## Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Author</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>04/11/2009</td>
<td>Yasunobu Chiba</td>
<td>Initial release.</td>
</tr>
<tr>
<td>1.1</td>
<td>04/11/2009</td>
<td>Yasunobu Chiba</td>
<td>Conditions that a flow entry is registered to the hardware search engine are described.</td>
</tr>
<tr>
<td>1.2</td>
<td>04/30/2009</td>
<td>Yasunobu Chiba</td>
<td>Rev159 support.</td>
</tr>
</tbody>
</table>
Contents

1. Basics ........................................................................................................................................... 4
   1.1 Interfaces ................................................................................................................................. 4
   1.2 Supported OpenFlow Spec ......................................................................................................... 4
   1.3 Features .................................................................................................................................... 5
   1.4 Flow Tables ............................................................................................................................... 5
   1.5 Performance ............................................................................................................................. 6

2. Pre-requirements ............................................................................................................................ 6

3. Hardware Installation ..................................................................................................................... 7

4. How to configure? .......................................................................................................................... 7
   4.1 Step 1: Login to the switch ......................................................................................................... 8
      4.1.1 Via network ....................................................................................................................... 8
      4.1.2 Serial Port .......................................................................................................................... 8
   4.2 Step 2: Creating vlan for OpenFlow switch ............................................................................... 9
   4.3 Step 3: Setup Control Interface ............................................................................................... 11
   4.4 Step 4: Save Configuration ....................................................................................................... 11
   4.5 Step 5: Configure OpenFlow Switch ......................................................................................... 11

5. How to run OpenFlow switch? ...................................................................................................... 11
   5.1 SD Card ...................................................................................................................................... 12
   5.2 openflow.conf ............................................................................................................................ 12
   5.3 Boot ........................................................................................................................................... 14
   5.4 To run openflow switch manually ............................................................................................ 14
      5.4.1 To stop ............................................................................................................................... 14
      5.4.2 To start ............................................................................................................................... 14

6. Useful command ............................................................................................................................ 14
   6.1 Unix commands ........................................................................................................................ 14
   6.2 showswitch ............................................................................................................................... 14
   6.3 showflow .................................................................................................................................... 15

7. Support ........................................................................................................................................... 18

Appendix – Example .......................................................................................................................... 19
1. Basics
There are two types of OpenFlow prototype switches which are based on NEC’s product IP8800/S3640-24T2XW and IP8800/S3640-48T2XW (http://www.nec.co.jp/ip88n/ip8800_s3640/index.html).

1.1 Interfaces

<table>
<thead>
<tr>
<th>Interface</th>
<th>S3640-24T2XW # of ports</th>
<th>S3640-48T2XW # of ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000BASE-T</td>
<td>24 (*1)</td>
<td>48</td>
</tr>
<tr>
<td>1000BASE-X(SFP)</td>
<td>4 (*1)</td>
<td>0</td>
</tr>
<tr>
<td>10G BASE-R (XFP)</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*1: Four ports can be configured as SFP ports.

1.2 Supported OpenFlow Spec
There are three releases:

<table>
<thead>
<tr>
<th>OpenFlow spec.</th>
<th>NEC software revision</th>
<th>Release date</th>
</tr>
</thead>
<tbody>
<tr>
<td>v0.8.1</td>
<td>113</td>
<td>11/09/2008</td>
</tr>
<tr>
<td>v0.8.2</td>
<td>113nh</td>
<td>11/09/2008</td>
</tr>
<tr>
<td>v0.8.9</td>
<td>159</td>
<td>04/30/2009</td>
</tr>
</tbody>
</table>

Note that both v0.8.1 and v0.8.2 are no longer supported. We suggest you to use the latest version of the software.
1.3 Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wirespeed OpenFlow Switching</td>
<td>Switching capacity:</td>
</tr>
<tr>
<td></td>
<td>88Gbps, 65.5Mpps (S3640-24T2XW)</td>
</tr>
<tr>
<td></td>
<td>136Gbps, 101.2Mpps (S3640-48T2XW)</td>
</tr>
<tr>
<td>Virtual OpenFlow Switch</td>
<td>Multiple OpenFlow switch instances on one box (port-based and VLAN Tag-based). Each switch can be controlled by the different controller.</td>
</tr>
<tr>
<td>Flow Table Quota</td>
<td>Number of flow entries can be statically allocated to each virtual OpenFlow switch.</td>
</tr>
</tbody>
</table>

1.4 Flow Tables

There are three types of flow tables, hardware table and two software tables. The hardware table is shared among virtual OpenFlow switches while software tables are dedicated to each virtual switch. If a flow entry satisfies the following four conditions, the entry is set to the hardware flow table. Otherwise, one of the software tables is used.

