The traffic-control module in ns-3

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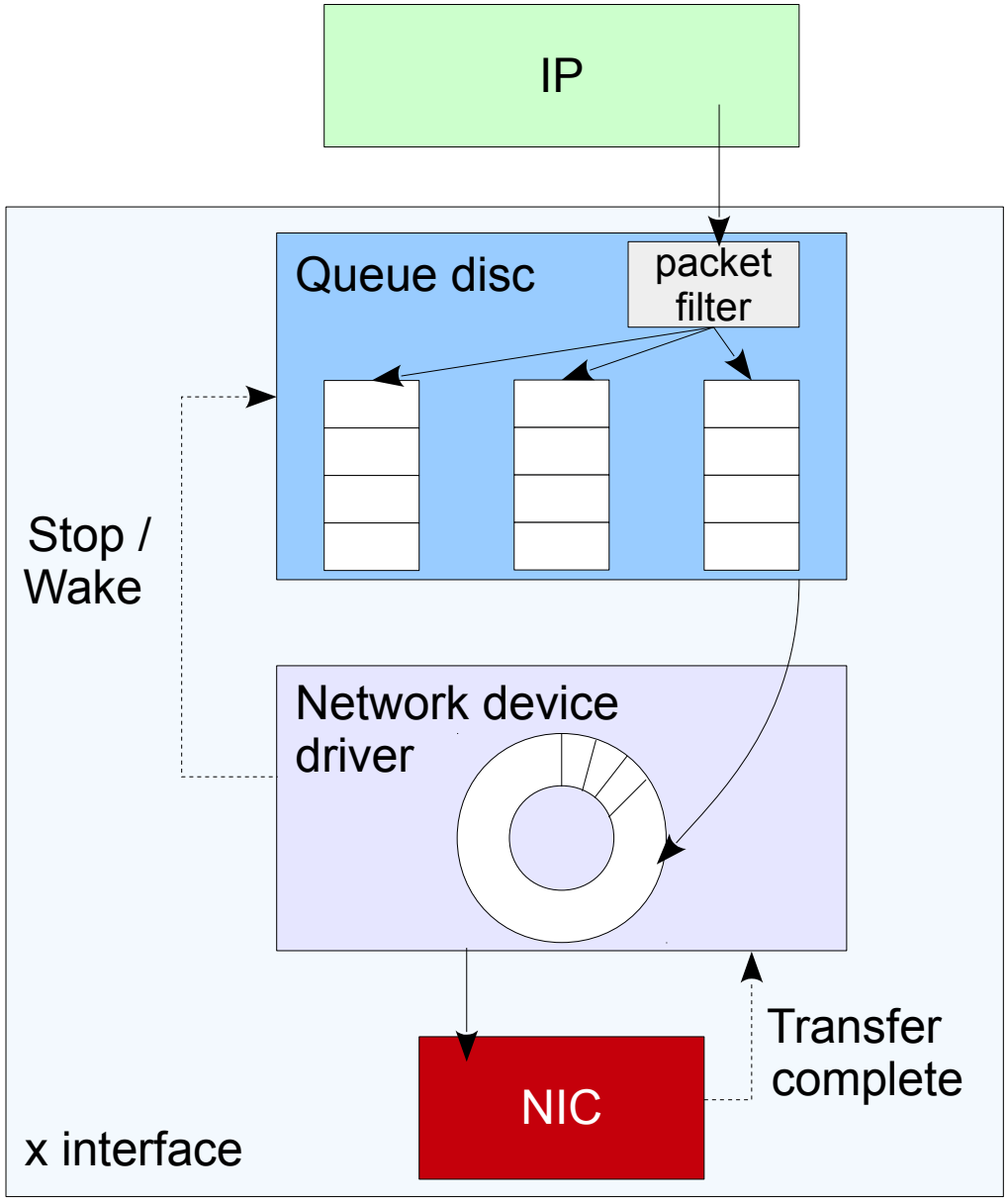
Introduction

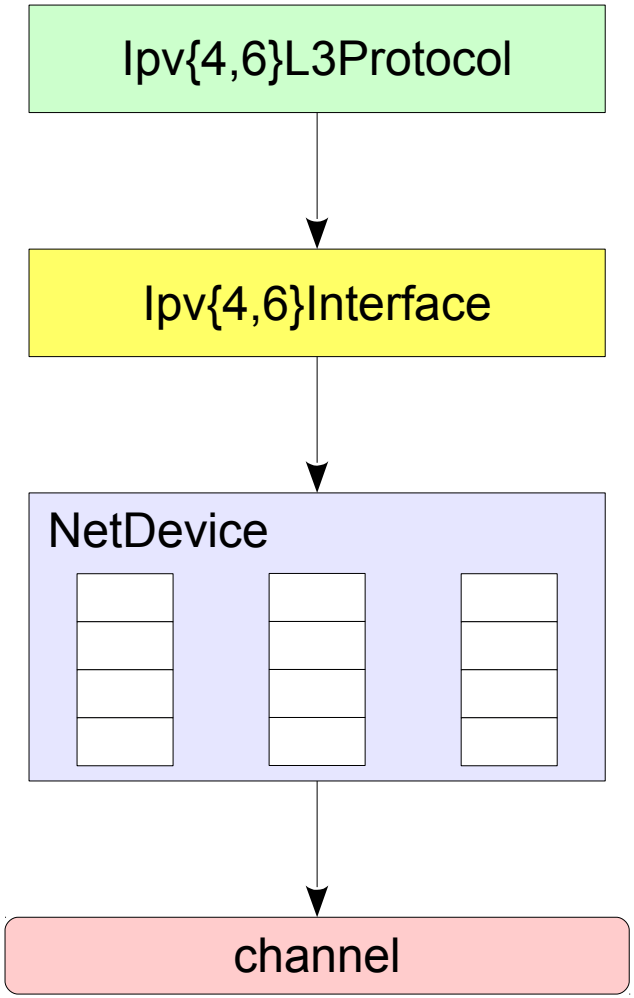
- The traffic-control module has been introduced in ns-3.25 (March 2016)
  - Advanced queue management and packet shaping
  - Modelled after the Linux Traffic Control (TC) infrastructure
- Some important pieces completed over the next releases
  - Packet priority handling, byte queue limit (ns-3.26)
  - Simplified flow control support (ns-3.27)
- traffic-control acts on the transmission of packets
  - Linux also allows to police incoming traffic

