October 03, 2019

OVERRIDING DETERMINISTIC FLOWS

Pascal Thubert

Patrick Wetterwald

Eric Levy-Abegnoli

OVERRIDING DETERMINISTIC FLOWS

AUTHORS:
Pascal Thubert
Patrick Wetterwald
Eric Levy-Abegnoli

ABSTRACT

Real aging is not desirable for Deterministic Network (DetNet) flows. Defined herein are new techniques that provide a similar service for DetNet flows. The new techniques involve: utilizing new Quality of Service (QoS) values to indicate a packet that is a normal DetNet packet versus a reclassified packet; reclassifying a DetNet packet to a higher priority to avoid discarding N contiguous packets of the flow; ensuring that a reclassified packet progresses through automatic repeat request (ARQ) methods; and declassifying a DetNet packet to a lower priority rather than discarding it using IP-in-IP encapsulation and a deadline header with a deadline that is computed on the fly based on the remaining time till the bounded time of delivery for the packet.

DETAILED DESCRIPTION

The intuition for deterministic flows is that in terms of priority they always beat anything whatever, so when it is time to send a DetNet packet, that packet will win against any other, even if already in transit through frame preemption. A corollary is that there can only be one packet scheduled at a given time for a time-triggered shaper, and/or there's always enough bandwidth for all the deterministic flows for a credit-based (peristaltic) shaper.

As it goes, DetNet and Time Sensitive Networks (TSN) really deal with the precise beat of scheduled flows, which does not necessarily imply that the flow is the highest priority ever. There can be times when it is acceptable–even a good idea–to stop a production line, which happens automatically if you lose say, 4 packets in a row, and the bandwidth must be used for other things. For example, someone pressed the red button, there's a fire, etc. and all the Ethernet capacity needs to be devoted to safety (e.g., cameras, people location, alarms, alerts, etc.).

If it is accepted that in emergency situations deterministic flows can be preempted, then the question becomes what to do with deterministic packets that could not be sent in time. Delaying and declassifying them does not necessarily work for a control application in which the packet itself is a sense of beat of the control system, meaning that the control system may oscillate if packets are not delivered in quasi-perfect time.

A number of DetNet applications can live with a rare packet loss and do not need 5 nines reliability. Such applications can reconstruct the missing measurement based on linear regression or similar algorithms. What such applications need, however, is to ensure that, whenever possible, the loss of contiguous packets is avoided because each additional regression is a chaotic deviation to the real world.

Consider a substation automation use case. International Electrotechnical Commission (IEC) standards 61850-5, 61850-8-1, and 61850-9-2 define several traffic patterns used either within a substation or for inter-substations communications including:

- General Object Oriented Substation Event (GOOSE) traffic for tripping or inter-tripping functions, interlocking merging unit, and other functions. This traffic could run on Layer 2 or 3 of the Open Systems Interconnect (OSI) model.
- Manufacturing Message Specification (MMS) traffic (which runs on Layer 3).
- Sampled values (SV) exchanges (over Layer 2 for intra-substation traffic or Layer 3 for inter-substation traffic).
- Synchro-Phasor traffic (Phasor Management Unit (PMU) traffic), which runs over Layer 3.
- Time synchronization traffic (over Layer 2 for intra-substation traffic or Layer 3 for inter-substation traffic),

SV traffic is transmitted cyclically at a relatively high frequency (e.g., 100 to 250 microseconds (us)) and has a typical size of 160 octets. GOOSE traffic is primarily based on event, but the traffic could be sent by burst in certain circumstances. One GOOSE application per Intelligent Electronic Device (IED) generates around 1 kilobit per second (kbt/s) of data in steady state and about 1 megabit per second (Mbt/s) in burst mode.

SV traffic is a cyclic deterministic traffic. Not receiving SV samples may have important impacts on the electrical distribution (e.g., potentially causing a shutdown) but missing 1 or 2 samples may be acceptable. GOOSE traffic is at the same priority. The network should handle traffic bursts in case of electrical event; thus, leading to the techniques described herein.

The normal behavior of a DetNet/TSN shaper is to drop a packet when it cannot be sent. Reclassifying to a lower priority is possible but the packet may be delivered in unbounded latency, which is not desirable for a number of DetNet applications.

Proposed herein are a number of new behaviors or methods to cope with the preemption of deterministic flows, which includes defining new DetNet classes.

With DetNet, there can be only one (or a controlled set of) packet(s) for a particular schedulable resource (really, 1-for-1 or N-for-N with peristaltic shapers). In other words, a DetNet packet is always the most important thing to do and there can never be a collision.