- Exact match
- IPv4 packet (Ether Type = IPv4)
- Single action
- (Output to a single physical port) or (Output to a single physical port + MAC DA modification)

Note that even if a flow entry is registered on the hardware table, IP fragment is forwarded by software forwarder exceptionally. The hardware table can be configured as “single-wide mode” or “double-wide mode”. If “single-wide mode” is selected, hardware forwarding engine will match only the fields in IP, TCP/UDP header and VLAN ID. In the case of “double-wide mode”, hardware forwarding engine will match all the header fields specified in OpenFlow Spec but the number of flow entries is limited. The following table shows the maximum number of flow entries in each table.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Single-wide mode (Exact match)</th>
<th>[IP8800/S3640-24T2XW] 3046 entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>[IP8800/S3640-48T2XW]</td>
<td>For port 1-24, 49-50: 3046 entries</td>
<td></td>
</tr>
</tbody>
</table>
1.5 Performance
Packets which hit hardware flow entry are forwarded in wire speed. Packets which hit software flow entry are forwarded by software. The following table shows the forwarding performance.

<table>
<thead>
<tr>
<th>Hardware Forwarding</th>
<th>88Gbps, 65.5Mpps (S3640-24T2XW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>136Gbps, 101.2Mpps (S3640-48T2XW)</td>
</tr>
<tr>
<td>Software Forwarding</td>
<td></td>
</tr>
<tr>
<td>64 bytes</td>
<td>1674 pps (0.8Mbps)</td>
</tr>
<tr>
<td>256 bytes</td>
<td>1611 pps (3.2Mbps)</td>
</tr>
<tr>
<td>512 bytes</td>
<td>1470 pps (6.0Mbps)</td>
</tr>
<tr>
<td>1024 bytes</td>
<td>1332 pps (10.9Mbps)</td>
</tr>
<tr>
<td>1518 bytes</td>
<td>1223 pps (14.8Mbps)</td>
</tr>
</tbody>
</table>

2. Pre-requisites
First of all, please make sure that you have all required hardware, OpenFlow enabled firmware and software license file before you start installation/configuration. The required items are shown in the table below.

<table>
<thead>
<tr>
<th>Item</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td></td>
</tr>
<tr>
<td>Switch: IP8800/S3640-24T2XW or IP8800/S3640-48T2XW</td>
<td>1</td>
</tr>
<tr>
<td>Power Supply Unit (PSU) and Power Cable: PS-A01</td>
<td>1-2</td>
</tr>
<tr>
<td>FAN Unit: FAN-01 (required if you use only one PSU)</td>
<td>0-1</td>
</tr>
<tr>
<td>SD Card: SD128(T)</td>
<td>1</td>
</tr>
<tr>
<td>Serial Cable: Crossover serial cable with DE9F connectors</td>
<td>1</td>
</tr>
<tr>
<td>Software</td>
<td></td>
</tr>
<tr>
<td>OpenFlow enabled IP8800 firmware (k.img)</td>
<td>1</td>
</tr>
<tr>
<td>Software license for OpenFlow enabled IP8800 (license.dat)</td>
<td>1</td>
</tr>
</tbody>
</table>
Serial console terminal with DE9M serial connector

If you do not have the firmware, please consult with us. Also, if you do not have the software license, please send an email with the serial number of your switch (the number can be found in the output of “show version” command).

3. Hardware Installation

(1) PSU Slot #1
(2) PSU Slot #2
(3) GND

Power Supply Unit Installation

Please look the figure above. If you have two PSUs (PS-A01), insert them to the slot #1 and #2. If you have only one PSU, insert PSU to the slot #1 and insert FAN unit (FAN-01) to the slot #2.

4. How to configure?
Follow the flow chart below to setup the OpenFlow enabled switch.
Here we explain how to configure the switch from CLI. You can create a configuration file containing the commands we explain here, store it in SD card, and copy the configuration to the startup configuration file.

