0.00	155.206
8.0-9.0	0.13	203.123
9.0-10.0	0.00	203.123
10.0-11.0	0.13	266.600
11.0-12.0	0.13	268.492
12.0-13.0	0.00	268.492
13.0-14.0	0.00	268.492
14.0-15.0	0.13	369.875
15.0-16.0	0.00	369.875
16.0-17.0	0.00	369.875
	0.08	189.317

C.1.3. Run Six

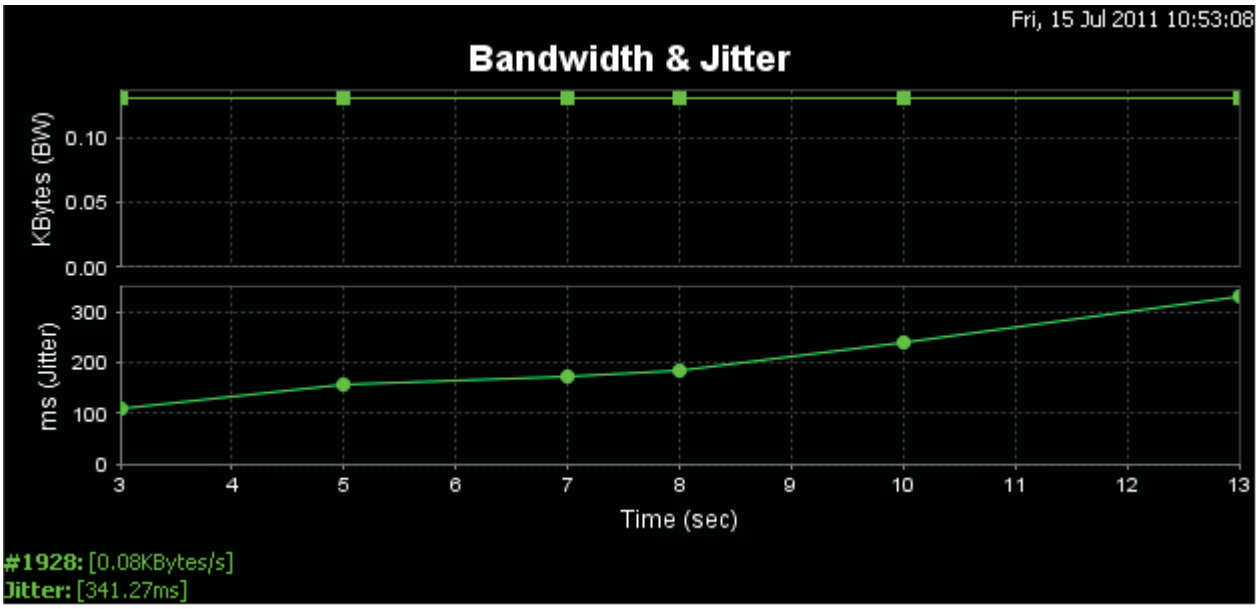

Figure C.7. Experiment Two-Six Graph

Table C.7. Experiment Two-Six Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.13	0.000
1.0-2.0	0.00	0.000
2.0-3.0	0.13	108.398
3.0-4.0	0.00	108.398
4.0-5.0	0.13	157.288
5.0-6.0	0.00	157.288
6.0-7.0	0.13	173.824
7.0-8.0	0.13	184.445
8.0-9.0	0.00	184.445
9.0-10.0	0.13	240.300
10.0-11.0	0.00	240.300
11.0-12.0	0.00	240.300
12.0-13.0	0.13	331.726
	0.07	163.59

C.1.3. Run Seven

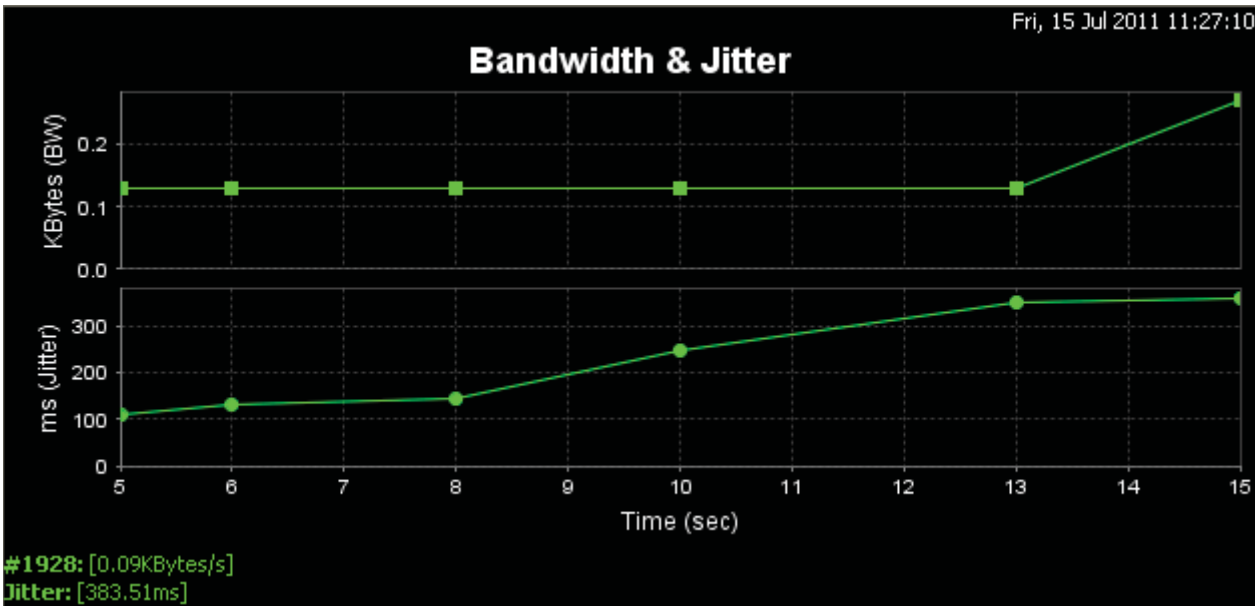

Figure C.8. Experiment Two-Seven Graph

Table C.8. Experiment Two-Seven Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.27	19.531
1.0-2.0	0.00	19.531
2.0-3.0	0.13	86.670
3.0-4.0	0.00	86.670
4.0-5.0	0.13	108.597
5.0-6.0	0.13	132.083
6.0-7.0	0.00	132.083
7.0-8.0	0.13	143.359
8.0-9.0	0.00	143.359
9.0-10.0	0.13	247.680
10.0-11.0	0.00	247.680
11.0-12.0	0.00	247.800
12.0-13.0	0.13	350.364
13.0-14.0	0.00	350.364
14.0-15.0	0.27	360.122
15.0-16.0	0.00	360.122
	0.08	189.751

