WHITE PAPER

NETFLOW PERFORMANCE ANALYSIS

INTRODUCTION

The Cisco IOS® NetFlow feature set allows for the tracking of individual IP flows as they are received at a Cisco router or switching device. Network administrators can use the NetFlow flow records for a variety of purposes, including accounting, billing, network planning, traffic engineering, and user or application monitoring.

NetFlow services are available on Cisco IOS Software-based routers including Cisco 800 thru 7500 Series Routers, as well as the Cisco Catalyst® 6500 Series Switch, Cisco 7600, 10000, 12000 Series Routers and CRS-1 devices.

For more details on NetFlow, refer to the "NetFlow Services Solutions Guide" white paper at http://www.cisco.com/univercd/cc/td/doc/cisintwk/intsolns/netflsol/nfwhite.htm.

Although many Cisco customers want to deploy NetFlow services, they are naturally cautious about introducing new technology into their network without completely understanding the potential performance impact. This paper examines the CPU impact of enabling NetFlow services in several different scenarios and on several different Cisco hardware platforms.

This information is valuable for planning potential NetFlow implementations, but these results are not a replacement for proper customer lab testing, pilot deployments, and other types of solution validation.

TESTING METHODOLOGY

All tests were performed using Cisco IOS Software Release 12.0S. The platforms and configurations tested include:

- Cisco 2600 Router
- Cisco 2851 Router
- Cisco 3640 Router
- Cisco 3745 Router
- Cisco 3845 Router
- Cisco 7200 Router with Network Processing Engine NPE-300
- Cisco 7200 Router with Network Processing Engine NPE-400
- Cisco 7200 Router with Network Services Engine NSE-1
- Cisco 7500 Router with Route Switch Processor 8 using Cisco Express Forwarding
- Cisco 7500 Router with Route Switch Processor 8 using Distributed Cisco Express Forwarding
- Cisco 12000 Internet Router running Distributed Cisco Express Forwarding (Engine 1)
- Cisco 12000 Internet Router running Distributed Cisco Express Forwarding, with 1:100 sampling enabled

Ten test cases were defined and not all are run on all the platforms listed. The test cases are documented below. A mnemonic has been assigned to each test case to make it easier to understand the charts and graphs in the "Test Results" and "Test Analysis" sections of this document. Table 1 describes the test cases.

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Table 1. NetFlow Test Cases

Mnemonic	Test Description
Baseline	Baseline test without NetFlow enabled; provides a context for the tests that follow
Nf-load	Statistics generated immediately after NetFlow services are enabled on the router; tests any unusual initialization requirements of NetFlow
Nf-enable	NetFlow Version 5 enabled but no export destination defined; documents the effects of NetFlow on the router itself
Nf-NDE	NetFlow Version 5 enabled and NetFlow data export (NDE) destination also defined; tests the effects of NDE on the router
Nf-NDE-2	NetFlow Version 5 enabled and two different NDE destinations also defined; tests the effects of NDE with multiple destinations on the router
v9-NDE1	NetFlow Version 9 enabled and NetFlow data export (NDE) destination also defined; tests the effects of NDE on the router
v9-NDE2	NetFlow Version 9 enabled and two different NDE destinations also defined; tests the effects of NDE with multiple destinations on the router
Nf-NDE-AS	NetFlow Version 5 enabled and recording autonomous-system origin of packets; NDE destination also defined; used to test the effects of maintaining information about autonomous systems with NetFlow
NF-Prefix-V8	NetFlow configured with a Version 8 prefix aggregation scheme (but no NDE); compare results with NetFlow Version 5
NF-AS-V8-NDE	NetFlow configured with a Version 8 autonomous system aggregation scheme and NDE; compare results with NetFlow v5
NF-AS-TOS	NetFlow configured with a Version 8 autonomous system- type of service (ToS) aggregation scheme and NDE; compare results with NetFlow Version 5

Each test case was performed with three different IP flow rates: 10,000, 45,000, and 65,000 flows (this represents the number of unique IP flows that were seen by the router for each test). For some platforms 70K flows were tested instead of 65k flows. The flows were sent in a loop, so that the NetFlow cache was populated by the first iteration of the traffic stream and used for switching the packets on subsequent iterations.

To ensure accuracy of the results and to eliminate any anomalies, output of the tests was not collected until NetFlow had been running for ten minutes (the Nf-load test case was the exception to this rule). Six samples of output were taken at one-minute intervals following that. The numbers presented in the “Test Results” portion of this document represent the average of those results.

Note that the testing provided a “worst-case scenario” in terms of the traffic flows seen by the routers, and the results must be viewed in that context.

- All packet sizes were 64 bytes, a scenario that tends to be more stressful on a router than a mixed traffic stream of various sizes.
- At each flow rate, there was no duplication of flows until the test began its second iteration through the testing loop.

TEST RESULTS

This section presents the results of the test cases described in the previous section. Interpretations and conclusions to be drawn from the data are discussed in the “Test Analysis and Conclusions” section of this document.

The results are presented in raw, tabular format, so that readers will have all available information, and can utilize the numbers to extrapolate the results into their own environment.

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CPU Load Results

Tables 2 through 7 give results from the CPU utilization tests.

Table 2. CPU Utilization---Cisco 2600 Series

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	16	16	16
Nf-load	25	42	49
Nf-enable	35	62	68
Nf-NDE	39	64	69
Nf-NDE-2	39	64	70
Nf-NDE-AS	39	64	70
NF-Prefix-V8	40	63	70
NF-AS-V8-NDE	40	63	70
NF-AS-TOS	40	65	70

Table 3. CPU Utilization---Cisco 2851 Router

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	10	22	25
v5, NDE 1	14	36	48
v5, NDE 2	13	36	49
v9, NDE1	15	33	48
v9, NDE2	14	37	60

Table 4. CPU Utilization---Cisco 3640 Router

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	6	3	7
Nf-load	9	13	15
Nf-enable	16	33	39
Nf-NDE	17	33	40
Nf-NDE-2	17	35	39

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Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Nf-NDE-AS	17	33	39
NF-Prefix-V8	20	35	41
NF-AS-V8-NDE	19	33	41
NF-AS-TOS	17	33	42

Table 5. CPU Utilization---Cisco 3745 Router

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	10	23	28
v5, NDE 1	14	35	47
v5, NDE 2	14	35	51
v9, NDE1	14	35	49
v9, NDE2	15	37	60

Table 6. CPU Utilization---Cisco 3845 Router

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	7	11	13
v5, NDE 1	10	19	24
v5, NDE 2	10	19	25
v9, NDE1	10	19	25
v9, NDE2	10	20	33