This can be illustrated via a train analogy in which only one train can be scheduled for an outgoing lane at a particular time with no collision loss. Now, consider that there is an explosion in the station, people walking on the railway, or an exceptional convoy that needs to leave the station. It is acceptable in exceptional circumstances not to let the scheduled train go and incur delays.

Methods of this proposal recognize that there can be exceptional conditions where a DetNet packet may not be the most urgent packet to send. Three DetNet classes can be created including:

- DetNet normal packets (green) as are typically known in the art;
- DetNet mission-critical packets (orange), which can be used to protect a minimal amount of the DetNet packets that keep an application alive though possibly under-performing; and
- DetNet do-not-discard packets (red), which can be used for safety applications that require deterministic networking (e.g., a control loops that keep a plane flying, etc.).

Asynchronous flows will be given QoS priorities that compare to the DetNet classes as follows:

- Classical flows for any QoS as of today (blue) that are typically known in the art;

- Any of the above DetNet flows that can win against a DetNet normal packet (yellow) such as an asynchronous packet that is critical but does not justify possibly stopping the production; and
- Any of the above DetNet flows that can win against a DetNet mission-critical packet (pink) such as an asynchronous packet that is so critical that all processes may stop, if needed.

As a result, priorities are now ordered as: blue < green < yellow < orange < pink < red. Arch-critical DetNet flows can be tagged with the red priority. The treatment for the red priority is the default as of today for DetNet flows, meaning that there can only be one red packet scheduled for a resource and that it wins against any other when contending for transmission.

Techniques of this proposal provide that when a DetNet packet collides with a non-DetNet packet, the new QoS values are compared to determine which packet is sent. The remainder of discussions herein deal with the operation on a DetNet packet when it loses the comparison.

As discussed previously, traditional QoS aging is not desirable for DetNet flows. Yet, the concept of aging can be adapted to provide a series of guarantees to DetNet packets that cannot be sent in due time. This can be applied to normal DetNet packets (green) that may be reclassified (to orange), declassified (to blue), or dropped. Various novel classification techniques are described below.

Reclassification to orange for DetNet "aging"

When a green packet loses versus a yellow packet, the intention of the new mechanism is to prevent a series of losses in a row. Say, for example, that it is desired to ensure that there are never N=4 contiguous losses in a row. For this example, a window of N=4 packets can be started in the case of a collision in which the first packet of the window is dropped. The second packet can be prioritized with an orange priority. The priority can be tagged in the packet so it will be treated as such till the end of the path.

When sending an orange packet, the sender can optionally require an acknowledgment (ACK) from the next hop to ensure that the packet progresses all the way, and positions a current window accordingly. This is performed by all nodes down the path of the node that reclassified the packet.

If the transmission of the orange packet is successful, the sender will mark the window as satisfied. The next packets may be dropped or declassified till the end of the window. When the window terminates, the process ends until the next collision, which can happen at any time in the future.

Declassification to blue for DetNet "aging"

After an orange transmission, the rest of the window is eligible for discarding or declassification without the risk of N=4 losses in a row. The window can be determined by the sequence counter in the DetNet header of the packet such that it accounts for packets that might have been lost in-between. If there is no collision, then the next green packet(s) in the window is/are sent as usual along the DetNet path. In case of a collision, a best effort can be made to enable the packet to reach its destination within its bounded latency.

Thus, the technique involves knowledge of the remaining time for a packet between a node and the destination within the bounded latency. In at least one implementation, this information can be provided by a controller that establishes the path. A sender can compute the deadline time for a packet based on the current time plus remaining time within the bounded latency. The sender can encapsulate the DetNet packet IP-in-IP to its destination, adding a deadline header that carries the computed deadline.

The packet can be tagged blue and placed in the normal flow with a high QoS to be served as a 'hot potato' on the remainder of the path. As is known in the art, the nodes on the way or the destination stack will drop any packet that has passed its deadline. Still, there is a chance that the packet can be delivered within bounded latency in which case the loss can be prevented.

Alternative encodings

Alternative encodings are possible. For example, the deadline could be added to the DetNet header and placed by the source. In another example, the green, orange, and red tags could also be DetNet tags in the DetNet header as opposed to QoS values. In yet another example, segment routing can also be used with the IP-in-IP to use a preferred route for declassified packets (e.g., with fast hot potato switching).

In summary, new techniques defined herein provide a service similar to real aging for DetNet flows. The new techniques involve: utilizing new QoS values to indicate a packet that is a normal DetNet packet versus a reclassified packet; reclassifying a DetNet packet to a higher priority to avoid discarding N contiguous packets of the flow; ensuring that a reclassified packet progresses through ARQ methods; and declassifying a DetNet packet to a lower priority rather than discarding it using IP-in-IP encapsulation and a deadline header with a deadline that is computed on the fly based on the remaining time till the bounded time of delivery for the packet.