C.2. Router Configurations

C.2.1. Router 1

```
Current configuration : 1868 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R1
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R1_Router_ID
 ip address 10.0.1.1 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R1_e1/0-R2_e2/2
 ip address 10.0.0.1 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/1
```

```
 description R1_f1/1-R3_f1/1
 ip address 10.0.0.5 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/2
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.1
 log-adjacency-changes
 network 10.0.0.0 0.0.0.3 area 0
 network 10.0.0.4 0.0.0.3 area 0
 network 10.0.1.1 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.1
 bgp cluster-id 167772161
 bgp log-neighbor-changes
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
```

```
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 no auto-summary
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.2. Router 2

```
Current configuration : 1607 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R2
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 ip address 10.0.1.2 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/0
 description R2_e2/0-R6_e2/0
 ip address 10.0.0.13 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/1
 description R2_e2/1-R5_e1/0
 ip address 10.0.0.9 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
```

```
!
interface Ethernet2/2
 description R2_e2/2-R1_e1/0
 ip address 10.0.0.2 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.2
 log-adjacency-changes
 network 10.0.0.0 0.0.0.3 area 0
 network 10.0.0.8 0.0.0.3 area 0
 network 10.0.0.12 0.0.0.3 area 0
 network 10.0.1.2 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
```

```
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.3. Router 3

```
Current configuration : 1634 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R3
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R3_Router_ID
 ip address 10.0.1.3 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R3_e1/0-R4_e1/1
 ip address 10.0.0.17 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/1
 description R3_e1/1-R1_e1/1
 ip address 10.0.0.6 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
```

```
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/2
 description R3_e1/2-R7e2/0
 ip address 10.0.0.21 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.3
 log-adjacency-changes
 network 10.0.0.4 0.0.0.3 area 0
 network 10.0.0.16 0.0.0.3 area 0
 network 10.0.0.20 0.0.0.3 area 0
 network 10.0.1.3 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
```

```
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.4. Router 4

```
Current configuration : 1637 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R4
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R4_Router_ID
 ip address 10.0.1.4 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R4_e1/0-R6_e2/1
 ip address 10.0.0.25 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/1
 description R4_e1/1-R3_e1/0
 ip address 10.0.0.18 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
```

```
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/2
 description R4_e1/2-R8_e2/1
 ip address 10.0.0.29 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.4
 log-adjacency-changes
 network 10.0.0.16 0.0.0.3 area 0
 network 10.0.0.24 0.0.0.3 area 0
 network 10.0.0.28 0.0.0.3 area 0
 network 10.0.1.4 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
```

```
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.5. Router 5

```
Current configuration : 1636 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R5
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R5_Router_ID
 ip address 10.0.1.5 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R5_e1/0-R2_e2/1
 ip address 10.0.0.10 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/1
 description R5_e1/1-R7_e2/1
 ip address 10.0.0.37 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
```

```
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/2
 description R5_e1/2-R8_e2/0
 ip address 10.0.0.33 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.5
 log-adjacency-changes
 network 10.0.0.8 0.0.0.3 area 0
 network 10.0.0.32 0.0.0.3 area 0
 network 10.0.0.36 0.0.0.3 area 0
 network 10.0.1.5 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
```

```
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.6. Router 6

```
Current configuration : 2602 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R6
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
no tag-switching ip
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R6_Router_ID
 ip address 10.0.1.6 255.255.255.255
!
interface Tunnel1
 ip unnumbered Loopback0
 tunnel destination 10.0.1.8
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth 1000
 tunnel mpls traffic-eng path-option 1 dynamic
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex auto
```

```
 speed auto
!
interface FastEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface Ethernet2/0
 description R6_e2/0-R2_e2/0
 ip address 10.0.0.14 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/1
 description R6_e2/1-R4_e1/0
 ip address 10.0.0.26 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/2
 description R6_e2/2-R9_e1/0
 ip address 10.0.0.41 255.255.255.252
 load-interval 30
 full-duplex
!
interface Ethernet2/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.6
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.12 0.0.0.3 area 0
 network 10.0.0.24 0.0.0.3 area 0
 network 10.0.1.6 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.6
 bgp log-neighbor-changes
 neighbor 10.0.0.42 remote-as 65521
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.7 remote-as 65520
```

```
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.7 next-hop-self
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 neighbor 10.0.1.8 next-hop-self
 no auto-summary
!
ip classless
ip route 192.168.2.0 255.255.255.128 Tunnel1
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.7. Router 7

```
Current configuration : 2565 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R7
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R7_Router_ID
 ip address 10.0.1.7 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface Ethernet2/0
 description R7_d2/0-R3_e1/2
 ip address 10.0.0.22 255.255.255.252
 full-duplex
```

```
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/1
 description R7_e2/1-R5_e1/1
 ip address 10.0.0.38 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/2
 description R7_e2/2-R11_e1/0
 ip address 10.0.0.45 255.255.255.252
 full-duplex
!
interface Ethernet2/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.7
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.20 0.0.0.3 area 0
 network 10.0.0.36 0.0.0.3 area 0
 network 10.0.1.7 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.7
 bgp log-neighbor-changes
 neighbor 10.0.0.46 remote-as 65523
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.6 next-hop-self
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 neighbor 10.0.1.8 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
!
!
dial-peer cor custom
```

```
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.8. Router 8

```
Current configuration : 2620 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R8
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R8_Router_ID
 ip address 10.0.1.8 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface Ethernet2/0
 description R8_e2/0-R5_e1/2
 ip address 10.0.0.34 255.255.255.252
 full-duplex
```

```
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/1
 description R8_e2/1-R4_e1/2
 ip address 10.0.0.30 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/2
 description R8_e2/2-R10_e1/0
 ip address 10.0.0.49 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet2/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.8
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.28 0.0.0.3 area 0
 network 10.0.0.32 0.0.0.3 area 0
 network 10.0.1.8 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.8
 bgp log-neighbor-changes
 neighbor 10.0.0.50 remote-as 65522
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.6 next-hop-self
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.7 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
!
```