The Linux TC infrastructure



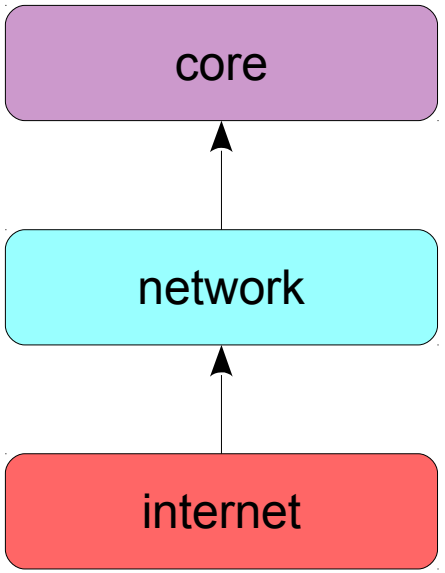
- 1 packet enqueued → multiple packets dequeued
- Device driver
  - Packet received: if there is no room for another packet, then *stop* the queue
  - Notification received from the device: if there is room for another packet, then *wake* the queue
- The size of the transmission ring can be dynamically adjusted by BQL
- Interrupt mitigation techniques or polling to reduce overhead

ns-3 network stack pre-3.25

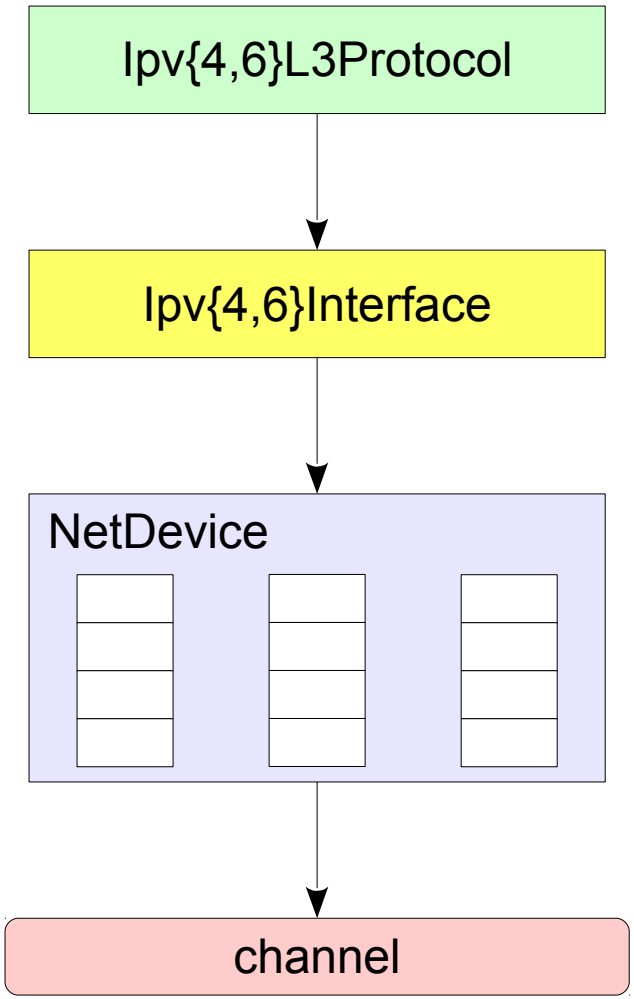


- AQM algorithms (RED, CoDel) available as subclasses of Queue
- No flow control: packets discarded by the NetDevice if no room

Dependencies among modules

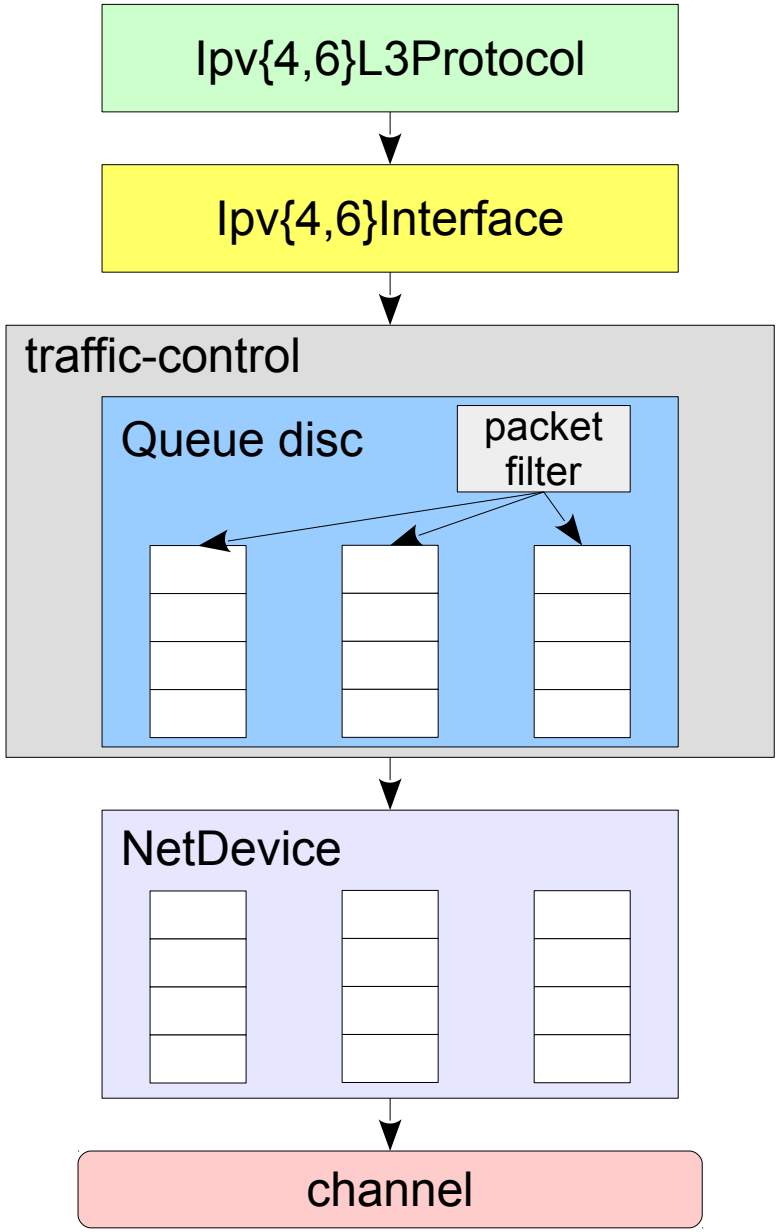


ns-3 network stack pre-3.25: Limitations

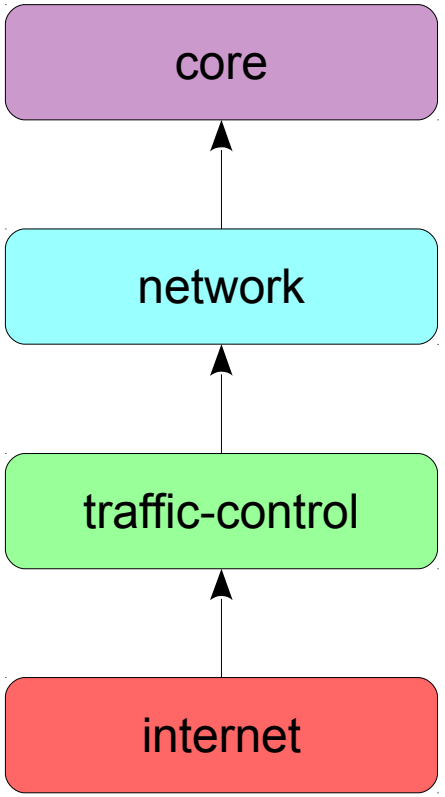


- AQM algorithms only available for devices using Queue objects
  - No wifi, lte, wimax,...
- ECN support difficult
  - IP header needs to be removed/modified/added
- Packet filtering based on L4 ports difficult
  - L4 header needs to be accessed
- Very difficult to reproduce the impact of BQL, interrupt mitigation, ...

