RTP Media Congestion Avoidance
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Coupled congestion control for RTP media
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Abstract

When multiple congestion controlled RTP sessions traverse the same network bottleneck, it can be beneficial to combine their controls such that the total on-the-wire behavior is improved. This document describes such a method for flows that have the same sender, in a way that is as flexible and simple as possible while minimizing the amount of changes needed to existing RTP applications. It specifies how to apply the method for both the NADA and Google congestion control algorithms.

Status of this Memo

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1. Introduction

When there is enough data to send, a congestion controller must increase its sending rate until the path's capacity has been reached; depending on the controller, sometimes the rate is increased further, until packets are ECN-marked or dropped. This process inevitably creates undesirable queuing delay -- an effect that is amplified when multiple congestion controlled connections traverse the same network bottleneck.

The Congestion Manager (CM) [RFC3124] couples flows by providing a single congestion controller. It is hard to implement because it requires an additional congestion controller and removes all per-connection congestion control functionality, which is quite a significant change to existing RTP based applications. This document presents a method to combine the behavior of congestion control mechanisms that is easier to implement than the Congestion Manager [RFC3124] and also requires less significant changes to existing RTP based applications. It attempts to roughly approximate the CM behavior by sharing information between existing congestion controllers. It is able to honor user-specified priorities, which is required by rtcweb [RFC7478].

2. Definitions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Available Bandwidth:
: The available bandwidth is the nominal link capacity minus the amount of traffic that traversed the link during a certain time interval, divided by that time interval.

Bottleneck:
: The first link with the smallest available bandwidth along the path between a sender and receiver.

Flow:
: A flow is the entity that congestion control is operating on. It could, for example, be a transport layer connection, an RTP session, or a subsession that is multiplexed onto a single RTP session together with other subsessions.

Flow Group Identifier (FGI):
A unique identifier for each subset of flows that is limited by a common bottleneck.

Flow State Exchange (FSE):
The entity that maintains information that is exchanged between flows.

Flow Group (FG):
A group of flows having the same FGI.

Shared Bottleneck Detection (SBD):
The entity that determines which flows traverse the same bottleneck in the network, or the process of doing so.

3. Limitations

Sender-side only:
Coupled congestion control as described here only operates inside a single host on the sender side. This is because, irrespective of where the major decisions for congestion control are taken, the sender of a flow needs to eventually decide the transmission rate. Additionally, the necessary information about how much data an application can currently send on a flow is often only available at the sender side, making the sender an obvious choice for placement of the elements and mechanisms described here.

Shared bottlenecks do not change quickly:
As per the definition above, a bottleneck depends on cross traffic, and since such traffic can heavily fluctuate, bottlenecks can change at a high frequency (e.g., there can be oscillation between two or more links). This means that, when flows are partially routed along different paths, they may quickly change between sharing and not sharing a bottleneck. For simplicity, here it is assumed that a shared bottleneck is valid for a time interval that is significantly longer than the interval at which congestion controllers operate. Note that, for the only SBD mechanism defined in this document (multiplexing on the same five-tuple), the notion of a shared bottleneck stays correct even in the presence of fast traffic fluctuations: since all flows that are assumed to share a bottleneck are routed in the same way, if the bottleneck changes, it will still be shared.

4. Architectural overview

Figure 1 shows the elements of the architecture for coupled congestion control: the Flow State Exchange (FSE), Shared Bottleneck Detection (SBD) and Flows. The FSE is a storage element that can be implemented in two ways: active and passive. In the active version, it initiates communication with flows and SBD. However, in the passive version, it does not actively initiate communication with flows and SBD; its only active role is internal state maintenance (e.g., an implementation could use soft state to remove a flow's data after long periods of inactivity). Every time a flow's congestion control mechanism would normally update its sending rate, the flow instead updates information in the FSE and performs a query on the FSE, leading to a sending rate that can be different from what the congestion controller originally determined. Using information about/from the currently active flows, SBD updates the FSE with the correct Flow State Identifiers (FSIs). This document describes both active and passive versions, however the passive version is put into the appendix as it is extremely experimental.

```
                       -------  <---  Flow 1
                       | FSE |  <---  Flow 2 ..
                       -------  <---  .. Flow N
                          ^
                          |             |
                       -------          |
                       | SBD |  <-------|
                       -------
```

Figure 1: Coupled congestion control architecture

Since everything shown in Figure 1 is assumed to operate on a single host (the sender) only, this document only describes aspects that have an influence on the resulting on-the-wire behavior. It does, for instance, not define how many bits must be used to represent FSIs, or in which way the entities communicate. Implementations can take various forms: for instance, all the elements in the figure could be implemented within a single application, thereby operating on flows generated by that application only. Another alternative could be to implement both the FSE and SBD together in a separate process which different applications communicate with via some form of Inter-Process Communication (IPC). Such an implementation would extend the scope to flows generated by multiple applications. The FSE and SBD could also be included in the Operating System kernel.