```
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

C.2.9. Router 9

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R9
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R9_Router_ID
 ip address 10.0.1.9 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.1.1 255.255.255.0
 full-duplex
!
interface Ethernet1/0
 description R9_e1/0-R6_e2/2
 ip address 10.0.0.42 255.255.255.252
 full-duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
 router-id 10.0.1.9
 log-adjacency-changes
 network 192.168.1.0 0.0.0.255 area 0
!
router bgp 65521
```

```
 no synchronization
 bgp router-id 10.0.1.9
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.41 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.41
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

C.2.10. Router 10

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R10
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R10_Router_ID
 ip address 10.0.1.10 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.2.1 255.255.255.128
 full-duplex
!
interface Ethernet1/0
 description R10_e1/0-R8_e2/2
 ip address 10.0.0.50 255.255.255.252
 full-duplex
!
interface Ethernet2/0
 ip address 192.168.2.129 255.255.255.128
 full-duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
 router-id 10.0.1.10
```

```
 log-adjacency-changes
 network 192.168.2.0 0.0.0.128 area 0
 network 192.168.2.128 0.0.0.128 area 0
!
router bgp 65522
 no synchronization
 bgp router-id 10.0.1.10
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.49 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.49
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

C.2.11. Router 11

```
Current configuration : 1256 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R11
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R11_Router_ID
 ip address 10.0.1.11 255.255.255.255
!
interface Ethernet0/0
 description R11_e0/0-R7_e2/2
 ip address 10.0.0.46 255.255.255.252
 full-duplex
!
interface Serial0/0
 no ip address
 shutdown
!
interface Serial0/1
 no ip address
 shutdown
!
interface Ethernet1/0
 description Customer_Site_3
 ip address 192.168.3.1 255.255.255.0
 full-duplex
!
interface Ethernet1/1
```

```
 no ip address
 shutdown
 half-duplex
!
interface Ethernet1/2
 no ip address
 shutdown
 half-duplex
!
interface Ethernet1/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.11
 log-adjacency-changes
 network 192.168.3.0 0.0.0.255 area 0
!
router bgp 65523
 no synchronization
 bgp router-id 10.0.1.11
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.45 remote-as 65520
!
ip classless
ip route 0.0.0.0 0.0.0.0 10.0.0.45
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

Appendix D

D.1. Experiment Three Data

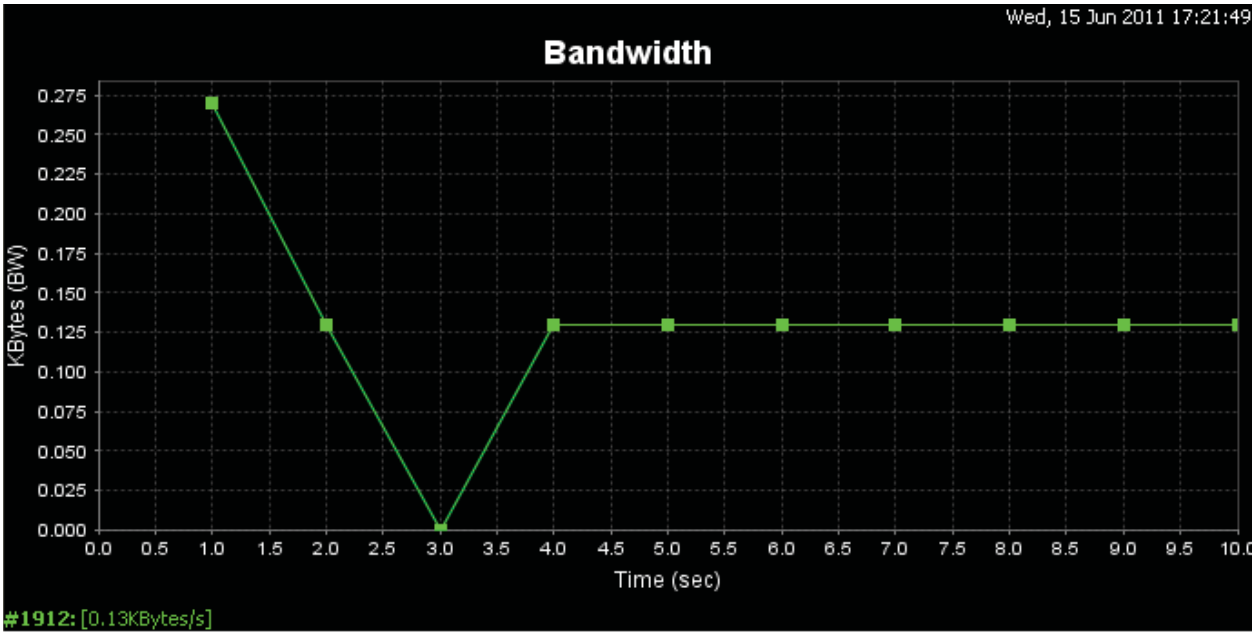

Figure D.1. All Experiments Three Jperf Client Graph

Table D.1. All Experiments Three Jperf Client

Interval (sec)	Transfer (Kbytes)
0.0-1.0	0.27
1.0-2.0	0.13
2.0-3.0	0.00
3.0-4.0	0.13
4.0-5.0	0.13
5.0-6.0	0.13
6.0-7.0	0.13
7.0-8.0	0.13
8.0-9.0	0.13
9.0-10.0	0.13

D.1.1. Run One

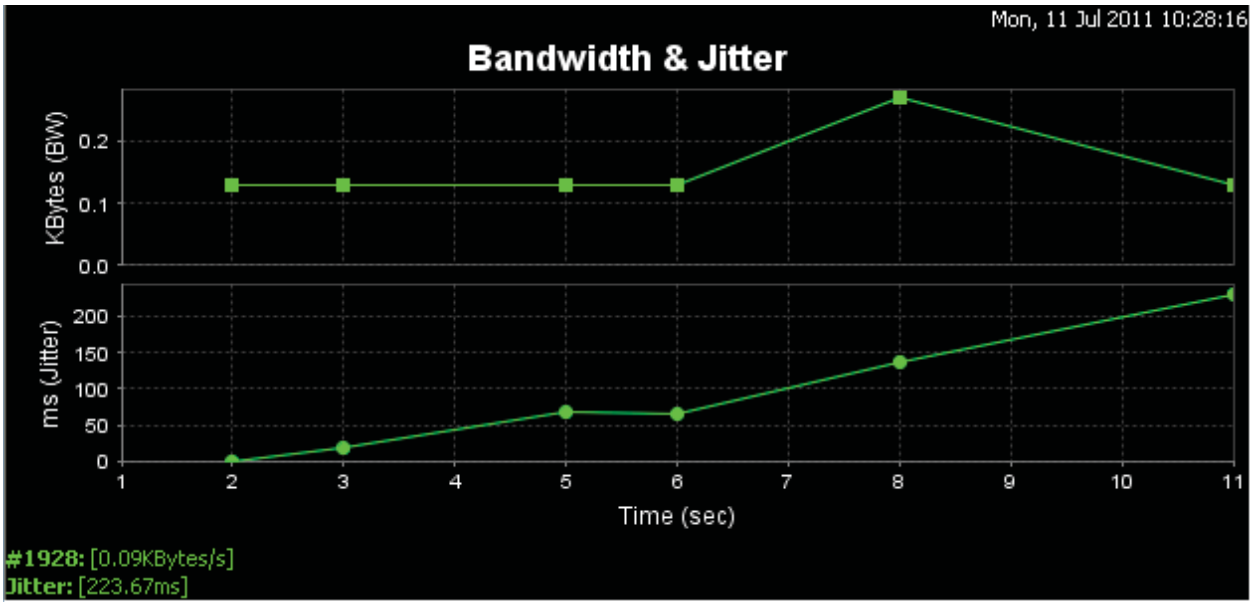

Figure D.2. Experiment Three-One Graph