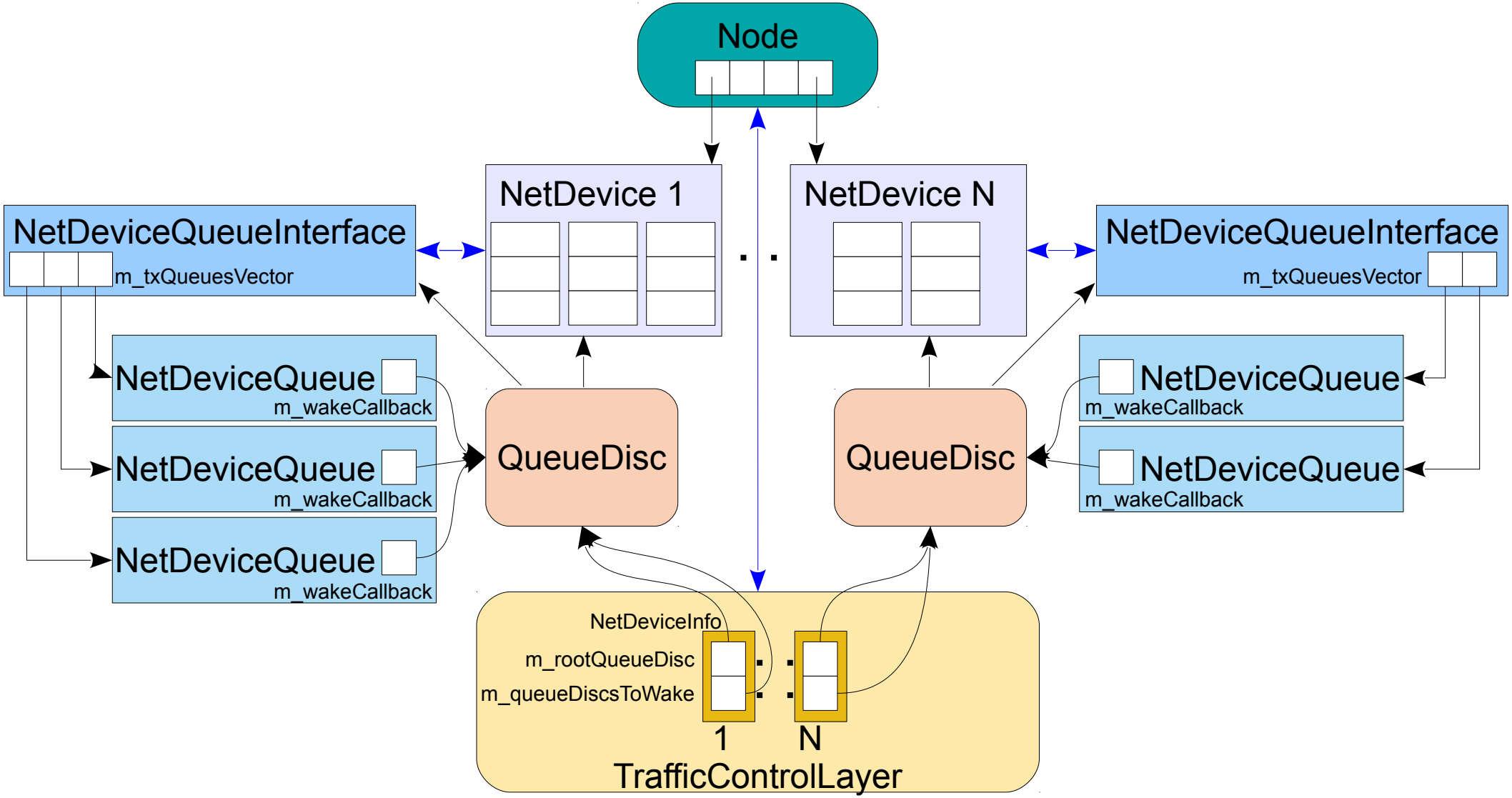
Introducing the traffic-control module



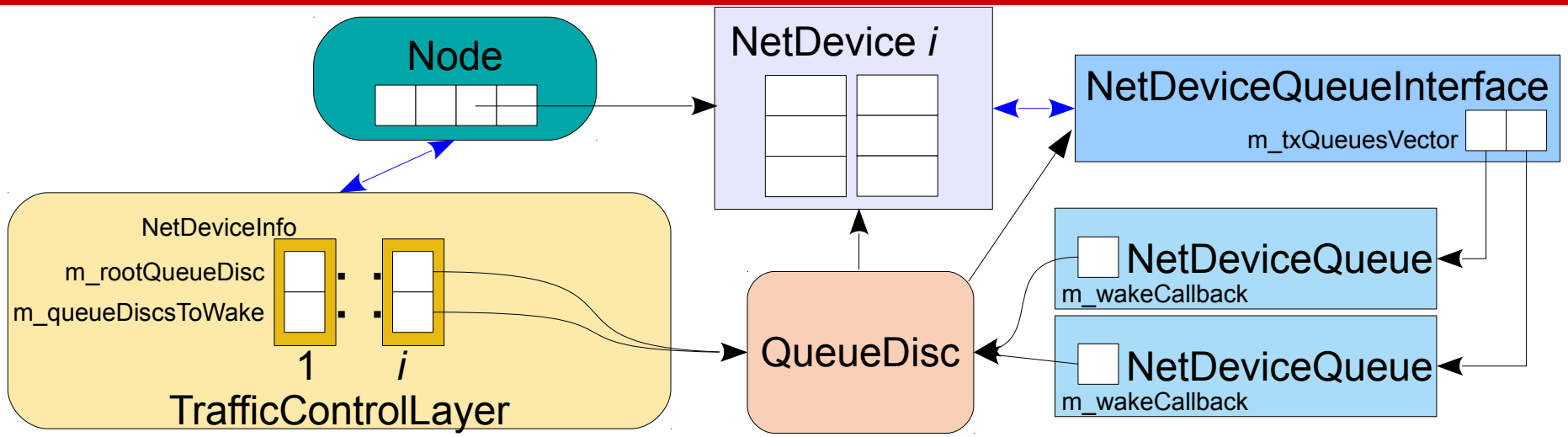
Dependencies among modules



Implementation details (1/5)