5. Roles

This section gives an overview of the roles of the elements of coupled congestion control, and provides an example of how coupled congestion control can operate.

5.1. SBD

SBD uses knowledge about the flows to determine which flows belong in the same Flow Group (FG), and assigns FGIs accordingly. This knowledge can be derived in three basic ways:

1. From multiplexing: it can be based on the simple assumption that packets sharing the same five-tuple (IP source and destination address, protocol, and transport layer port number pair) and having the same Differentiated Services Code Point (DSCP) in the IP header are typically treated in the same way along the path. The latter method is the only one specified in this document: SBD MAY consider all flows that use the same five-tuple and DSCP to belong to the same FG. This classification applies to certain tunnels, or RTP flows that are multiplexed over one transport (cf. [transport-multiplex]). Such multiplexing is also a recommended usage of RTP in rtcweb [rtcweb-rtp-usage].

2. Via configuration: e.g. by assuming that a common wireless uplink is also a shared bottleneck.

3. From measurements: e.g. by considering correlations among measured delay and loss as an indication of a shared bottleneck.

The methods above have some essential trade-offs: e.g., multiplexing is a completely reliable measure, however it is limited in scope to two end points (i.e., it cannot be applied to couple congestion controllers of one sender talking to multiple receivers). A measurement-based SBD mechanism is described in [I-D.ietf-rmcat-sbd]. Measurements can never be 100% reliable, in particular because they are based on the past but applying coupled congestion control means to make an assumption about the future; it is therefore recommended to implement cautionary measures, e.g. by disabling coupled congestion control if enabling it causes a significant increase in delay and/or packet loss. Measurements also take time, which entails a certain delay for turning on coupling (refer to [I-D.ietf-rmcat-sbd] for details).

5.2. FSE

The FSE contains a list of all flows that have registered with it. For each flow, it stores the following:

- a unique flow number to identify the flow
- the FGI of the FG that it belongs to (based on the definitions in this document, a flow has only one bottleneck, and can therefore be in only one FG)
- a priority P, which here is assumed to be represented as a floating point number in the range from 0.1 (unimportant) to 1 (very important).
- The rate used by the flow in bits per second, FSE_R.

Note that the priority does not need to be a floating point value and its value range does not matter for this algorithm: the algorithm works with a flow's priority portion of the sum of all priority values. Priority values can therefore also be mapped to the "very-low", "low", "medium" or "high" priority levels described in [I-D.ietf-rtcweb-transports].

The FSE can operate on window-based as well as rate-based congestion controllers (TEMPORARY NOTE: and probably -- not yet tested -- combinations thereof, with calculations to convert from one to the other). In case of a window-based controller, FSE_R is a window, and all the text below should be considered to refer to window, not rates.

In the FSE, each FG contains one static variable S_CR which is the sum of the calculated rates of all flows in the same FG. This value is used to calculate the sending rate.

The information listed here is enough to implement the sample flow algorithm given below. FSE implementations could easily be extended to store, e.g., a flow's current sending rate for statistics gathering or future potential optimizations.

5.3. Flows

Flows register themselves with SBD and FSE when they start, deregister from the FSE when they stop, and carry out an UPDATE function call every time their congestion controller calculates a new sending rate. Via UPDATE, they provide the newly calculated rate and optionally (if the algorithm supports it) the desired rate. The desired rate is less than the calculated rate in case of application-limited flows; otherwise, it is the same as the calculated rate.

Below, two example algorithms are described. While other algorithms could be used instead, the same algorithm must be applied to all flows.

5.3.1. Example algorithm 1 - Active FSE

This algorithm was designed to be the simplest possible method to assign rates according to the priorities of flows. Simulations results in [fse] indicate that it does however not significantly reduce queuing delay and packet loss.

(1) When a flow f starts, it registers itself with SBD and the FSE. FSE_R is initialized with the congestion controller's initial rate. SBD will assign the correct FGI. When a flow is assigned an FGI, it adds its FSE_R to S_CR.