Table D.2. Experiment Three-One Results

Interval (sec)	Transfer (Kbytes)	Bandwidth (Kbytes/sec)	Jitter (ms)
0.0-1.0	0.00	0.00	0.000
1.0-2.0	0.13	0.13	0.000
2.0-3.0	0.13	0.13	17.578
3.0-4.0	0.00	0.00	17.578
4.0-5.0	0.13	0.13	67.261
5.0-6.0	0.13	0.13	65.010
6.0-7.0	0.00	0.00	65.010
7.0-8.0	0.27	0.27	137.338
8.0-9.0	0.00	0.00	137.338
9.0-10.0	0.00	0.00	137.338
10.0-11.0	0.13	0.13	231.293
	0.08	0.08	79.6131

D.1.2. Run Two

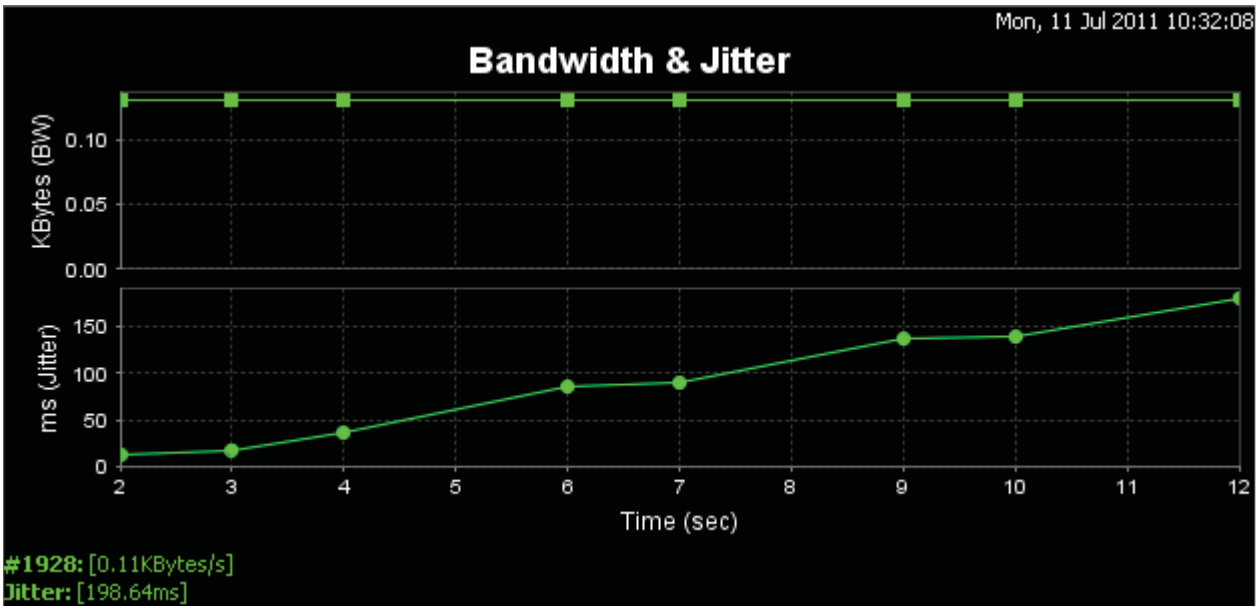

Figure D.3. Experiment Three-Two Graph

Table D.3. Experiment Three-Two Results

Interval (sec)	Transfer (Kbytes)	Bandwidth (Kbytes/sec)	Jitter (ms)
0.0-1.0	0.13	0.13	0.000
1.0-2.0	0.13	0.13	12.695
2.0-3.0	0.13	0.13	17.761
3.0-4.0	0.13	0.13	36.182
4.0-5.0	0.00	0.00	36.182
5.0-6.0	0.13	0.13	85.679
6.0-7.0	0.13	0.13	89.113
7.0-8.0	0.00	0.00	89.113
8.0-9.0	0.13	0.13	136.278
9.0-10.0	0.13	0.13	138.503
10.0-11.0	0.00	0.00	138.503
11.0-12.0	0.13	0.13	180.635
	0.10	0.10	80.0537

D.1.3. Run Three

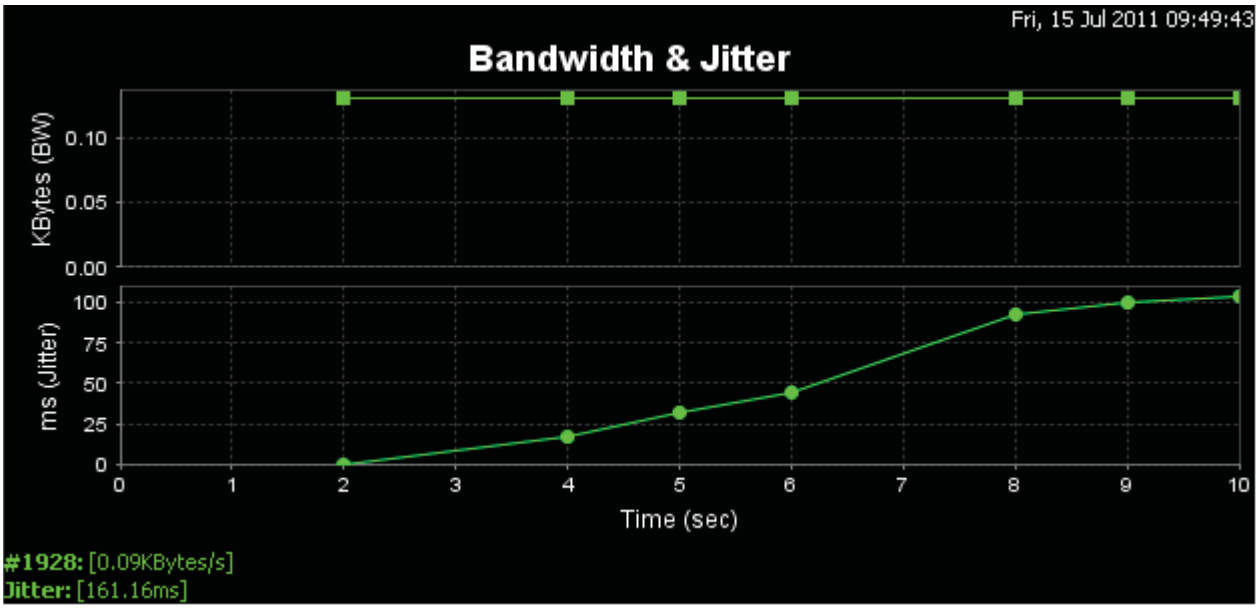

Figure D.4. Experiment Three-Three Graph

Table D.4. Experiment Three-Three Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.00	0.000
1.0-2.0	0.13	0.000
2.0-3.0	0.00	0.000
3.0-4.0	0.13	16.602
4.0-5.0	0.13	32.165
5.0-6.0	0.13	44.804
6.0-7.0	0.00	44.804
7.0-8.0	0.13	92.785
8.0-9.0	0.13	99.681
9.0-10.0	0.13	104.193
10.0-11.0	0.00	104.193
	0.08	49.02

D.1.4. Run Four

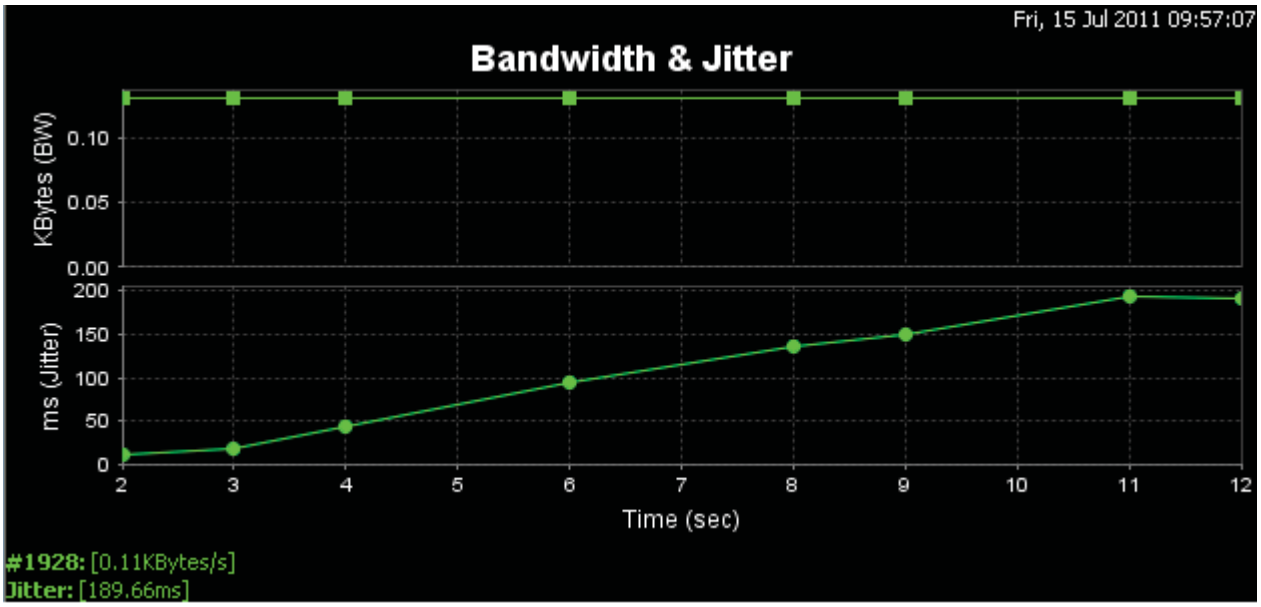

Figure D.5. Experiment Three-Four Graph

Table D.5. Experiment Three-Four Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.13	0.000
1.0-2.0	0.13	11.719