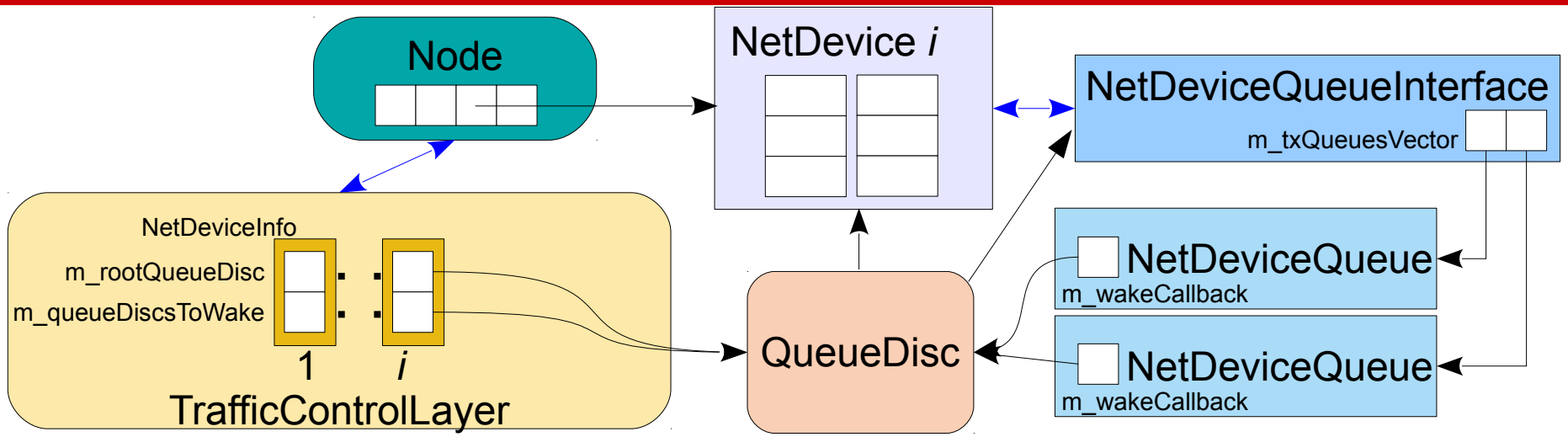
Implementation details (2/5)




```
void
TrafficControlLayer::Send
(Ptr<NetDevice> device,
Ptr<QueueDiscItem> item)
{
  …
  uint8_t txq = 0;
  …
  Ptr<QueueDisc> qDisc =
ndi->second.m_queueDiscsToWake[txq];

  qDisc->Enqueue (item);
  qDisc->Run ();
}
```

```
void
QueueDisc::Run (void)
{
  …
  uint32_t quota = m_quota;
  while (Restart ())
    {
      quota -= 1;
      if (quota <= 0)
        {
          break;
        }
    }
}
```

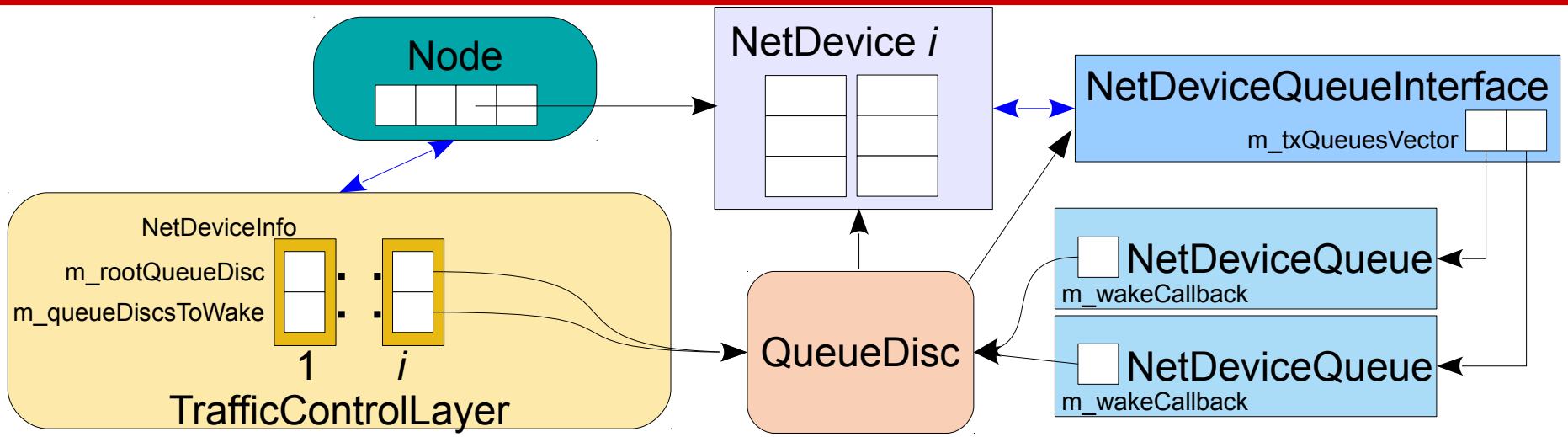
Implementation details (3/5)




```
bool
QueueDisc::Restart (void)
{
  Ptr<QueueDiscItem> item =
DequeuePacket();
  if (item == 0)
    {
      NS_LOG_LOGIC ("No packet to
                     send");
      return false;
    }

  return Transmit (item);

}
```