Table 7. Cisco 7200 NSE-1---CPU Utilization

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	6	8	12
Nf-load	9	19	26
Nf-enable	9	19	27
Nf-NDE	9	19	26
Nf-NDE-2	9	19	27
Nf-NDE-AS	9	19	27

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Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
NF-Prefix-V8	9	19	27
NF-AS-V8-NDE	9	19	26
NF-AS-TOS	9	19	27

Table 8. CPU Utilization---Cisco 7200 NPE 300

Mnemonic	10,000 Flows	45,000 Flows	70,000 Flows
Baseline	11	27	35
v5, NDE 1	18	35	38
v5, NDE 2	16	35	43
v9, NDE1	17	37	40
v9, NDE2	16	27	35

Table 9. CPU Utilization---Cisco 7200 with NPE-400

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	8	18	22
v5, NDE 1	8	20	24
v5, NDE 2	7	18	23
v9, NDE1	10	20	24
v9, NDE2	8	18	22

Table 10. CPU Utilization---Cisco 7500---RSP8---Cisco Express Forwarding

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	2	3	5
Nf-load	5	15	21
Nf-enable	5	15	22
Nf-NDE	5	16	22
Nf-NDE-2	5	16	22
Nf-NDE-AS	5	16	22
NF-Prefix-V8	6	15	23

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Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
NF-AS-V8-NDE	6	15	22
NF-AS-TOS	6	16	22

Table 11. CPU Utilization---Cisco 7500---RSP8---Distributed Cisco Express Forwarding

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	6	9	15
Nf-load	9	20	28
Nf-enable	9	20	28
Nf-NDE	9	20	28
Nf-NDE-2	9	20	28
Nf-NDE-AS	9	19	28
NF-Prefix-V8	9	20	29
NF-AS-V8-NDE	9	20	28
NF-AS-TOS	9	20	28

Note: Because Distributed Cisco Express Forwarding was employed in this test, the CPU utilization numbers were collected on the Versatile Interface Processors (VIPs), not the main CPU.

Table 12. CPU Utilization---Cisco 12000---Distributed Cisco Express Forwarding

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	7	8	11
Nf-load	12	23	30
Nf-enable	12	23	31
Nf-NDE	12	24	31
Nf-NDE-2	12	23	31
Nf-NDE-AS	12	24	31
NF-Prefix-V8	12	25	32
NF-AS-V8-NDE	12	23	31
NF-AS-TOS	12	23	31

Note: Because Distributed Cisco Express Forwarding was employed in this test, the CPU utilization numbers were collected on the line cards, not the main CPU.

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Table 13. CPU Utilization---Cisco 12000 Distributed Cisco Express Forwarding---1:100 Sampling

Mnemonic	10,000 Flows	45,000 Flows	65,000 Flows
Baseline	7	8	11
Nf-load	9	12	14
Nf-enable	9	12	14
Nf-NDE	9	12	14
Nf-NDE-2	9	12	14
Nf-NDE-AS	9	12	14
NF-Prefix-V8	9	12	14
NF-AS-V8-NDE	9	12	15
NF-AS-TOS	9	12	14

Note: As above, because Distributed Cisco Express Forwarding was employed in this test, the CPU utilization numbers were collected on the line cards, not the main CPU.

TEST ANALYSIS AND CONCLUSIONS

NetFlow CPU Utilization Versus Baseline

As mentioned in the introduction, customers need to understand the potential performance impact of enabling NetFlow before they are willing to deploy it. The first series of charts in this section examines test cases and illustrates the effect of NetFlow on CPU utilization.

In terms of additional CPU utilization (over and above the baseline), a few trends can easily be discerned. As the number of flows increases, the delta between the baseline and NetFlow-enabled CPU utilization widens. In other words, the more IP flows present, the more system resources NetFlow requires. Although these results were expected, they confirm the accuracy of the expectation. The more active flows NetFlow is maintaining in its cache, the larger the cache becomes and the more CPU it requires to sort through the cache.

Note that, in the Figures below CPU utilization does not seem to vary greatly, depending on the particular NetFlow features that are enabled. Neither the recording of autonomous-system numbers nor the addition of NetFlow data export (even to multiple destinations) makes a large impact on overall CPU utilization. Not surprisingly, the Cisco 2600 Router seems to vary the most in this regard.