4.1 Step1: Login to the switch

4.1.1 Via network
Telnet to the switch's IP address (if you've already configure the switch's IP address)

4.1.2 Serial Port
Use normal null-modem cable (crossover serial cable). Here is the configuration of serial connection:
First, you need to login to the switch. Default username is "operator". Password is not set.

```bash
login: operator
```

Then you need to run "enable" command and "configure" command.

```bash
> enable
# configure
(config)#
```

Now you can start putting the following command.

```
4.2 Step2: Creating vlan for OpenFlow switch
```

First, you need to disable STP because it does not work in OpenFlow enabled mode.

```bash
spanning-tree disable
```

Then create a vlan for OpenFlow switch. Here is an example:

```bash
vlan 1
name "OpenFlow Project A"
```

Then associate ports to the created vlan. Specify "switchport mode dot1q-tunnel" to those interfaces.
As we see later, we can have multiple OpenFlow switches on one physical switch. You need to create different vlans and associate ports exclusively to each vlan.

```
interface gigabitethernet 0/1
  switchport mode dot1q-tunnel
  switchport access vlan 1
interface gigabitethernet 0/2
  switchport mode dot1q-tunnel
  switchport access vlan 1
interface gigabitethernet 0/3
  switchport mode dot1q-tunnel
  switchport access vlan 1
interface gigabitethernet 0/4
  switchport mode dot1q-tunnel
  switchport access vlan 1
```

The switch also allows us to assign a tagged VLAN on a single interface to OpenFlow switch (as a logical port of OpenFlow switch). In such cases, specify “switchport mode trunk” and “switchport trunk allowed vlan VLANIDs” to receive tagged frames on the
interface. Here is an example.

```
interface gigabitethernet 0/9
  switchport mode trunk
  switchport trunk allowed vlan 1,2
```

In this case, frames received on the interface 0/9 can be forwarded to vlan 1 or vlan 2 based on VLAN tag.

### 4.3 Step3: Setup Control Interface
You need to have at least one interface through which OpenFlow switch can talk to the controller. To do so, create another vlan and associate at least one interface to the vlan, and then give the IP address to the vlan. You probably need to specify the default gateway (or routing table) to reach the controller. Here is an example.

```
vlan 3
  name "OpenFlow Control Vlan"
interface gigabitethernet 0/22
  switchport mode access
  switchport access vlan 3
interface vlan 3
  ip address 171.67.74.60 255.255.255.240
  ip route 0.0.0.0 0.0.0.0 171.67.74.49
```

### 4.4 Step4: Save Configuration
Finally, you need to save current configuration as follows. “save” command copies current configuration to startup configuration.

```
(config)# save
```

### 4.5 Step5: Configure OpenFlow Switch
Please refer to the next chapter.

5. How to run OpenFlow switch?
To boot as an OpenFlow enabled switch, insert SD card (Secure Digital card) which
contains the OpenFlow-enabled boot image, a special license file for the OpenFlow enabled switch, and OpenFlow configuration file. The switch will boot as a normal IP8800/S3640 switch if the boot image is missing. The switch will not boot if the license file is missing or invalid but the boot image is provided.

5.1 SD Card
SD card has to contain the following files:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>k.img</td>
<td>Binary file (executable image) for OpenFlow enabled IP8800/S3640.</td>
</tr>
<tr>
<td>license.dat</td>
<td>License file for OpenFlow enabled switch.</td>
</tr>
<tr>
<td>openflow.conf</td>
<td>Configuration file for (only) OpenFlow related features.</td>
</tr>
</tbody>
</table>

In addition, if you want to use SSL for secure channel, following files need to exist in SD card as well.

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ca_cert.pem</td>
<td>Certification of CA (will be used for validating controller's certification).</td>
</tr>
<tr>
<td>sw_cert.pem</td>
<td>Certification of this switch (with CA's signature).</td>
</tr>
<tr>
<td>sw_key.pem</td>
<td>Secret key of this switch.</td>
</tr>
</tbody>
</table>

Note that we suggest you to use NEC certified SD card. Otherwise, you may encounter a problem. A license file is associated with a specific physical switch. You cannot copy it to non-authorized switches. If you do not have the license file, please contact us with the output of the “show version” command.

5.2 openflow.conf
The file has to be Unix-style LF line-endings (not CR+LF). Be careful if you edit ofconf.txt with Windows. The line beginning with "#" will be ignored. There are three commands defined.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>no-save</td>
<td>If specified, configuration changes won’t be saved to the SD card (useful if using non-official SD card)</td>
</tr>
</tbody>
</table>
double-wide-mode  |  If specified, hardware forwarding engine will match all the header fields specified in OpenFlow Spec. If not specified, hardware forwarding engine will match only the fields in IP, TCP/UDP header and VLAN ID.

setvsi  |  Start OpenFlow switch. You can start multiple OpenFlow Switch on different vlans. This command has several parameters as shown in the table below.

