Connection-Oriented Software-Defined Networking

Date: 2013-05-14

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Abstract

Conventional software-defined networking (SDN) is essentially about managing switches. In order to control the overall network, SDN can be extending to allow management of links as well. Connection-oriented link control, as provided in IEEE 802.16 and other standards, allows a pathway for SDN to manage links. The set of connections within a link can operate on a mixture of mixed access technologies, allowing the Connection-Oriented Software-Defined Networking (COSDN) controller to assign service flows to connections on various media and access technologies.
Connection-Oriented Software-Defined Networking (COSDN)

This contribution based on IEEE 802.16-13-0098 and IEEE 802.16-13-0084.

Followup to IEEE 802.16-13-0049 (“Integration of IEEE 802.16 and Carrier Ethernet”)

• proposed a switch-centric architecture with a switch in the 802.16 BS
• switch is presumably based on 802.1Q functionality (learning, spanning tree, etc.)

IEEE 802.16-13-0084 (“Integration of IEEE 802.16 with Software-Defined Network Control”)

• followup to IEEE 802.16-13-0049, introducing SDN controller to program the switch and link connections, including QoS control, as an alternative to pure 802.1Q behavior.
SDN

- SDN controller communicates with switches via control path
- SDN controller controls flow forwarding by managing flow tables
- limited QoS enabled by associating a flow with a customized queue
  - Can schedule packets onto a link
  - Can’t control what happens on the link
Connection-Oriented SDN (COSDN)

- Links are connection-oriented and managed
- COSDN controller manages not only switches but also:
  - link connections
    - Connection setup, teardown, maintenance
    - packet classification
    - source ports for connection classification
- Links may be unmanaged
  - e.g. they may not be connection-oriented or may support only a single connection
Connection-Oriented SDN

One point-to-point link. Arbitrary number of unidirectional connections, per link. Connections can be created, changed, and deleted. Connection properties include QoS requirements. Frames assigned to a service flow based on frame headers. Service flow assigned to a connection. Scheduler manages the overall QoS. Header suppression, per connection.
Connection-Oriented SDN
Full Connection Control
Connection-Oriented SDN
Partial Connection Control

COSDN Controller

S

D1

D2

D3
Connection-Oriented SDN with Shared Physical Medium

- Multiple Links may share a physical medium
- This points out a major limitation of queuing only on the link: if the link resource is shared, the entire shared resource must be managed as a single resource, with scheduling to accommodate connection QoS requirements across all links.
- Example: Point-to-multipoint radio links, as in IEEE 802.16.
- Note: the switch ports are virtual, not physical.
Connection-Oriented SDN
Shared Physical Medium
Connection-Oriented SDN with Multiple Physical Media

- Connections need to deliver packets to ports. There are many ways to do so.
- Could separate link connections by physical media.
  - May require a physical switch, not just virtual
- Example: an edge device may support IEEE 802.16 and IEEE 802.11.
  - Provision some connections (e.g., QoS-sensitive ones) over 802.16.
  - Provision other connections (e.g., best-effort) over 802.11.
- Manage all connections in a coordinated fashion using COSDN.
- Enable cross-media handover.
  - Use link aggregation tricks (e.g. IEEE 802.1AX Marker Protocol) to speed transition while maintaining correct packet sequence.
Connection-Oriented SDN
Multiple Physical Media

COSDN Controller

S

D1
D2
D3
Connection-Oriented SDN with Multiple Physical Media - Uplink

- The previous figures illustrate the “downlink” problem of a point-to-multipoint architecture.
- “Uplink” can be managed in a similar fashion.
- Source packets must be classified and assigned to flows that map to connections appropriate to their QoS requirements.
- COSDN Controller manages connections.
- COSDN Controller configures packet source flow tables
  - Not for switching but for QoS sorting and matching to appropriate connections.
802.16 Control (AAA, synch etc.) & SDN Control

OpenFlow channel

SDN Controller Example
# 802.16 Packet CS compared to OpenFlow

<table>
<thead>
<tr>
<th>Feature</th>
<th>802.16-2012 Packet CS</th>
<th>OpenFlow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination</td>
<td>CID</td>
<td>Port</td>
</tr>
<tr>
<td>Table Pipeline</td>
<td>No; one table, plus PHS</td>
<td>Pipeline sequence</td>
</tr>
<tr>
<td>Match on</td>
<td>Headers, with masks</td>
<td>Headers, with masks</td>
</tr>
<tr>
<td>Match Priority</td>
<td>Prioritized rules</td>
<td>Prioritized rules</td>
</tr>
<tr>
<td>Action without match</td>
<td>Drop</td>
<td>Specified by Table Miss entry; can send to controller for learning, etc.</td>
</tr>
<tr>
<td>Match actions &amp; Match instructions</td>
<td>Forward; Drop [PHS]</td>
<td>Forward; Drop; Group; &amp;&lt;br&gt;&amp;&lt;br&gt;&amp;&lt;br&gt;&amp;Set Queue;&amp;&lt;br&gt;&amp;&lt;br&gt;&amp;Push/Pop Tag;&amp;&lt;br&gt;&amp;&lt;br&gt;&amp;Set Field;&amp;&lt;br&gt;&amp;&lt;br&gt;&amp;Change TTL;&amp;&lt;br&gt;&amp;&lt;br&gt;&amp;Write Metadata&gt;</td>
</tr>
<tr>
<td>Counters &amp; Timers</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Meter Tables</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Automatic Rule Deletion</td>
<td>No</td>
<td>Timeouts (hard and idle)</td>
</tr>
</tbody>
</table>
Switch-Centric Architecture