2.0-3.0	0.13	17.822
3.0-4.0	0.13	44.052
4.0-5.0	0.00	44.052
5.0-6.0	0.13	95.010
6.0-7.0	0.00	95.010
7.0-8.0	0.13	136.923
8.0-9.0	0.13	149.850
9.0-10.0	0.00	149.850
10.0-11.0	0.13	194.195
11.0-12.0	0.13	190.847
	0.10	94.11

D.1.5. Run Five

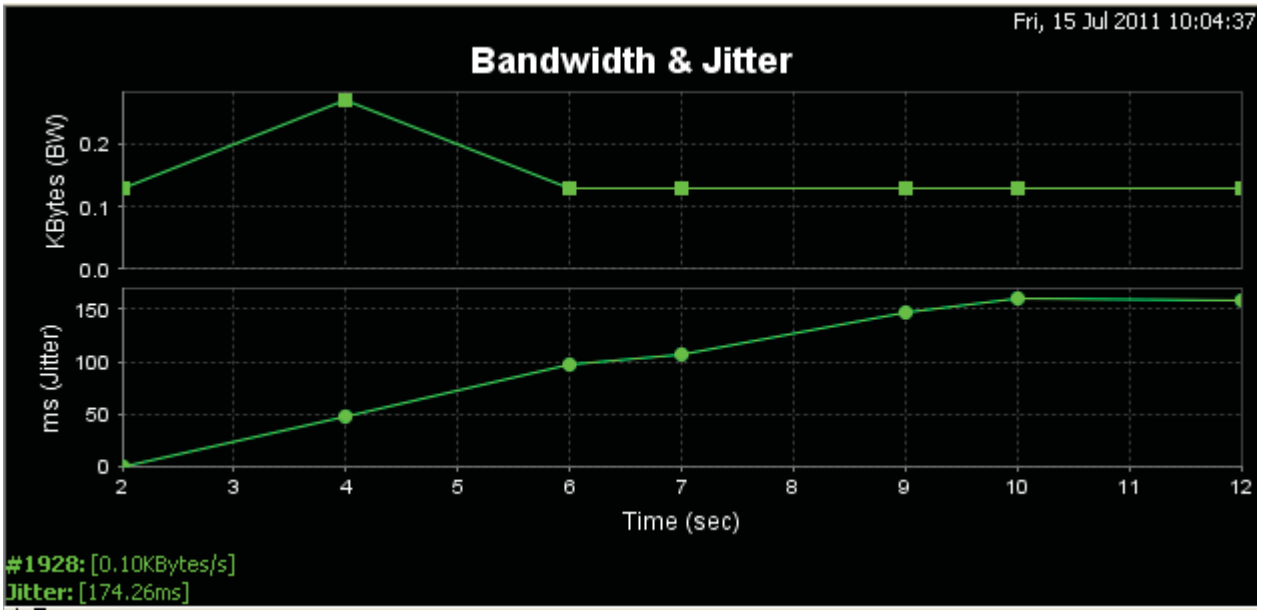

Figure D.6. Experiment Three-Five Graph

Table D.6. Experiment Three-Five Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.00	0.000
1.0-2.0	0.13	0.000
2.0-3.0	0.00	0.000
3.0-4.0	0.27	48.340
4.0-5.0	0.00	48.340
5.0-6.0	0.13	97.076
6.0-7.0	0.13	107.611
7.0-8.0	0.00	107.611
8.0-9.0	0.13	146.783
9.0-10.0	0.13	161.047
10.0-11.0	0.00	161.047
11.0-12.0	0.13	148.794
	0.09	85.55

D.1.6. Run Six

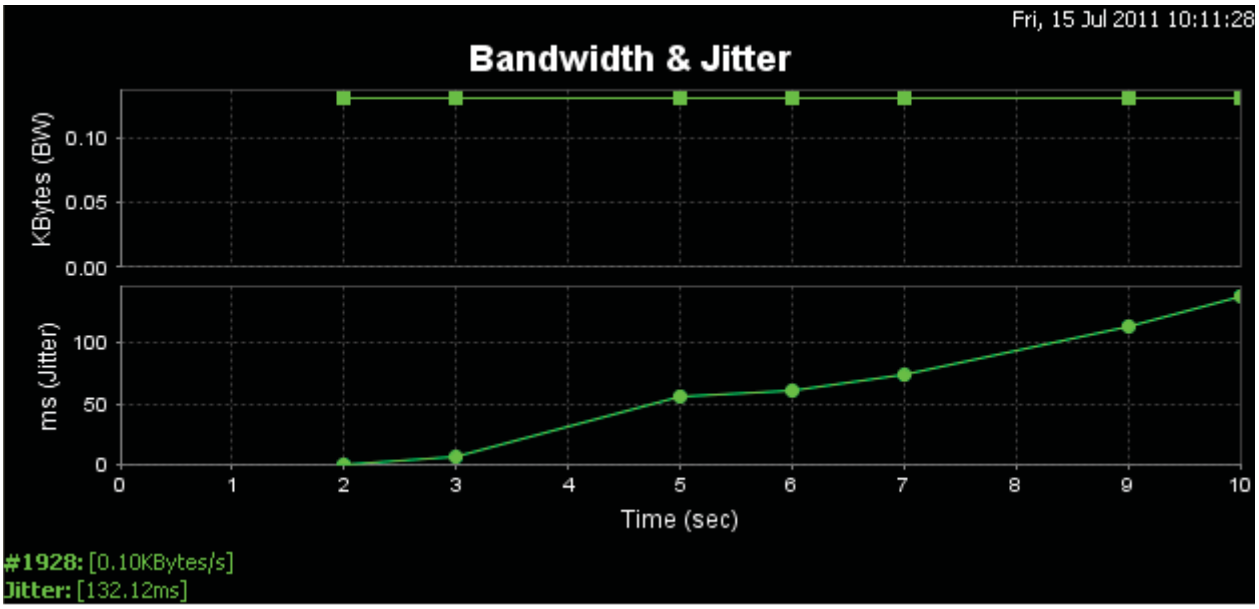

Figure D.7. Experiment Three-Six Graph

Table D.7. Experiment Three-Six Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.00	0.000
1.0-2.0	0.13	0.000
2.0-3.0	0.13	5.859
3.0-4.0	0.00	5.859
4.0-5.0	0.13	56.274
5.0-6.0	0.13	60.570
6.0-7.0	0.13	73.386
7.0-8.0	0.00	73.386
8.0-9.0	0.13	113.721
9.0-10.0	0.13	138.840
	0.09	52.790

D.1.7. Run Seven

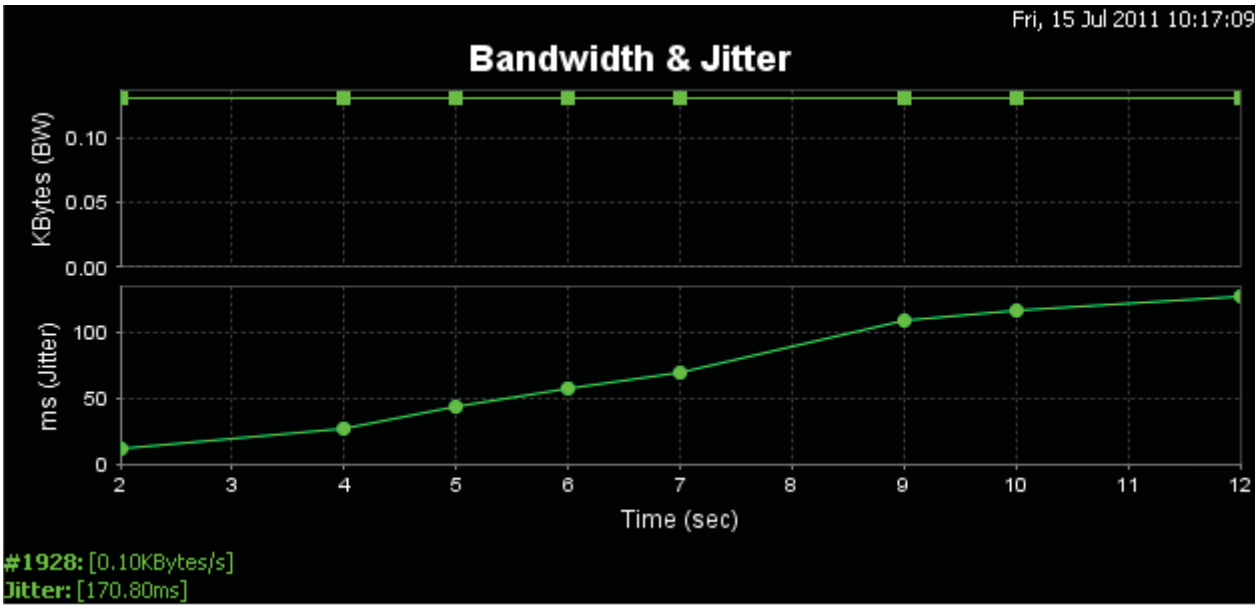

Figure D.8. Experiment Three-Seven Graph

Table D.8. Experiment Three-Seven Results

Interval (sec)	Transfer (Kbytes)	Jitter (ms)
0.0-1.0	0.13	0.000
1.0-2.0	0.13	11.719
2.0-3.0	0.00	11.719
3.0-4.0	0.13	27.588
4.0-5.0	0.13	43.442
5.0-6.0	0.13	58.305
6.0-7.0	0.13	69.309
7.0-8.0	0.00	69.309
8.0-9.0	0.13	108.923
9.0-10.0	0.13	116.763
10.0-11.0	0.00	116.763
11.0-12.0	0.13	128.020
12.0-13.0	0.00	128.02
	0.09	68.452

D.2. Router Configurations

D.2.1. Router 1