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Figure 1. Cisco 2600 Router

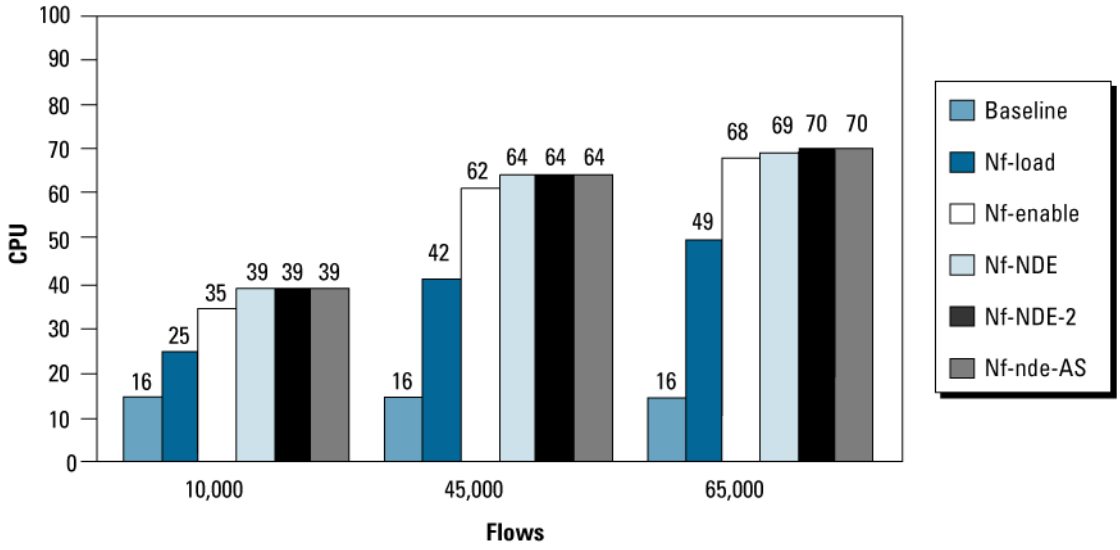

Figure 2. Cisco 2851 Router

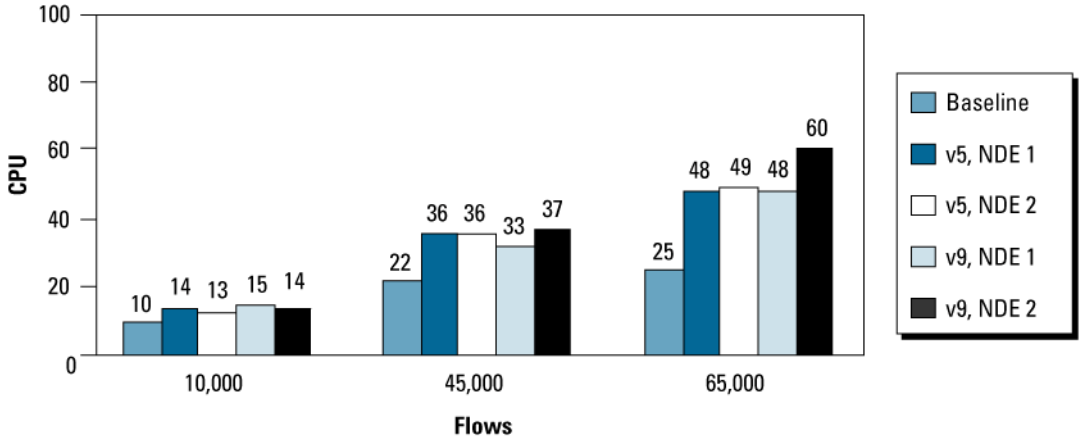

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Figure 3. Cisco 3640

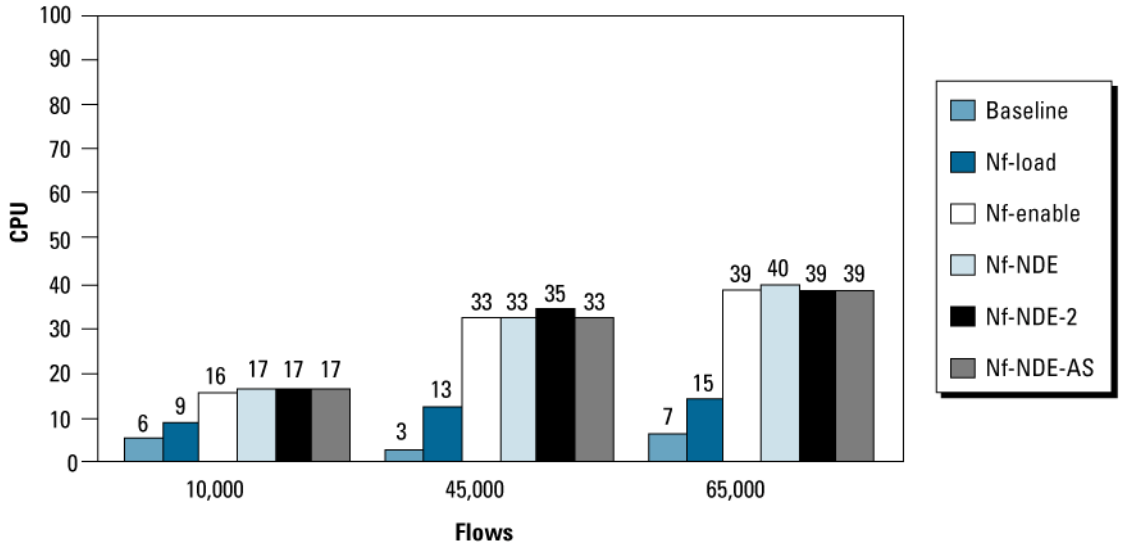

Figure 4. Cisco 3745

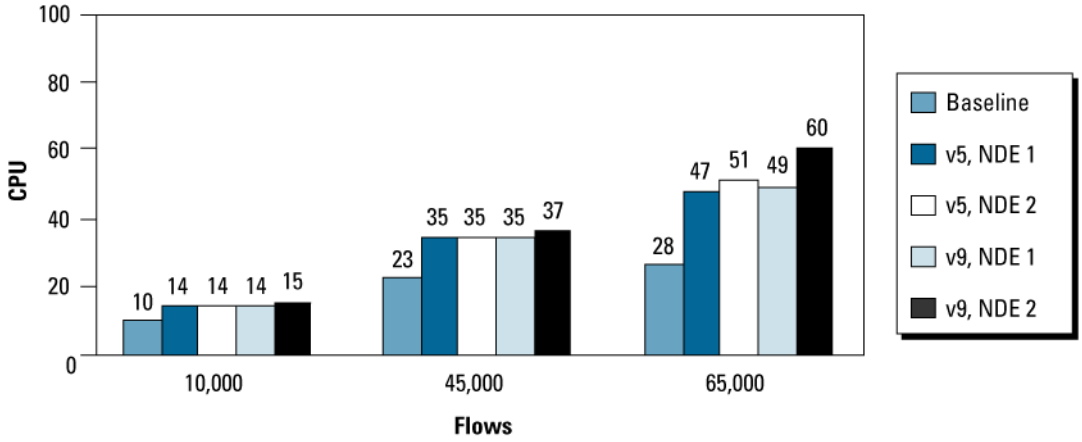