- Multiple SS Ports per SS
- One SS per SS Port
- One CS instance per SS
- Port-aware CS
- Unidirectional Connections
- Multiple Connections per SS Port
- One SS Port per Connection
- Connections labeled by SS Port
- All Connections linked via PHY

[several examples highlighted]
Downlink Pipeline

OpenFlow

Convergence Sublayer

Table 0
- Action: specify egress port as metadata
- Match on: headers

Table 1
- Action: select output queue (of selected egress port) and headers
- Match on: egress port (in metadata) and headers

CID Classification
- Match on: egress port and output queue (and possibly other headers)
- Action: select CID

PHS
- Match on: CID
- Action: prepend selected PHSI (PHS rule index) to frame
- Replace tags per PHSI

Align 802.16 DL CIDs with OpenFlow output queues for simplest classification. Allows OpenFlow controller to indirectly control DL QoS. OpenFlow could be customized for direct CID control.

Convergence Sublayer can be driven by queue-servicing scheduler.
Downlink Data Plane

OpenFlow Table 0: egress port switch table

OpenFlow Table 1: queue lookup and tag strip/replace

CID Classification

PHS (per CID)

Physical Switch (based on CID or CID range)

SS a port
- frame
- header-suppressed frame, CID, PHSI

SS a de-PHS
- header-suppressed frame, CID, PHSI

BS a MAC Entity

SS a MAC Entity

SS b port
- frame
- header-suppressed frame, CID, PHSI

SS b de-PHS
- header-suppressed frame, CID, PHSI

BS b MAC Entity

SS b MAC Entity

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Uplink Pipeline

Align 802.16 UL CIDs with OpenFlow output queues for simplest classification. Allows OpenFlow controller to indirectly control UL QoS. OpenFlow could be customized for direct CID control.

Table 0
- Action: none
- Match on: headers
- Action: select output queue (of port), specify VLAN and priority tag suppression or replacement

Table 1
- Match on: port and output queue (and possibly other headers)
- Action: select CID

CID Classification
- Match on: port and output queue (and possibly other headers)
- Action: prepend selected PHSI (PHS rule index) to frame, replace tags per PHSI

Convergence Sublayer
- Can be driven by queue-servicing scheduler

OpenFlow

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Uplink Data Plane

OpenFlow Table 0: egress port lookup

- frame delivered to egress port (to network, or to Downlink)

OpenFlow Table 1: queue lookup and tag strip/replace

- header-suppressed frame, CID, PHSI
- PHS (per CID)
- CID lookup
- frame, CID
- Physical Switch
- header-suppressed frame, CID, PHSI

BS MAC Entity

- frame, CID
- BS de-PHS
- header-suppressed frame, CID, PHSI

SS MAC Entity

- SS port
- frame
- OpenFlow Table 1: queue lookup and tag strip/replace
- frame, queue
- CID lookup
- frame, CID
- PHS (per CID)
- header-suppressed frame, CID, PHSI

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Control Plane

Driven by OpenFlow queue configuration.

OpenFlow switch control

OpenFlow queue control

DL connection control

OpenFlow queue control

UL connection control

OpenFlow Table 0
switching table VLANs and flows

OpenFlow Table 1
DL queues

DL CID configuration including queue mapping and PHS rules

OpenFlow Table 1
UL queues

UL CID configuration including queue mapping and PHS rules

Network side

Terminal side
OpenFlow Table 0: egress port switch table

OpenFlow Table 1: queue lookup and tag strip/replace

CID Classification

PHS (per CID)

Physical Switch (based on CID or CID range)

Connections can be transported on various media.
If "SS a port" = "SS b port", provides alternative to link aggregation.
Distribution and collection functions are already handled.
Process maintains flow frame sequence.
OpenFlow can change the medium by changing queue table (Table 1).
-Marker protocol (as in 802.1AX) can improve handover speed while maintaining flow sequence.
-Flow can be queued until handover acknowledged.

any MAC/PHY capable of delivering frame to port with suitable QoS
- e.g. 802.3, 802.11, etc.

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Conclusions

- SDN manages switches but not links
- Connection-oriented transport networks, like IEEE 802.16 and others, provide QoS control by managing connections in a manner that is parallel to SDN switch management
- SDN can be extended to COSDN to allow control of the entire port-to-port network flow, including, switches and links.