```
Current configuration : 1868 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R1
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R1_Router_ID
 ip address 10.0.1.1 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R1_e1/0-R2_e2/2
 ip address 10.0.0.1 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/1
 description R1_f1/1-R3_f1/1
```

```
 ip address 10.0.0.5 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/2
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.1
 log-adjacency-changes
 network 10.0.0.0 0.0.0.3 area 0
 network 10.0.0.4 0.0.0.3 area 0
 network 10.0.1.1 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.1
 bgp cluster-id 167772161
 bgp log-neighbor-changes
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.7 remote-as 65520
```

```
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 no auto-summary
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.2. Router 2

```
Current configuration : 1607 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R2
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 ip address 10.0.1.2 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/0
 description R2_e2/0-R6_e2/0
 ip address 10.0.0.13 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/1
 description R2_e2/1-R5_e1/0
 ip address 10.0.0.9 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
```

```
!
interface Ethernet2/2
 description R2_e2/2-R1_e1/0
 ip address 10.0.0.2 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet2/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.2
 log-adjacency-changes
 network 10.0.0.0 0.0.0.3 area 0
 network 10.0.0.8 0.0.0.3 area 0
 network 10.0.0.12 0.0.0.3 area 0
 network 10.0.1.2 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
!
```

```
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.3. Router 3

```
Current configuration : 1634 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R3
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R3_Router_ID
 ip address 10.0.1.3 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R3_e1/0-R4_e1/1
 ip address 10.0.0.17 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/1
 description R3_e1/1-R1_e1/1
 ip address 10.0.0.6 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
```

```
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/2
 description R3_e1/2-R7e2/0
 ip address 10.0.0.21 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.3
 log-adjacency-changes
 network 10.0.0.4 0.0.0.3 area 0
 network 10.0.0.16 0.0.0.3 area 0
 network 10.0.0.20 0.0.0.3 area 0
 network 10.0.1.3 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
!
```

```
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.4. Router 4

```
Current configuration : 1637 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R4
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R4_Router_ID
 ip address 10.0.1.4 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R4_e1/0-R6_e2/1
 ip address 10.0.0.25 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/1
 description R4_e1/1-R3_e1/0
 ip address 10.0.0.18 255.255.255.252
 duplex full
```

```
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/2
 description R4_e1/2-R8_e2/1
 ip address 10.0.0.29 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.4
 log-adjacency-changes
 network 10.0.0.16 0.0.0.3 area 0
 network 10.0.0.24 0.0.0.3 area 0
 network 10.0.0.28 0.0.0.3 area 0
 network 10.0.1.4 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
```

```
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.5. Router 5

```
Current configuration : 1636 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R5
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R5_Router_ID
 ip address 10.0.1.5 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/0
 description R5_e1/0-R2_e2/1
 ip address 10.0.0.10 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/1
 description R5_e1/1-R7_e2/1
 ip address 10.0.0.37 255.255.255.252
 duplex full
```

```
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000 1000
!
interface Ethernet1/2
 description R5_e1/2-R8_e2/0
 ip address 10.0.0.33 255.255.255.252
 duplex full
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet1/3
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/4
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/5
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/6
 no ip address
 shutdown
 duplex half
!
interface Ethernet1/7
 no ip address
 shutdown
 duplex half
!
router ospf 1
 router-id 10.0.1.5
 log-adjacency-changes
 network 10.0.0.8 0.0.0.3 area 0
 network 10.0.0.32 0.0.0.3 area 0
 network 10.0.0.36 0.0.0.3 area 0
 network 10.0.1.5 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip classless
no ip http server
!
!
!
dial-peer cor custom
!
```

```
!
!
!
gatekeeper
 shutdown
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.6. Router 6

```
Current configuration : 2602 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R6
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng tunnels
mpls traffic-eng reoptimize events link-up
!
no tag-switching ip
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R6_Router_ID
 ip address 10.0.1.6 255.255.255.255
!
interface Tunnel1
 ip unnumbered Loopback0
 tunnel destination 10.0.1.8
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 0 0
 tunnel mpls traffic-eng bandwidth sub-pool 1000
 tunnel mpls traffic-eng path-option 1 dynamic
!
interface Tunnel2
 ip unnumbered Loopback0
 tunnel destination 10.0.1.8
```

```
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth 5000
 tunnel mpls traffic-eng path-option 1 dynamic
!
interface Tunnel3
 ip unnumbered Loopback0
 tunnel destination 10.0.1.7
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth 5000
 tunnel mpls traffic-eng path-option 1 dynamic
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface Ethernet2/0
 description R6_e2/0-R2_e2/0
 ip address 10.0.0.14 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/1
 description R6_e2/1-R4_e1/0
 ip address 10.0.0.26 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/2
 description R6_e2/2-R9_e1/0
 ip address 10.0.0.41 255.255.255.252
 load-interval 30
 full-duplex
!
interface Ethernet2/3
 no ip address
 shutdown
 half-duplex
!
```

```
router ospf 1
 router-id 10.0.1.6
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.12 0.0.0.3 area 0
 network 10.0.0.24 0.0.0.3 area 0
 network 10.0.1.6 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.6
 bgp log-neighbor-changes
 neighbor 10.0.0.42 remote-as 65521
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.7 next-hop-self
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 neighbor 10.0.1.8 next-hop-self
 no auto-summary
!
ip classless
ip route 192.168.2.0 255.255.255.128 Tunnel1
ip route 192.168.2.128 255.255.255.128 Tunnel2
ip route 192.168.3.0 255.255.255.0 Tunnel3
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.7. Router 7