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Figure 5. Cisco 3845

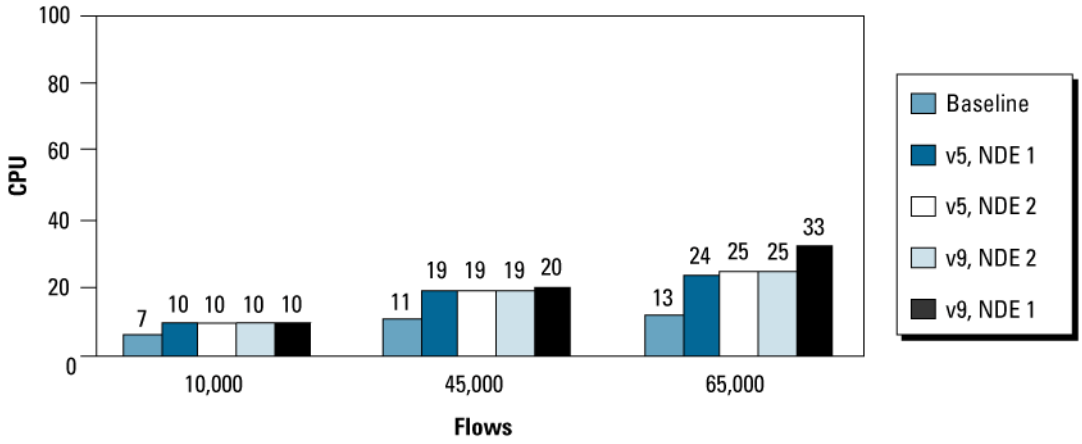

Figure 6. Cisco 7200 NPE 400---CPU Utilization

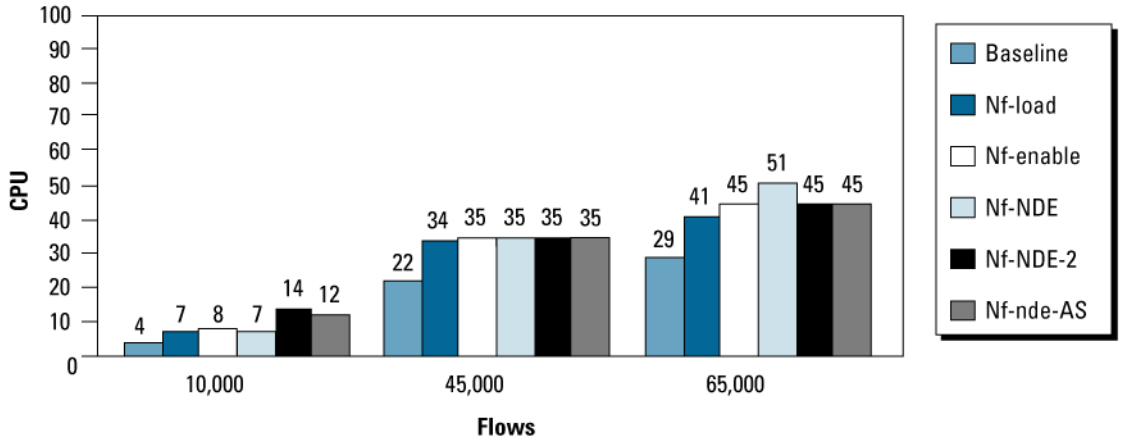

Figure 7. Cisco 7200 NSE-1---CPU Utilization

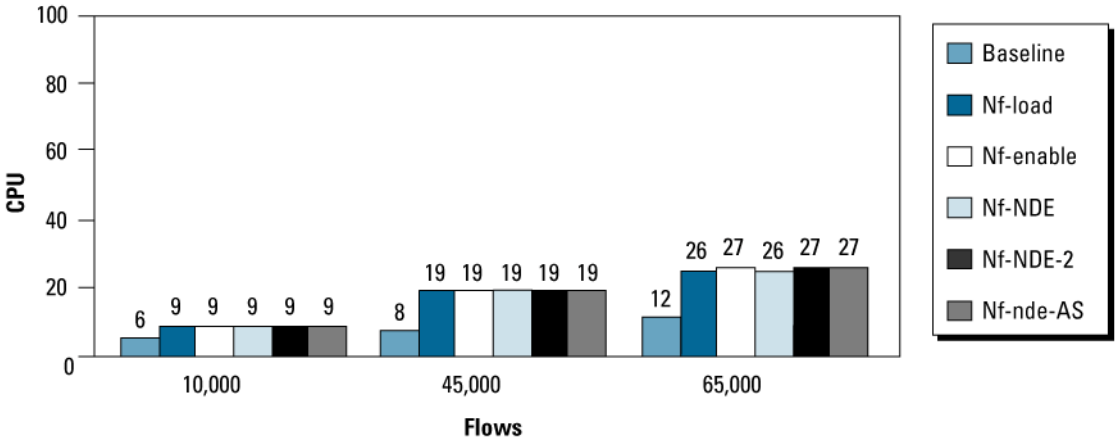

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Figure 8. Cisco 7200 NPE-300---CPU Utilization