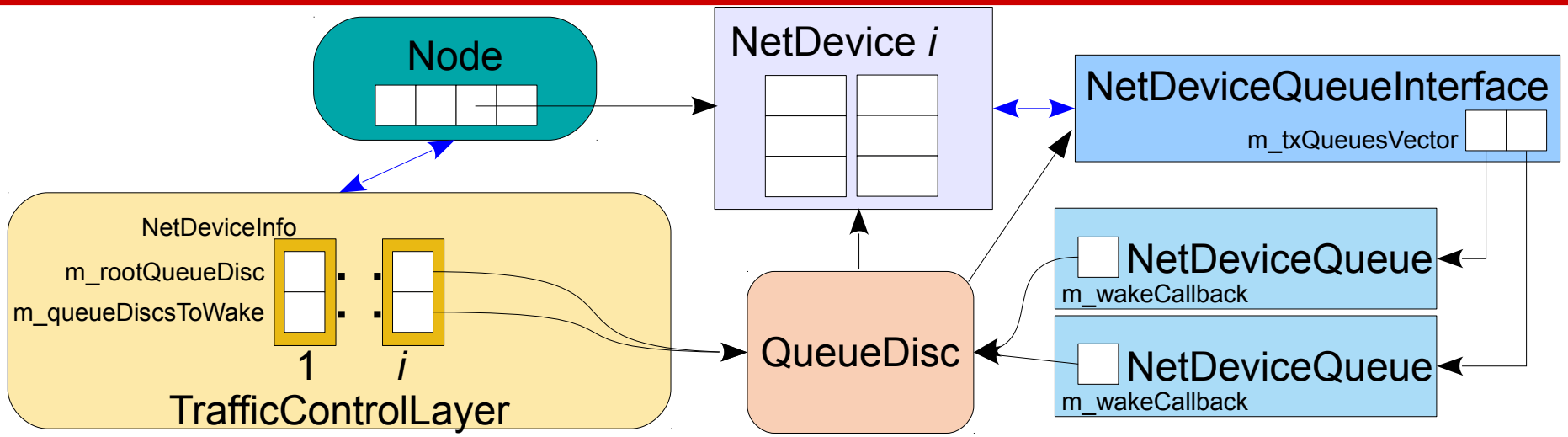
```
Ptr<QueueDiscItem>
QueueDisc::DequeuePacket (void)
{
  Ptr<QueueDiscItem> item;
  if (m_devQueueIface->GetNTxQueues ()>1 ||
 !m_devQueueIface->GetTxQueue(0)->IsStopped())
    {
      item = Dequeue ();
      if (item != 0)
        {
          item->AddHeader ();
        }
    }
  return item;
}
```

Implementation details (4/5)




```
bool
QueueDisc::Transmit (Ptr<QueueDiscItem> item)
{
  m_device->Send (item->GetPacket (), item->GetAddress (), item->GetProtocol ());

  if (GetNPackets () == 0 ||
      m_devQueueIface->GetTxQueue (item->GetTxQueueIndex ())->IsStopped ())
    {
      return false;
    }

  return true;
}
```

Implementation details (5/5)



- After enqueuing a packet into one of its queues, the NetDevice has to **stop** the corresponding NetDeviceQueue if that queue cannot store another packet
  - By calling NetDeviceQueue::Stop ()
- After dequeuing a packet from a queue, the NetDevice has to **wake** the corresponding NetDeviceQueue if there is room for another packet in that queue
  - By calling NetDeviceQueue::Wake ()

Flow control

- NetDevices should be modified to add support for flow control
- Queue discs are useless if the NetDevice does not support flow control
  - If NetDeviceQueues are never stopped, packets are enqueued and immediately dequeued from the queue disc
- As of ns-3.26, PointToPointNetDevice is the only NetDevice supporting flow control
- Adding flow control support to WifiNetDevice is tricky
  - Packets are dequeued at multiple points in the code
  - Packets are dequeued by subclasses that do not hold a pointer to WifiNetDevice

Simplified flow control support

- Starting from the upcoming ns-3.27, a NetDevice *using a Queue subclass to store its packets* can gain support for flow control (and BQL) by calling:

```
NetDeviceQueueInterface::ConnectQueueTraces
(Ptr<Queue<Item>> queue, uint8_t txq)
```

- which connects:
  - NetDeviceQueue::PacketEnqueued to the “Enqueue” traced callback of the queue
  - NetDeviceQueue::PacketDequeued to the “Dequeue” and “DropAfterDequeue” traced callbacks of the queue
  - NetDeviceQueue::PacketDiscarded to the “DropBeforeEnqueue” traced callback of the queue

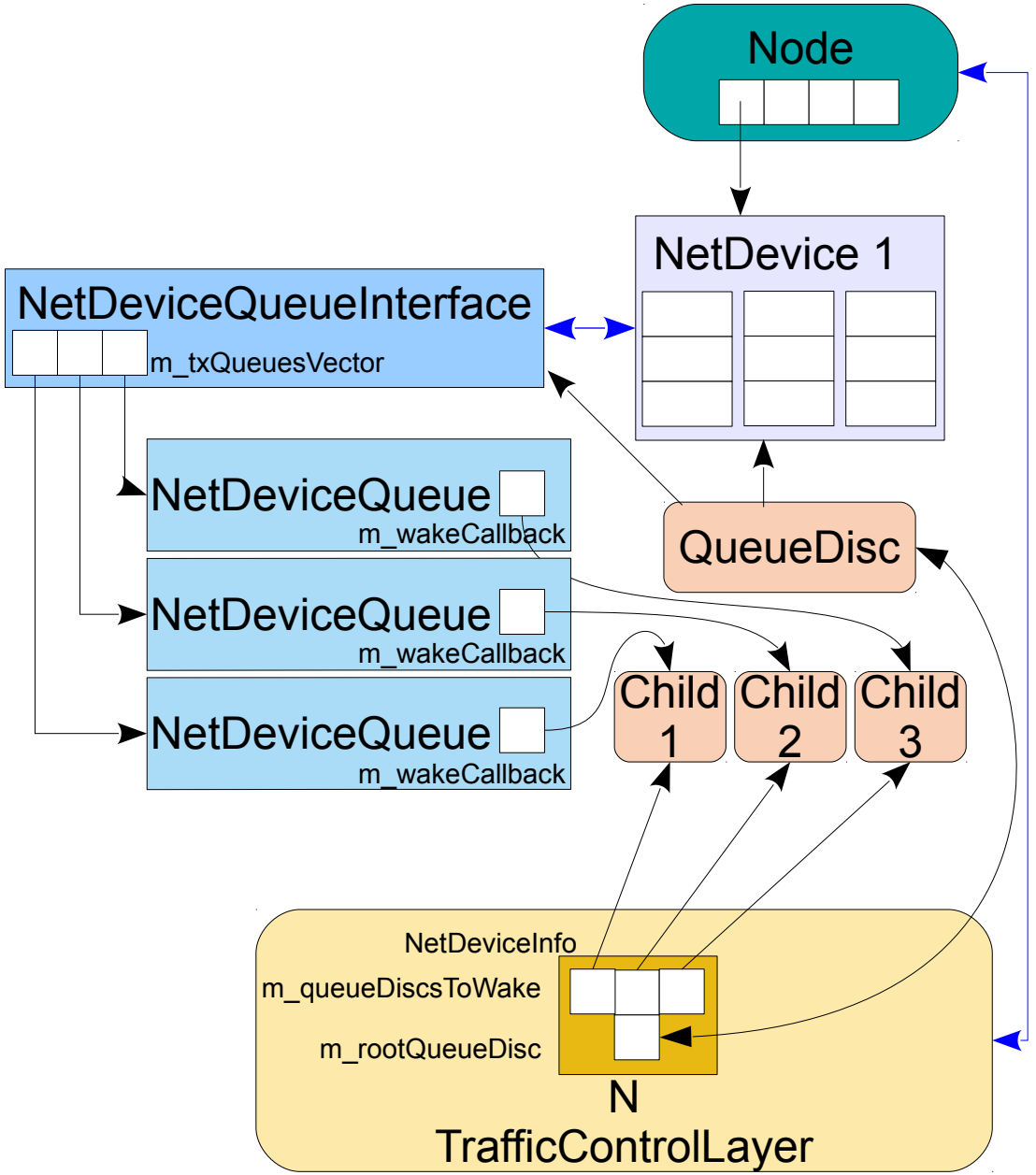
Flow control support status

- PointToPointNetDevice, CsmaNetDevice, SimpleNetDevice easily gained flow control support
  - These NetDevices were already using Queue
- The Queue class was reworked to define WifiMacQueue as a subclass of Queue and have WifiNetDevice gain flow control support
  - Queue is now a template class
    - The type parameter is the type of the elements stored in the queue (Queue<Packet>, Queue<QueueDiscItem>, …)
  - Allowed us to get rid of static casts in queue discs
- To add flow control support for other NetDevices
  - Let them use Queue<Item>
  - Add the required operations when packets are enqueued or dequeued from their queues