(2) When a flow f stops, its entry is removed from the list.

(3) Every time the congestion controller of the flow f determines a new sending rate CC_R, the flow calls UPDATE, which carries out the tasks listed below to derive the new sending rates for all the flows in the FG. A flow's UPDATE function uses a local (i.e. per-flow) temporary variable S_P, which is the sum of all the priorities.

(a) It updates S_CR.

```
S_CR = S_CR + CC_R - FSE_R(f)
```

(b) It calculates the sum of all the priorities, S_P.

```
S_P = 0
for all flows i in FG do
    S_P = S_P + P(i)
end for
```

(c) It calculates the sending rates for all the flows in an FG and distributes them.

```
for all flows i in FG do
    FSE_R(i) = (P(i)*S_CR)/S_P
    send FSE_R(i) to the flow i
end for
```

5.3.2. Example algorithm 2 - Conservative Active FSE

This algorithm extends algorithm 1 to conservatively emulate the behavior of a single flow by proportionally reducing the aggregate rate on congestion. Simulations results in [fse] indicate that it

can significantly reduce queuing delay and packet loss.

(1) When a flow f starts, it registers itself with SBD and the FSE. FSE_R is initialized with the congestion controller's initial rate. SBD will assign the correct FGI. When a flow is assigned an FGI, it adds its FSE_R to S_CR.

(2) When a flow f stops, its entry is removed from the list.

(3) Every time the congestion controller of the flow f determines a new sending rate CC_R, the flow calls UPDATE, which carries out the tasks listed below to derive the new sending rates for all the flows in the FG. A flow's UPDATE function uses a local (i.e. per-flow) temporary variable S_P, which is the sum of all the priorities, and a local variable DELTA, which is used to calculate the difference between CC_R and the previously stored FSE_R. To prevent flows from either ignoring congestion or overreacting, a timer keeps them from changing their rates immediately after the common rate reduction that follows a congestion event. This timer is set to 2 RTTs of the flow that experienced congestion because it is assumed that a congestion event can persist for up to one RTT of that flow, with another RTT added to compensate for fluctuations in the measured RTT value.

(a) It updates S_CR based on DELTA.

```
if Timer has expired or not set then
  DELTA = CC_R - FSE_R(f)
  if DELTA < 0 then  // Reduce S_CR proportionally
    S_CR = S_CR * CC_R / FSE_R(f)
    Set Timer for 2 RTTs
  else
    S_CR = S_CR + DELTA
  end if
 end if
```

(b) It calculates the sum of all the priorities, S_P.

```
S_P = 0
for all flows i in FG do
    S_P = S_P + P(i)
end for
```

(c) It calculates the sending rates for all the flows in an FG and distributes them.

```
for all flows i in FG do
    FSE_R(i) = (P(i)*S_CR)/S_P
    send FSE_R(i) to the flow i
end for
```

6. Application

This section specifies how the FSE can be applied to specific congestion control mechanisms and makes general recommendations that facilitate applying the FSE to future congestion controls.

6.1. NADA

Network-Assisted Dynamic Adapation (NADA) [I-D.ietf-rmcat-nada] is a congestion control scheme for rtcweb. It calculates a reference rate r_ref upon receiving an acknowledgment, and then, based on the reference rate, it calculates a video target rate r_vin and a sending rate for the flows, r_send.

When applying the FSE to NADA, the UPDATE function call described in Section 5.3 gives the FSE NADA's reference rate r_ref. The recommended algorithm for NADA is the Active FSE in Section 5.3.1. In step 3 (c), when the FSE_R(i) is "sent" to the flow i, this means updating r_ref(r_vin and r_send) of flow i with the value of FSE_R(i).

6.2. GCC

Google Congestion Control (GCC) [I-D.ietf-rmcat-gcc] is another congestion control scheme for rtcweb. The rate control of GCC employs two parts: controlling the bandwidth estimate based on delay, and controlling the bandwidth estimate based on loss. Both are designed to estimate the available bandwidth, A_hat.

When applying the FSE to GCC, the UPDATE function call described in Section 5.3 gives the FSE GCC's estimate of available bandwidth A_hat. The recommended algorithm for GCC is the Active FSE in Section 5.3.1. In step 3 (c), when the FSE_R(i) is "sent" to the flow i, this means updating A_hat of flow i with the value of FSE_R(i).

6.3. General recommendations

This section will provides general advice for applying the FSE to congestion control mechanisms. TEMPORARY NOTE: Future versions of this document will contain a longer list.