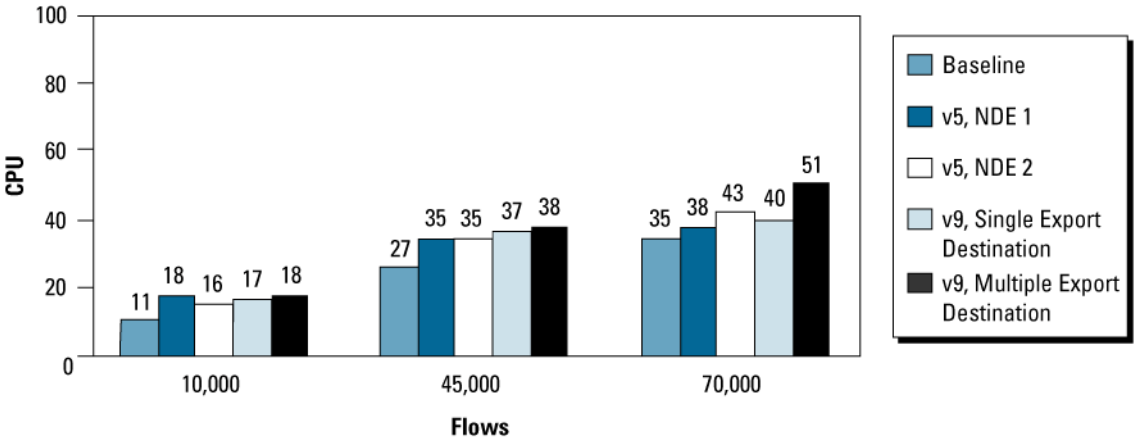

Figure 9. Cisco 7200 NPE-400---CPU Utilization

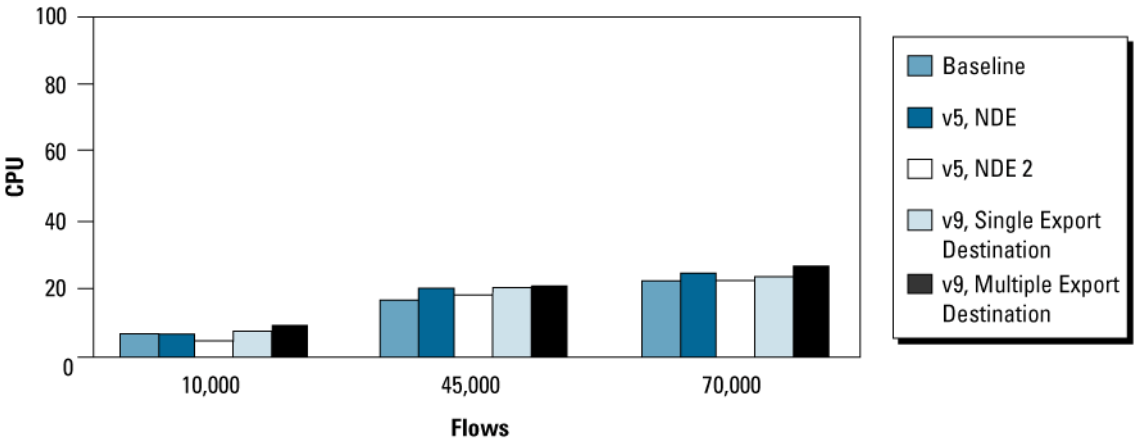

Figure 10. Cisco 7500 RSP8 Cisco Express Forwarding---CPU Utilization

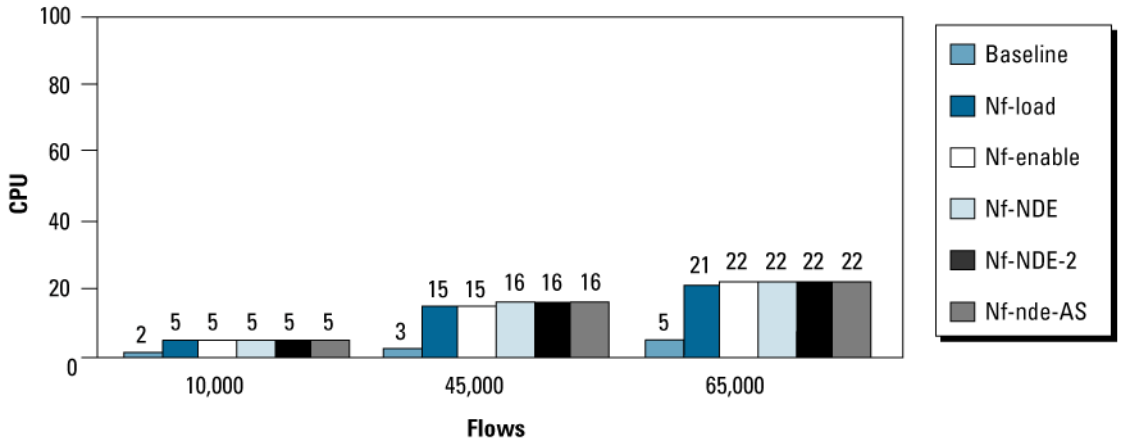

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Figure 11. Cisco 7500 RSP 8 Distributed Cisco Express Forwarding---CPU Utilization

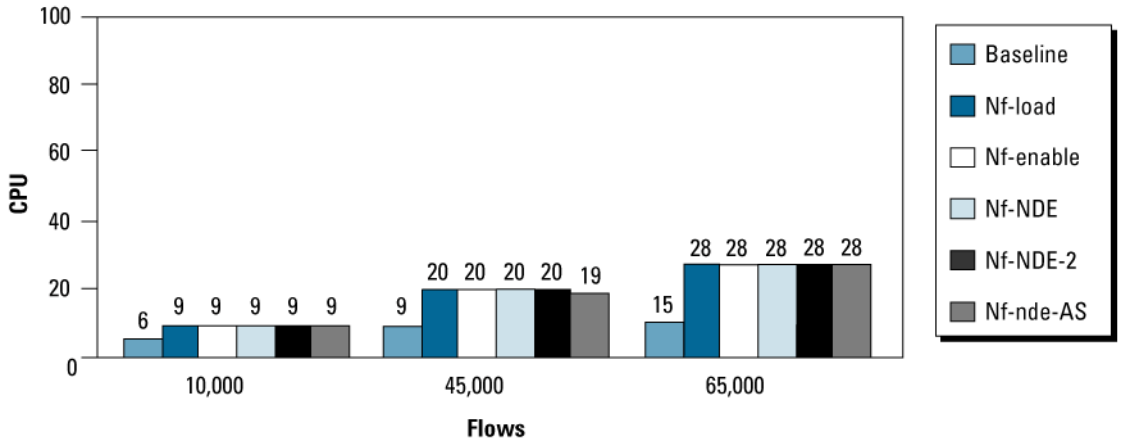


Figure 12. Cisco 12000 Distributed Cisco Express Forwarding---CPU Utilization

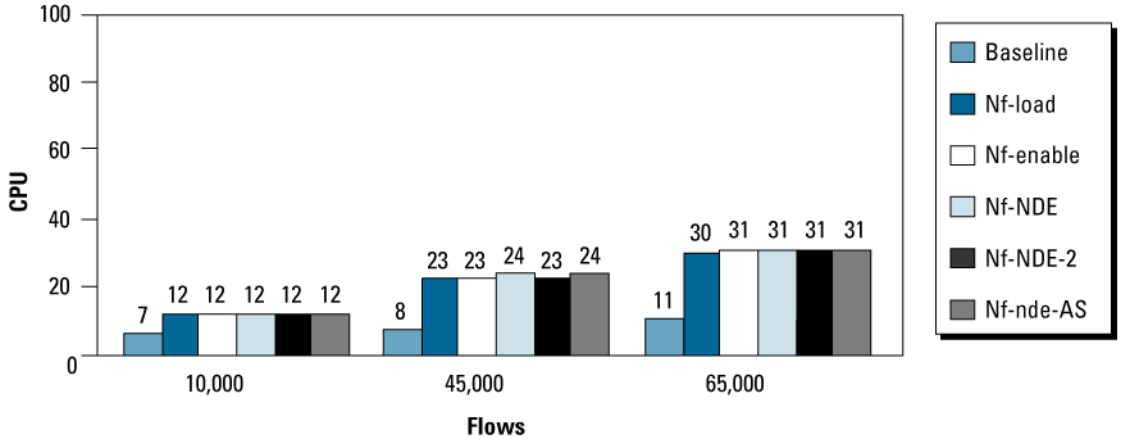
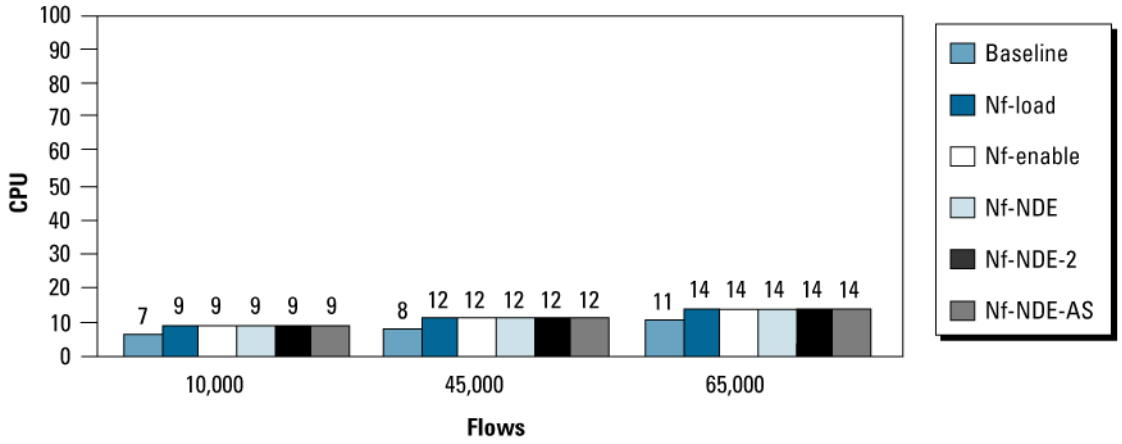


Figure 13. Cisco 12000---Distributed Cisco Express Forwarding with 1:100 Sampling---CPU Utilization



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Using Sampled NetFlow

Packet sampling is available on all Cisco IOS Software supported NetFlow platforms except the Cisco Catalyst 4500 Series Switch. Random packet sampling is available on all software based Cisco. The Cisco Catalyst 6500 Series Switch can utilize both random flow sampling and time based flow sampling techniques. Packet sampling was introduced on software based platforms in Releases 12.0(26)S, 12.2S(18), and 12.3(2)T in the Cisco Catalyst 6500 Series Switch in Release 12.1(13)E1 and above. The GSR supports NetFlow deterministic sampling since Release 12.0(11)S.