Multi-queue networking

- Many network device drivers have multiple queues
  - To exploit the availability of multiple cores (Ethernet drivers)
  - For QoS purposes (Wi-Fi drivers)
- Multi-queue aware queue discs have been introduced
  - mq, multiq, mq-prio
  - Create as many child queue discs as the number of queues used by the network device driver
  - Each child queue disc corresponds to a queue
  - Packets are enqueued in the queue disc corresponding to the queue in which the network device driver will enqueue the packet
  - Network device drivers have to provide a select callback

Multi-queue aware queue discs




```
void
TrafficControlLayer::Send
(Ptr<NetDevice> device,
Ptr<QueueDiscItem> item)
{
  …
  uint8_t txq = 0;
  if (devQueueIface->GetNTxQueues()> 1)
    {
      if (!ndi->
second.m_selectQueueCallback.IsNull ())
        {
          txq = ndi->
second.m_selectQueueCallback (item);
        }
  Ptr<QueueDisc> qDisc =
ndi->second.m_queueDiscsToWake[txq];

  qDisc->Enqueue (item);
  qDisc->Run ();
}
```

Selecting a wifi queue

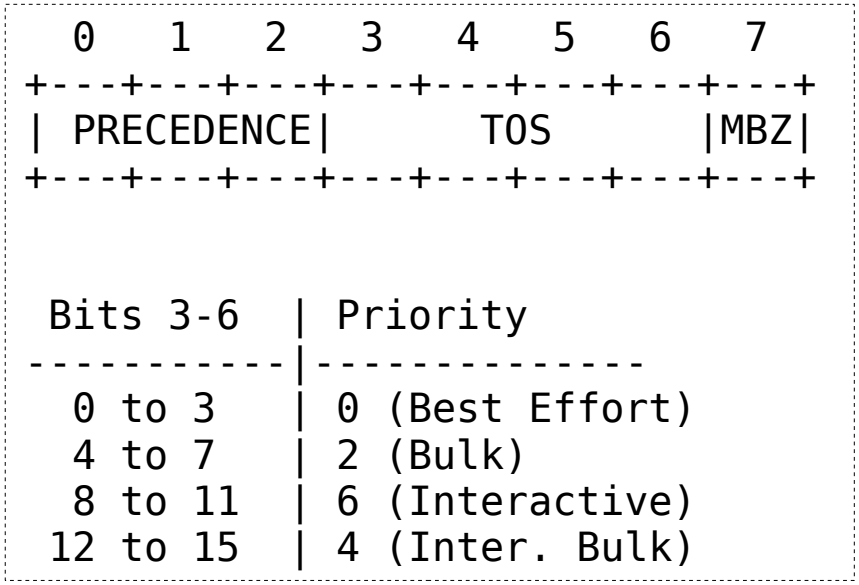
```
uint8_t
WifiNetDevice::SelectQueue
(Ptr<QueueItem> item) const
{
  uint8_t dscp, priority = 0;
  if (item->GetUint8Value
(QueueItem::IP_DSFIELD, dscp))
    {
      priority = dscp >> 5;
    }
  // replace the priority tag
  …
  return QosUtilsMapTidToAc (priority);
}
```

UP	Access Category
0	AC_BE
1	AC_BK
2	AC_BK
3	AC_BE
4	AC_VI
5	AC_VI
6	AC_VO
7	AC_VO

PHB	TOS (binary)	UP	Access Category
EF	101110xx	5	AC_VI
AF11	001010xx	1	AC_BK
AF21	010010xx	2	AC_BK
AF31	011010xx	3	AC_BE
AF41	100010xx	4	AC_VI
AF12	001100xx	1	AC_BK
AF22	010100xx	2	AC_BK
AF32	011100xx	3	AC_BE
AF42	100100xx	4	AC_VI
AF13	001110xx	1	AC_BK
AF23	010110xx	2	AC_BK
AF33	011110xx	3	AC_BE
AF43	100110xx	4	AC_VI
CS0	000000xx	0	AC_BE
CS1	001000xx	1	AC_BK
CS2	010000xx	2	AC_BK
CS3	011000xx	3	AC_BE
CS4	100000xx	4	AC_VI
CS5	101000xx	5	AC_VI
CS6	110000xx	6	AC_VO
CS7	111000xx	7	AC_VO

Packet priority

- The socket priority is set based on the socket ToS
  - Socket::SetIpTos (tos) calls Socket::IpTos2Priority (tos)
- The packet priority is set equal to the socket priority
  - Ipv4L3Protocol::IpForward



Bits 3-6	Priority
0 to 3	0 (Best Effort)
4 to 7	2 (Bulk)
8 to 11	6 (Interactive)
12 to 15	4 (Inter. Bulk)

PHB	TOS (binary)	bits 3-6	Priority
EF	101110xx	12-13	4
AF11	001010xx	4-5	2
AF21	010010xx	4-5	2
AF31	011010xx	4-5	2
AF41	100010xx	4-5	2
AF12	001100xx	8-9	6
AF22	010100xx	8-9	6
AF32	011100xx	8-9	6
AF42	100100xx	8-9	6
AF13	001110xx	12-13	4
AF23	010110xx	12-13	4
AF33	011110xx	12-13	4
AF43	100110xx	12-13	4
CS0	000000xx	0-1	0
CS1	001000xx	0-1	0
CS2	010000xx	0-1	0
CS3	011000xx	0-1	0
CS4	100000xx	0-1	0
CS5	101000xx	0-1	0
CS6	110000xx	0-1	0
CS7	111000xx	0-1	0

PfifoFastQueueDisc

- PfifoFastQueueDisc behaves like the pfifo_fast qdisc
  - default qdisc in Linux
- Packets are enqueued into three priority bands (queues) based on (the four least significant bits of) the packet priority
  - Carried by the SocketPriorityTag
  - As modified by the select queue callback (e.g., wifi)
- Band 1 is the default band