<table>
<thead>
<tr>
<th>setvsi &lt;vlan id&gt; &lt;list of ports&gt; &lt;tcp</th>
<th>ssl&gt; &lt;controller ip address[:port]&gt; [&quot;&lt;ca cert&gt; &lt;my cert&gt; &lt;my private key&gt;&quot;] [dpid &lt;datapath id&gt;] [hwlimit &lt;max entry num&gt;] [max-backoff &lt;backoff time&gt;] [echo-interval &lt;interval time&gt;]</th>
</tr>
</thead>
<tbody>
<tr>
<td>vlan id</td>
<td>OpenFlow vlan id, i.e., vlan id for OpenFlow switch.</td>
</tr>
<tr>
<td>list of ports</td>
<td>Port numbers belongs to OpenFlow vlan. Ports should be separated by &quot;,&quot;. The range of ports can be specified by &quot;-&quot;. &quot;,&quot; is used to specify VLAN on a tagged port (e.g. 1.2 means vlan 2 on port 1).</td>
</tr>
<tr>
<td>tcp</td>
<td>ssl</td>
</tr>
<tr>
<td>controller ip</td>
<td>IP address of the controller.</td>
</tr>
<tr>
<td>port</td>
<td>TCP port number of the controller.</td>
</tr>
<tr>
<td>ca cert</td>
<td>File name for the certification of CA.</td>
</tr>
<tr>
<td>my cert</td>
<td>File name for the certification of this switch.</td>
</tr>
<tr>
<td>my private key</td>
<td>File name for the secret key of this switch.</td>
</tr>
<tr>
<td>datapath id</td>
<td>OpenFlow switch id (12 hex digits).</td>
</tr>
<tr>
<td>max entry num</td>
<td>Number of hardware flow entries will be allocated.</td>
</tr>
<tr>
<td>backoff time</td>
<td>Maximum interval between controller connection attempts in seconds.</td>
</tr>
<tr>
<td>Interval time</td>
<td>Interval between echo requests in seconds. If 0 is specified, echo is never sent.</td>
</tr>
</tbody>
</table>

Here is an example of the configuration file.
5.3 Boot
Insert SD card, and turn on the switch. OpenFlow switch will start automatically based on openflow.conf in SD card.

5.4 To run openflow switch manually
5.4.1 To stop
To stop a running openflow switch on vlan <vlan id>, use deletevsi command.

```
deletevsi <vlan id>
```

<table>
<thead>
<tr>
<th>vlan id</th>
<th>OpenFlow vlan id, i.e., vlan id for OpenFlow switch.</th>
</tr>
</thead>
</table>

```
# deletevsi 1
```

5.4.2 To start
Use setvsi command. Please refer to openflow.conf section.

6. Useful command
6.1 Unix commands
Please take a look at /usr/bin, /usr/local/bin, /usr/sbin/, /usr/local/sbin.

6.2 showswitch
You can see the OpenFlow tables.

```
showswitch [<vlan id>] [detail]
```

<table>
<thead>
<tr>
<th>vlan id</th>
<th>OpenFlow vlan id.</th>
</tr>
</thead>
<tbody>
<tr>
<td>detail</td>
<td>Show detailed switch information.</td>
</tr>
</tbody>
</table>

Example:
6.3 showflow

You can see the OpenFlow tables.

```
<table>
<thead>
<tr>
<th>showflow [&lt;vlan id&gt;] [detail]</th>
</tr>
</thead>
<tbody>
<tr>
<td>vlan id</td>
</tr>
<tr>
<td>detail</td>
</tr>
</tbody>
</table>
```