There are two sampling techniques packet sampling and flow sampling. In packet sampling only a subset of the total packets switched in the box are used to create flows in the NetFlow cache. Many customers utilize one in one hundred or one in one thousand packet with packet sampling and this is optimum for capacity planning. When 1:100 packets are sampled then approximately 80% of the flows will be created in the NetFlow cache. This obviously reduces the number of flows created and exported decreasing CPU utilization and export traffic volumes.

The Cisco Catalyst 6500 Series Switch uses flow sampling where a subset of the total flows in the NetFlow cache are exported to the collector and again this saves on CPU utilization and export traffic volume. The following table outlines CPU decrease possible with packet sampling on a Cisco 7500 Router. This table is provided as a guideline to how sampling can reduce CPU utilization. The reduction of CPU utilization is dramatic when packet sampling is implemented.

Table 14. CPU Utilization and Sampling Rate for 7505

Sampling Rate	Average % Decrease in CPU
1:100	75
1:1000	82

The Cisco 12000 Series Router can make most forwarding decisions directly in the hardware on the line cards and, can achieve very high levels of packet throughput.

When enabling NetFlow on the Cisco 12000 Series Router, the hardware forwarding mechanism is bypassed, and packet-forwarding decisions are made in software.. This caveat is relevant only on line cards on the Cisco 12000 Series Router that utilize a software-based version of NetFlow (Engine 0, 1). Cisco 12000 Engine 2, 3, 4+ and 5 line cards have NetFlow implemented on a hardware application-specific integrated circuit (ASIC), so they can switch NetFlow packets at or near line rate. In addition, because all this occurs in hardware, there is no performance penalty on the CPU of the line card.

When using a software-based NetFlow implementation on the Cisco 12000 Series Router, sampled NetFlow is recommended. The sampled NetFlow feature allows the router to sample one out of “x” IP packets being forwarded. Sampled packets are accounted for in the router NetFlow flow cache. Sampling packets substantially decrease the CPU utilization for NetFlow packets, allowing most packets to be switched faster without additional NetFlow processing.

Although the use of sampled NetFlow on the Cisco 12000 Series Router has always been strongly encouraged, this testing makes the benefits quite clear. Figure 14 illustrates that with a sampling rate of 1:100 (that is, one out of every 100 packets is sampled to give a representative picture of the data), the increase in CPU utilization is negligible. This result can be contrasted with cases in which nonsampled NetFlow was enabled, and the impact on CPU is significant.

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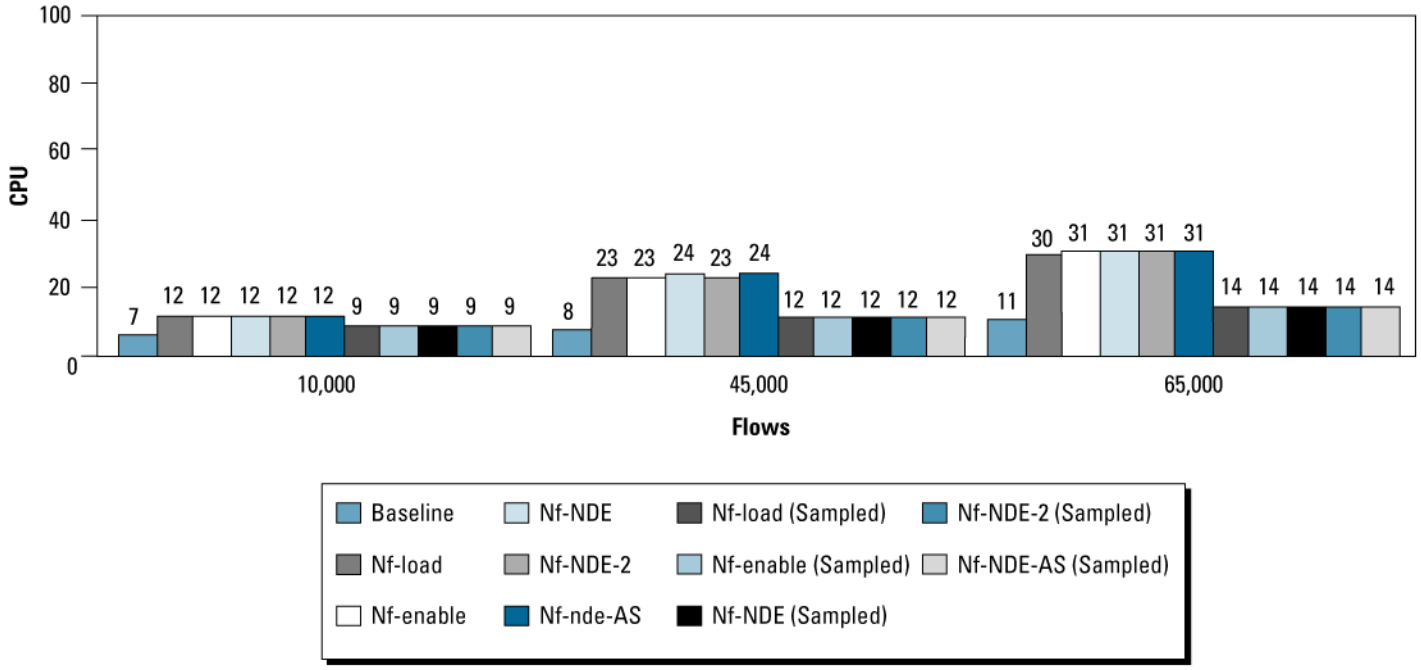
Figure 14. Cisco 12000---Sampled vs. Nonsampled NetFlow



Note that sampled NetFlow does not provide the level of granularity that "full-flow" NetFlow does. Thus, the user must always attempt to strike a balance between granularity and performance. The configurable sampling rate can be used to help achieve that balance.

Additional CPU Requirements for Running NetFlow

Figure 15 breaks out the amount of additional CPU above the baseline by platform. The numbers were obtained by averaging the results in tests, and then subtracting the result of the baseline utilization.