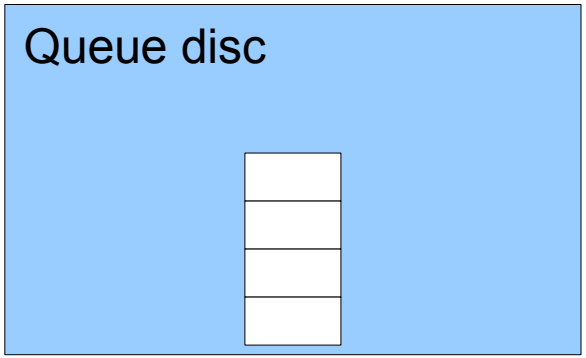
Priority & 0xf	Band
0	1
1	2
2	2
3	2
4	1
5	2
6	0
7	0
8	1
9	1
10	1
11	1
12	1
13	1
14	1
15	1

Default configuration

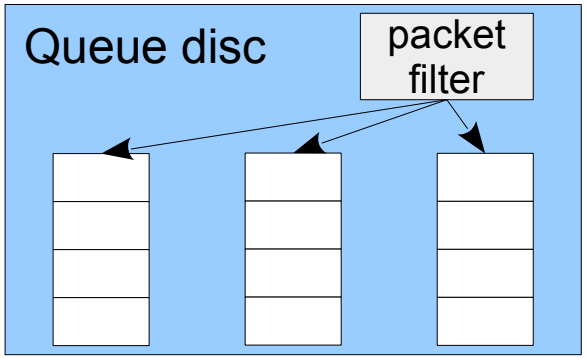
- A TrafficControlLayer object is aggregated to a node by InternetStackHelper::Install (node)
- **By default**, when an IPv{4,6} address is assigned to a NetDevice, a PfifoFast queue disc is installed on the NetDevice
  - Ipv{4,6}AddressHelper::Assign (const NetDeviceContainer &c)
- In order to install a queue disc other than PfifoFast
  - Install the queue disc before assigning IP addresses
    - Ipv{4,6}AddressHelper::Assign does not install PfifoFast on a NetDevice if a queue disc is already installed
  - Remove PfifoFast and install a different queue disc

Various queue disc types

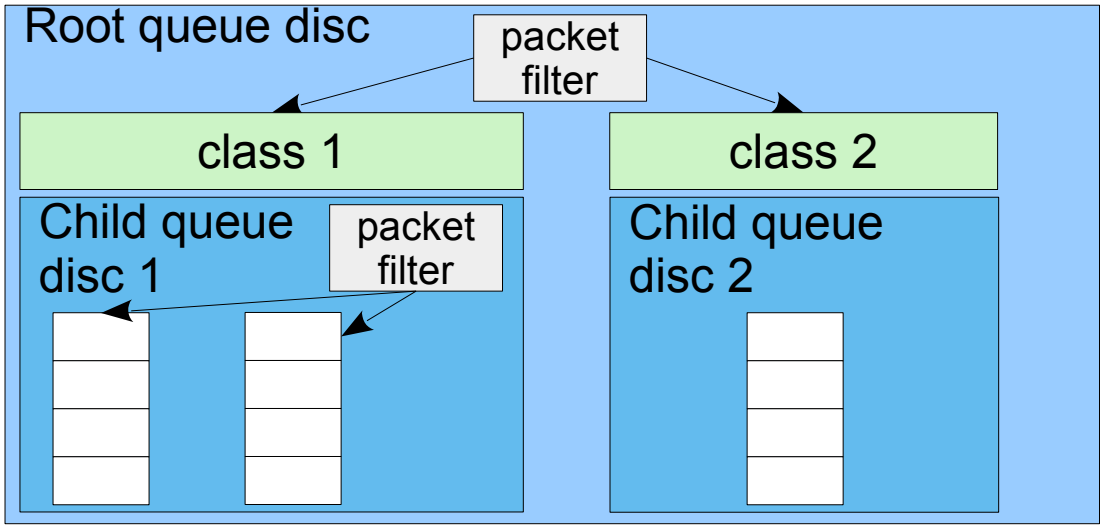
- Classless, single queue



- Classless, multiple queues



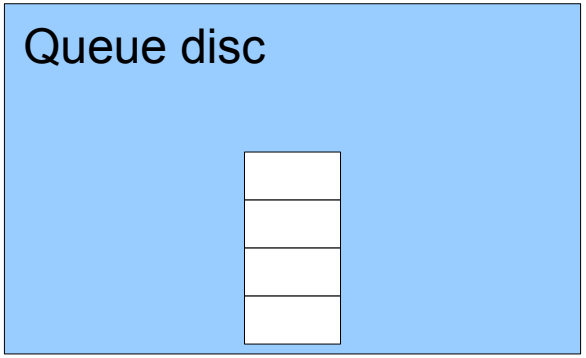
- Classful



TrafficControlHelper API

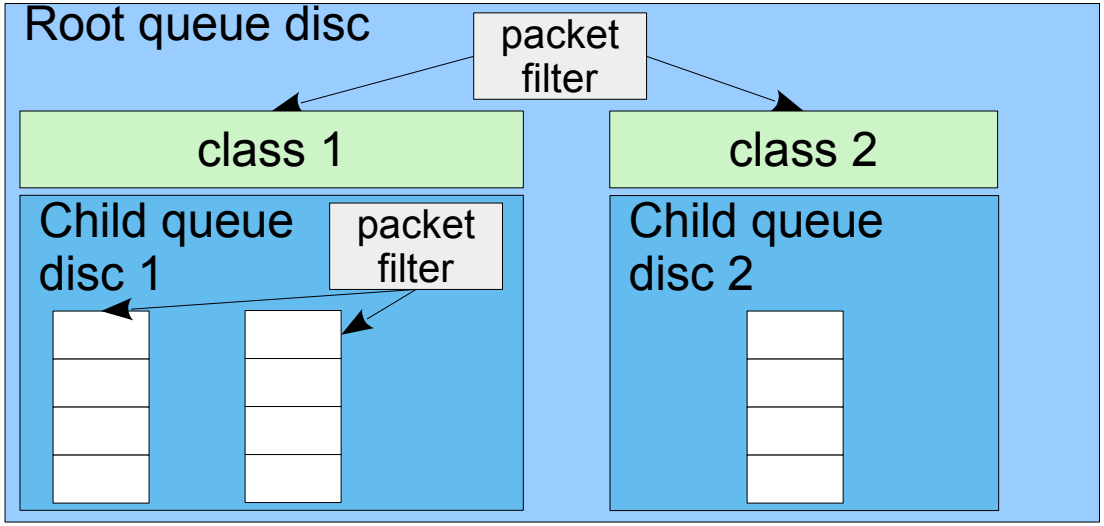
```
uint16_t SetRootQueueDisc (string type, string n01, const AttributeValue &v01,…);

void AddInternalQueues (uint16_t handle, uint16_t count, string type,
                        string n01, const AttributeValue &v01,…);

void AddPacketFilter (uint16_t handle, string type,
                      string n01, const AttributeValue &v01,…);

ClassIdList AddQueueDiscClasses (uint16_t handle, uint16_t count, string type,
                                 string n01, const AttributeValue &v01,…);

uint16_t AddChildQueueDisc (uint16_t handle, uint16_t classId, string type,
                            string n01, const AttributeValue &v01,…);

HandleList AddChildQueueDiscs (uint16_t handle, const ClassIdList &classes,
                               string type, string n01, const AttributeValue &v01,…);


QueueDiscContainer Install (Ptr<NetDevice> d);

void Uninstall (Ptr<NetDevice> d);
```