Example:

```
# showswitch 1 detail
Virtual switch 1
Datapath ID : 1250999896491 (0x123456789ab)
Port : gigabitethernet 0/1 (link up, 1G full)
gigabitethernet 0/2 (link up, 1G full)
gigabitethernet 0/3 (link up, 1G full)
gigabitethernet 0/4 (link up, 1G full)
gigabitethernet 0/9.1 (link down)
Conn mode : tcp
Controller : 172.16.4.180:6633 (connected)
Exact match : hw 0 / hw max 1510
Exact match : sw 0 / sw max 131072
Wildcard : sw 0 / sw max 100
Packet buff : 256 packets / 4294967295 MB
Miss sendlen: 128 bytes
```
# showflow
duration=87s,table_id=0,priority=65535,n_packets=17,n_bytes=142, 
idle_timeout=60,hard_timeout=0,in_port=1,dl_vlan=ffff,dl_src=0:00:00:00:00:00, 
0:00:00:00:00:01,dl_dst=00:00:00:00:00:03,dl_type=0800,nw_src=192.168.1.1/32, 
nw_dst=192.168.1.3/32,nw_proto=17,tp_src=1024,tp_dst=1024,action=output:3
duration=8s,table_id=0,priority=65535,n_packets=1,n_bytes=142, 
idle_timeout=60,hard_timeout=0,in_port=2,dl_vlan=ffff,dl_src=00:00:00:00:00:02, 
0:00:00:00:00:01,dl_dst=00:00:00:00:00:01,dl_type=0800,nw_src=192.168.1.2/32, 
nw_dst=192.168.1.1/32,nw_proto=17,tp_src=1024,tp_dst=1024,action=output:1
$ showflow 1 detail

--------------------------------------------------------------------------------
Matching key
Input port : 1                     VLAN ID     : 65535(0xffff)
MAC SA      : 00:00:00:00:00:01     MAC DA      : 00:00:00:00:00:03
TYPE        : 0x800[IP]             IP protocol : 17[UDP]
Source port : 1024(0x400)           Dest port   : 1024(0x400)

Information
Idle timeout: 60 sec                Hard timeout: 0 sec
Priority    : 65535
IFP slice no: 15                    IFP entry no: 0
Packet count: 17                    Byte count : 142
Created     : Wed Mar  4 15:34:41 2009
Action type : 0[OUTPUT]             Max length  : 0
Output port : 3(0x3)

--------------------------------------------------------------------------------
Matching key
Input port : 2                     VLAN ID     : 65535(0xffff)
MAC SA      : 00:00:00:00:00:02     MAC DA      : 00:00:00:00:00:01
TYPE        : 0x800[IP]             IP protocol : 17[UDP]
Source port : 1024(0x400)           Dest port   : 1024(0x400)

Information
Idle timeout: 60 sec                Hard timeout: 0 sec
Priority    : 65535
IFP slice no: 15                    IFP entry no: 0
Packet count: 1                      Byte count : 142
Created     : Wed Mar  4 15:36:00 2009
Expires     : Wed Mar  4 15:37:00 2009
Action type : 0[OUTPUT]             Max length  : 0
Output port : 1(0x1)
7. Support
If you have any question, problem, or enhancement request regarding the switch, please feel free to contact us, ofs-support@spf.jp.nec.com. Please provide us with your network configuration and the output of the following commands when you send a problem report or question.

```
# cat /build_info
# cat /mnt/openflow.conf
# ls -l /mnt/k.img
# showswitch detail
# showflow detail
# show tech-support
```

We are on your side.
Appendix – Example
Here we provide a configuration example of the switch shown in the figure below.

In this example, port #1 to #6 are associated with VLAN2. VLAN2 is configured as an OpenFlow switch instance. The switch instance works in “double-wide” mode. Port #23 and #24 are associated with VLAN3 and port #23 is used to connect with OpenFlow controller. Remaining ports (#7-#22) are associated with default vlan (VLAN1) and work as a legacy L2 switch. VLAN and interface configuration might be:
spanning-tree disable

vlan 2
   name "OpenFlow VLAN"

vlan 3
   name "OpenFlow Control VLAN"

interface vlan 3
   ip address 172.16.4.181 255.255.255.0

interface gigabitethernet 0/1
   switchport mode dot1q-tunnel
   switchport access vlan 2

interface gigabitethernet 0/2
   switchport mode dot1q-tunnel
   switchport access vlan 2

interface gigabitethernet 0/3
   switchport mode dot1q-tunnel
   switchport access vlan 2

interface gigabitethernet 0/4
   switchport mode dot1q-tunnel
   switchport access vlan 2

interface gigabitethernet 0/5
   switchport mode dot1q-tunnel
   switchport access vlan 2

interface gigabitethernet 0/6
   switchport mode dot1q-tunnel
   switchport access vlan 2

interface gigabitethernet 0/23
   switchport mode access
   switchport access vlan 3

interface gigabitethernet 0/24
   switchport mode access
   switchport access vlan 3

SD card contains three files; OpenFlow enabled firmware (k.img), software license (license.dat), and OpenFlow configuration (openflow.conf). openflow.conf might contain:
double-wide-mode
setvsi 2 1-6 tcp 172.16.4.180 dpid 0x0123456789ab