Software based platforms benefit from sampling with large reductions in CPU as shown in Table 14. The Cisco 12000 Series Router with 1:100 sampling is the clear winner here, averaging only 3 percent excess CPU utilization when enabling sampled NetFlow. However, as mentioned in the previous section, there is a resulting loss of granularity when sampling.

Among the non-sampled platforms, the Cisco 7500 Series Router with Distributed Cisco Express Forwarding does the best, using only 13 percent additional CPU when tracking 65,000 IP flows. The following results do not include Cisco 7200 NPE300, 2800, 3700 or 3800 Series Routers.

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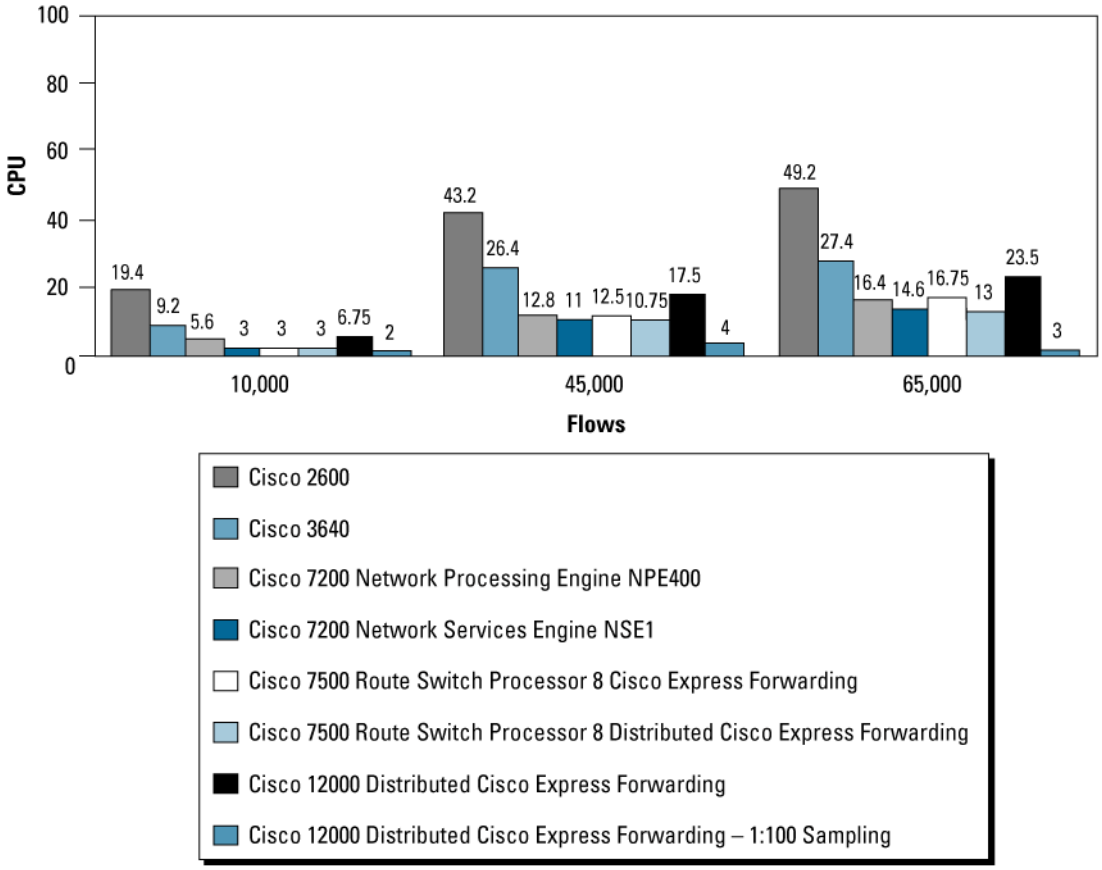
Figure 15. NetFlow CPU Utilization by Platform



Trying to provide some reasonable expectations for CPU utilization when enabling NetFlow is a complex task. With the Cisco 12000 Series Router, clearly the numbers will vary according to the sampling rate selected.

Averaging the results across the different (nonsampled) platforms yields some reasonable expectations for the impact of enabling NetFlow:

- With ~10,000 active flows: 7.14 percentage points of additional CPU utilization
- With ~45,000 active flows: 19.16 percentage points of additional CPU utilization
- With ~65,000 active flows: 22.98 percentage points of additional CPU utilization

The following methodology was used to obtain these averages:

- First, the Cisco 12000 Series Router numbers (both sampled and nonsampled) are an anomaly, because they depend so much on the sampling rate. Therefore, these numbers were not used in calculating the average.
- There is not a significant CPU difference caused by enabling any particular set of NetFlow features. This observation results in the average CPU per platform in Figure 15.
- This average obtained tends to obscure differences between platforms. However, the testing tends to confirm that the most relevant factor in determining additional CPU utilization is the flow rate, where the difference is much more significant than the platform differences.
- On the other hand, the numbers obtained are an average of an average (of numbers which, themselves, are averages). These numbers are provided as an approximation of additional CPU utilization. Individual platform results may vary.

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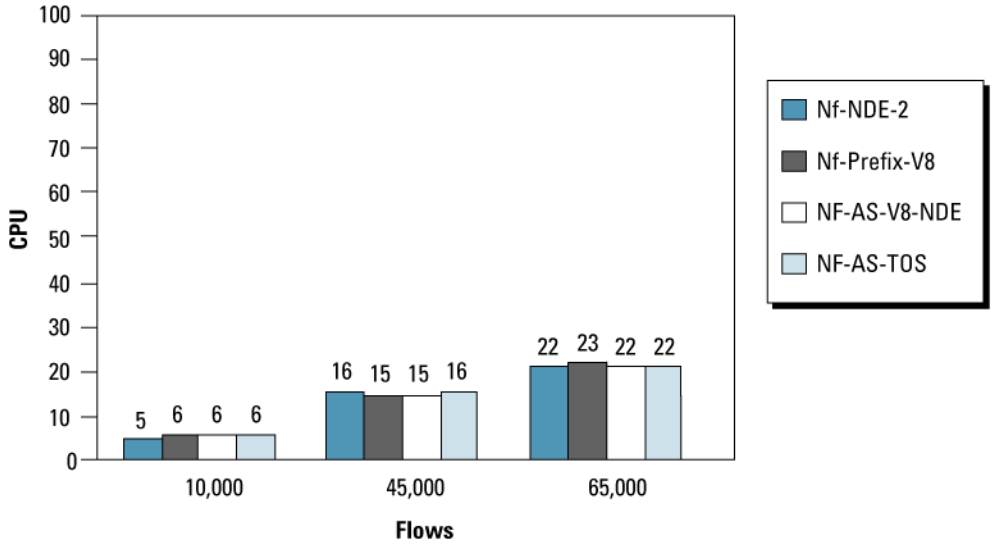
NetFlow version 5 versus NetFlow Version 8

This testing also helped provide some insight into a frequently asked question about NetFlow. For some reason, Version 8 of NetFlow has developed the reputation that it is more CPU intensive than NetFlow Version 5. Because NetFlow version 8 supports aggregation schemes, this reputation may have grown out of the assumption that aggregating data is causing the router to "work harder."