Installing classless queue discs



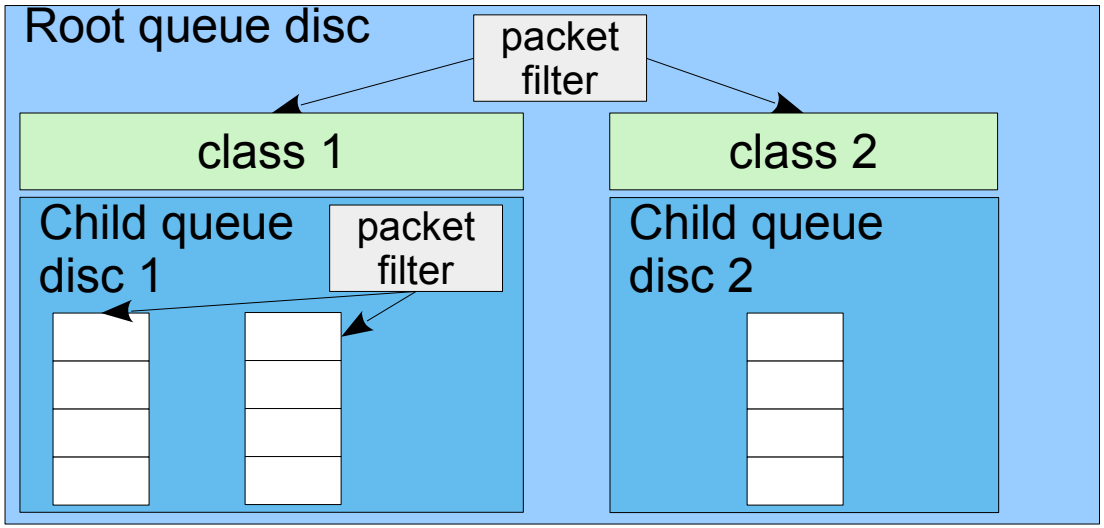

```
TrafficControlHelper tch;

// PfifoFast
uint16_t h = tch.SetRootQueueDisc ("ns3::PfifoFastQueueDisc");
tch.AddInternalQueues (h, 3, “ns3::DropTailQueue”);  // optional

// RED
tch.SetRootQueueDisc (“ns3::RedQueueDisc”);

// CoDel
tch.SetRootQueueDisc (“ns3::CoDelQueueDisc”);

// PIE
tch.SetRootQueueDisc (“ns3::PieQueueDisc”);
```

Installing classful queue discs



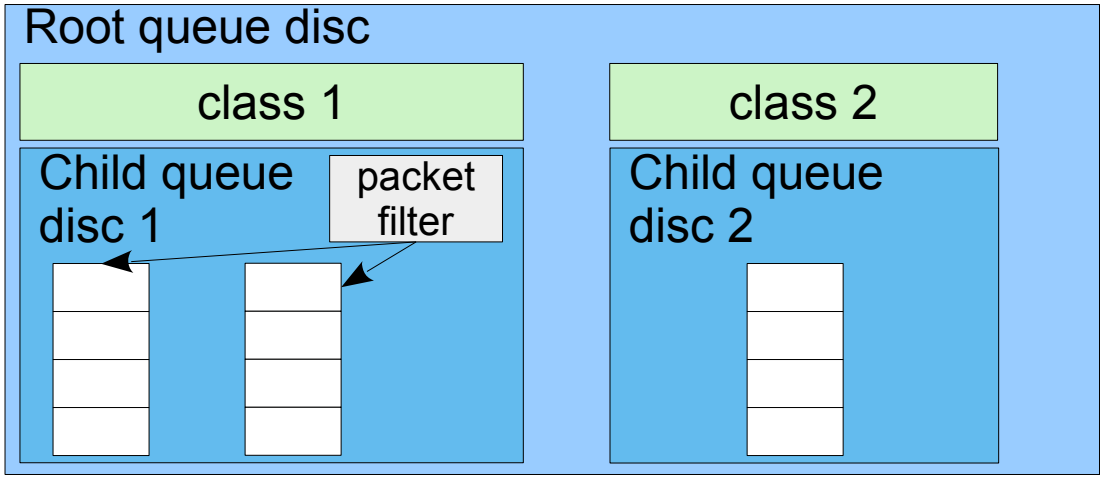

```
TrafficControlHelper tch;

// FqCodel
// Classes and child queue discs are dynamically created by the Enqueue method

uint32_t h = tch.SetRootQueueDisc ("ns3::FqCoDelQueueDisc",
                                   "PacketLimit", UintegerValue (1000));

tch.AddPacketFilter (handle, "ns3::FqCoDelIpv4PacketFilter");
tch.AddPacketFilter (handle, "ns3::FqCoDelIpv6PacketFilter");
```

Installing classful queue discs




```
TrafficControlHelper tch;

// Prio – ns.3-28
// An internal packet filter may be used

uint16_t h = tch.SetRootQueueDisc ("ns3::PrioQueueDisc");
TrafficControlHelper::ClassIdList cid = tch.AddQueueDiscClasses (h, 2,
                                                    "ns3::QueueDiscClass");
tch.AddChildQueueDisc (h, cid[0], "ns3::FifoQueueDisc");
tch.AddChildQueueDisc (h, cid[1], "ns3::RedQueueDisc");
```

Installing multi-queue aware queue discs




```
TrafficControlHelper tch;

// Mq installed on a WifiNetDevice
// Classes are created just for convenience

uint16_t h = tch.SetRootQueueDisc ("ns3::MqQueueDisc");
TrafficControlHelper::ClassIdList cls = tch.AddQueueDiscClasses (h, 4,
                                                                 "ns3::QueueDiscClass");
  TrafficControlHelper::HandleList hdl = tch.AddChildQueueDiscs (h, cls,
                                                                 "ns3::FqCoDelQueueDisc");
  for (auto hh : hdl)
    {
      tch.AddPacketFilter (hh, "ns3::FqCoDelIpv4PacketFilter");
    }
```

Thank you!