```
Current configuration : 2565 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R7
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R7_Router_ID
 ip address 10.0.1.7 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface Ethernet2/0
 description R7_d2/0-R3_e1/2
 ip address 10.0.0.22 255.255.255.252
```

```
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/1
 description R7_e2/1-R5_e1/1
 ip address 10.0.0.38 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/2
 description R7_e2/2-R11_e1/0
 ip address 10.0.0.45 255.255.255.252
 full-duplex
!
interface Ethernet2/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.7
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.20 0.0.0.3 area 0
 network 10.0.0.36 0.0.0.3 area 0
 network 10.0.1.7 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.7
 bgp log-neighbor-changes
 neighbor 10.0.0.46 remote-as 65523
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.6 next-hop-self
 neighbor 10.0.1.8 remote-as 65520
 neighbor 10.0.1.8 update-source Loopback0
 neighbor 10.0.1.8 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
!
!
```

```
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.8. Router 8

```
Current configuration : 2620 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R8
!
!
ip subnet-zero
!
!
!
ip cef
ip audit notify log
ip audit po max-events 100
mpls traffic-eng reoptimize events link-up
!
call rsvp-sync
!
!
!
!
!
fax interface-type fax-mail
mta receive maximum-recipients 0
!
!
!
interface Loopback0
 description R8_Router_ID
 ip address 10.0.1.8 255.255.255.255
!
interface FastEthernet0/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface Ethernet2/0
 description R8_e2/0-R5_e1/2
 ip address 10.0.0.34 255.255.255.252
```

```
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/1
 description R8_e2/1-R4_e1/2
 ip address 10.0.0.30 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/2
 description R8_e2/2-R10_e1/0
 ip address 10.0.0.49 255.255.255.252
 full-duplex
 mpls traffic-eng tunnels
 ip rsvp bandwidth 10000 sub-pool 1000
!
interface Ethernet2/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.8
 log-adjacency-changes
 redistribute bgp 65520 subnets
 network 10.0.0.28 0.0.0.3 area 0
 network 10.0.0.32 0.0.0.3 area 0
 network 10.0.1.8 0.0.0.0 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
router bgp 65520
 no synchronization
 bgp router-id 10.0.1.8
 bgp log-neighbor-changes
 neighbor 10.0.0.50 remote-as 65522
 neighbor 10.0.1.1 remote-as 65520
 neighbor 10.0.1.1 update-source Loopback0
 neighbor 10.0.1.1 next-hop-self
 neighbor 10.0.1.6 remote-as 65520
 neighbor 10.0.1.6 update-source Loopback0
 neighbor 10.0.1.6 next-hop-self
 neighbor 10.0.1.7 remote-as 65520
 neighbor 10.0.1.7 update-source Loopback0
 neighbor 10.0.1.7 next-hop-self
 no auto-summary
!
ip classless
ip http server
!
```

```
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```

D.2.9. Router 9

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R9
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R9_Router_ID
 ip address 10.0.1.9 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.1.1 255.255.255.0
 full-duplex
!
interface Ethernet1/0
 description R9_e1/0-R6_e2/2
 ip address 10.0.0.42 255.255.255.252
 full-duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
 router-id 10.0.1.9
 log-adjacency-changes
 network 192.168.1.0 0.0.0.255 area 0
!
```

```
router bgp 65521
 no synchronization
 bgp router-id 10.0.1.9
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.41 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.41
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

D.2.10. Router 10

```
Current configuration : 937 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R10
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R10_Router_ID
 ip address 10.0.1.10 255.255.255.255
!
interface Ethernet0/0
 ip address 192.168.2.1 255.255.255.128
 full-duplex
!
interface Ethernet1/0
 description R10_e1/0-R8_e2/2
 ip address 10.0.0.50 255.255.255.252
 full-duplex
!
interface Ethernet2/0
 ip address 192.168.2.129 255.255.255.128
 full-duplex
!
interface Serial0/1
 no ip address
 shutdown
!
router ospf 1
```

```
 router-id 10.0.1.10
 log-adjacency-changes
 network 192.168.2.0 0.0.0.128 area 0
 network 192.168.2.128 0.0.0.128 area 0
!
router bgp 65522
 no synchronization
 bgp router-id 10.0.1.10
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.49 remote-as 65520
!
ip classless
ip http server
!
!
ip route 0.0.0.0 0.0.0.0 10.0.0.49
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
!
end
```

D.2.11. Router 11

```
Current configuration : 1256 bytes
!
version 12.2
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname R11
!
!
memory-size iomem 15
ip subnet-zero
!
!
!
ip audit notify log
ip audit po max-events 100
!
call rsvp-sync
!
!
!
!
!
!
!
!
interface Loopback0
 description R11_Router_ID
 ip address 10.0.1.11 255.255.255.255
!
interface Ethernet0/0
 description R11_e0/0-R7_e2/2
 ip address 10.0.0.46 255.255.255.252
 full-duplex
!
interface Serial0/0
 no ip address
 shutdown
!
interface Serial0/1
 no ip address
 shutdown
!
interface Ethernet1/0
 description Customer_Site_3
 ip address 192.168.3.1 255.255.255.0
 full-duplex
!
```

```
interface Ethernet1/1
 no ip address
 shutdown
 half-duplex
!
interface Ethernet1/2
 no ip address
 shutdown
 half-duplex
!
interface Ethernet1/3
 no ip address
 shutdown
 half-duplex
!
router ospf 1
 router-id 10.0.1.11
 log-adjacency-changes
 network 192.168.3.0 0.0.0.255 area 0
!
router bgp 65523
 no synchronization
 bgp router-id 10.0.1.11
 bgp log-neighbor-changes
 redistribute ospf 1 match internal external 1 external 2
 neighbor 10.0.0.45 remote-as 65520
!
ip classless
ip route 0.0.0.0 0.0.0.0 10.0.0.45
ip http server
!
!
!
dial-peer cor custom
!
!
!
!
!
line con 0
line aux 0
line vty 0 4
 login
!
end
```