The testing does not bear out this assumption. As illustrated in Figure 16, there is minimal to no impact in turning on Version 8 aggregation schemes, as compared to the same router running NetFlow Version 5. Although the Cisco 7500 Series Router was used to demonstrate this point, the results are typical of the results across all tested platforms.

Figure 16. Cisco 7500 RSP 8 Cisco Express Forwarding---Version 5 vs. Version 8



NetFlow Version 5 Versus NetFlow Version 9

This testing also helped provide some insight into a frequently asked question about NetFlow and compares NetFlow version 5 with version 9. The Cisco 7200 Series Router is used for the results, but the results shown are typical. There is no major difference in performance between version 5 and version 9 exports.

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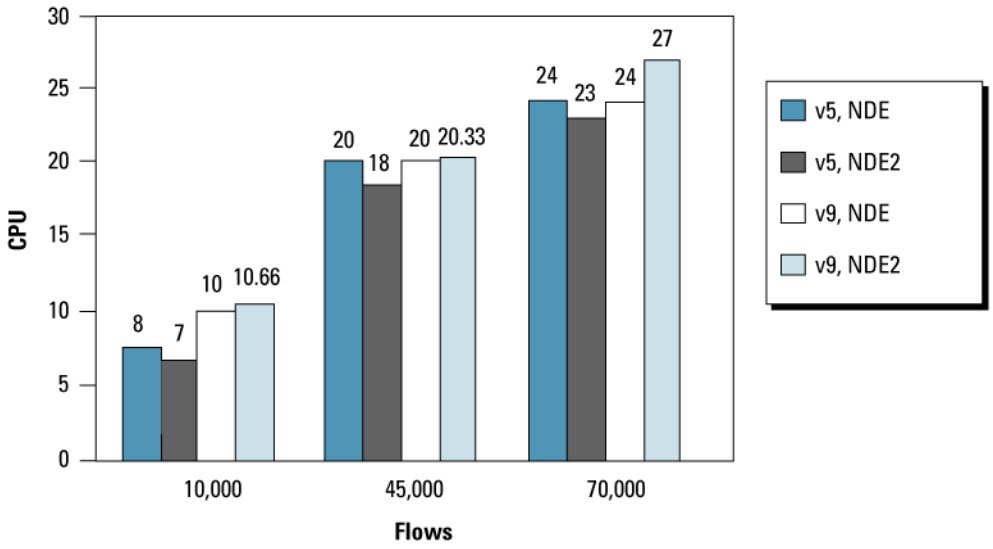
Figure 17. Cisco 7200 NPE400---Version 5 versus Version 9



RECOMMENDATIONS

Using Sampled NetFlow

Random Sampled NetFlow has dramatic affects in reducing CPU on software platforms and should be used for some applications such as traffic engineering and capacity planning.

This testing illustrated a significant benefit to using sampled NetFlow on the Cisco 12000 Series Router. Whereas a Cisco 12000 Series Router running in nonsampled “full-flow” mode required 23.5-percent more CPU to handle 65,000 IP flows, the same router using 1:100 sampling required only 3-percent additional CPU. CPU utilization will vary, depending on the sampling rate.

Customers are encouraged to use sampled NetFlow on the Cisco 12000 Series Router, and to use a high sampling rate (for example, 1 to 100) for initial deployment. Then, if more granularity in the NetFlow output is required, the sampling rate can be adjusted downward.

Expected CPU Utilization

As mentioned previously, some reasonable expectations for CPU utilization (on nonsampled platforms) when enabling NetFlow include the following:

- With ~10,000 active flows: 7.14percentage points of additional CPU utilization
- With ~45,000 active flows: 19.16 percentage points of additional CPU utilization
- With ~65,000 active flows: 22.98percentage points of additional CPU utilization

These results are based on an average of several different tests on several different hardware platforms. Individual platform results may vary.

Customers are encouraged to:

- Estimate the average number of IP flows passing through their target NetFlow deployment platforms (an IP flow is defined as a unique combination of the source and destination IP addresses, source and destination TCP/User Datagram Protocol [UDP] port numbers, IP protocol type, IP type of service, and input interface).
- Monitor the average CPU utilization on these platforms.

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- Add in the expected additional CPU requirements for NetFlow. Customers may wish to add a few additional points of CPU requirement to this number, to account for platform differences or exceptional circumstances on their network.
- Determine whether the derived number falls within an acceptable range of CPU utilization for their particular network.

Enabling NetFlow Version 5 Features

Tests showed very little CPU utilization impact associated with enabling NetFlow Version 5 features such as NetFlow data export to multiple destinations or collecting origin-as/peer-as information.

Customers who have considered enabling these features may now feel more confident about doing so.

NetFlow Version 5 Versus NetFlow Version 8 or 9

These tests have shown that NetFlow version 8 or version 9 uses no more system resources than does Version 5. Selecting which version to deploy becomes a matter of customer preference and relates to the customer's business case for deploying NetFlow in the first place.

NetFlow Version 8 decreases the bandwidth and storage requirements on the NetFlow collector device, because flow records are aggregated at the router prior to export. However, the records it produces are also less granular, so customers must be sure that the Version 8 records will provide all the information necessary for fulfilling their business needs.

NetFlow version 9 is used for the latest technology and features for NetFlow and should be considered for new deployments because the impact is no greater than version 5.

These test results do not change that recommendation. They do, however, illustrate that concern over additional CPU requirements of NetFlow version 8 or version 9 should not be one of the assessment criteria for its deployment.

CONCLUSION

The numbers included in this paper can be used as an initial reference for customers who wish to deploy the NetFlow feature set. Note that---as extensive as the testing was---it was done on only a specific set of platforms, and with a specific code release. Cisco is constantly working to improve the NetFlow caching scheme and hashing algorithms, so future releases of code may produce even better results.

As with all lab testing, an attempt was made to model real-world scenarios. However, no such modeling can ever be perfect. Remember that these benchmarks are to guide initial deployment decisions, but they do not replace the due diligence of customer lab testing, pilot deployments, and other types of solution validation.

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205283.a_ETMG_SH_4.05

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