Receiver-side calculations:
: When receiver-side calculations make assumptions about the rate of the sender, the calculations need to be synchronized or the receiver needs to be updated accordingly. This applies to TFRC [RFC5348], for example, where simulations showed somewhat less favorable results when using the FSE without a receiver-side change [fse].

7. Acknowledgements

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8. IANA Considerations

This memo includes no request to IANA.

9. Security Considerations

In scenarios where the architecture described in this document is applied across applications, various cheating possibilities arise: e.g., supporting wrong values for the calculated rate, the desired rate, or the priority of a flow. In the worst case, such cheating could either prevent other flows from sending or make them send at a rate that is unreasonably large. The end result would be unfair behavior at the network bottleneck, akin to what could be achieved with any UDP based application. Hence, since this is no worse than UDP in general, there seems to be no significant harm in using this in the absence of UDP rate limiters.

In the case of a single-user system, it should also be in the interest of any application programmer to give the user the best

possible experience by using reasonable flow priorities or even letting the user choose them. In a multi-user system, this interest may not be given, and one could imagine the worst case of an "arms race" situation, where applications end up setting their priorities to the maximum value. If all applications do this, the end result is a fair allocation in which the priority mechanism is implicitly eliminated, and no major harm is done.

10. References

10.1. Normative References

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Appendix A. Scheduling

When connections originate from the same host, it would be possible to use only one single sender-side congestion controller which determines the overall allowed sending rate, and then use a local scheduler to assign a proportion of this rate to each RTP session. This way, priorities could also be implemented as a function of the scheduler. The Congestion Manager (CM) [RFC3124] also uses such a scheduling function.

Appendix B. Example algorithm - Passive FSE

Active algorithms calculate the rates for all the flows in the FG and actively distribute them. In a passive algorithm, UPDATE returns a rate that should be used instead of the rate that the congestion controller has determined. This can make a passive algorithm easier to implement; however, when round-trip times of flows are unequal,

shorter-RTT flows will update and react to the overall FSE state more often than longer-RTT flows, which can produce unwanted side effects. This problem is more significant when the congestion control convergence depends on the RTT. While the passive algorithm works better for congestion controls with RTT-independent convergence, it can still produce oscillations on short time scales. The algorithm described below is therefore considered as highly experimental.

This passive version of the FSE stores the following information in addition to the variables described in Section 5.2:

o The desired rate DR. This can be smaller than the calculated rate if the application feeding into the flow has less data to send than the congestion controller would allow. In case of a bulk transfer, DR must be set to CC_R received from the flow's congestion module.

The passive version of the FSE contains one static variable per FG called TLO (Total Leftover Rate -- used to let a flow 'take' bandwidth from application-limited or terminated flows) which is initialized to 0. For the passive version, S_CR is limited to increase or decrease as conservatively as a flow's congestion controller decides in order to prohibit sudden rate jumps.

(1) When a flow f starts, it registers itself with SBD and the FSE. FSE_R and DR are initialized with the congestion controller's initial rate. SBD will assign the correct FGI. When a flow is assigned an FGI, it adds its FSE_R to S_CR.

(2) When a flow f stops, it sets its DR to 0 and sets P to -1.

(3) Every time the congestion controller of the flow f determines a new sending rate CC_R, assuming the flow's new desired rate new_DR to be "infinity" in case of a bulk data transfer with an unknown maximum rate, the flow calls UPDATE, which carries out the tasks listed below to derive the flow's new sending rate, Rate. A flow's UPDATE function uses a few local (i.e. per-flow) temporary variables, which are all initialized to 0: DELTA, new_S_CR and S_P.

    (a) For all the flows in its FG (including itself), it calculates the sum of all the calculated rates, new_S_CR. Then it calculates the difference between FSE_R(f) and CC_R, DELTA.

```
for all flows i in FG do
    new_S_CR = new_S_CR + FSE_R(i)
```

```
           end for
           DELTA =  CC_R - FSE_R(f)
```

(b) It updates S_CR, FSE_R(f) and DR(f).

```
           FSE_R(f) = CC_R
           if DELTA > 0 then  // the flow's rate has increased
               S_CR = S_CR + DELTA
           else if DELTA < 0 then
               S_CR = new_S_CR + DELTA
           end if
           DR(f) = min(new_DR,FSE_R(f))
```

(c) It calculates the leftover rate TLO, removes the terminated flows from the FSE and calculates the sum of all the priorities, S_P.

```
           for all flows i in FG do
              if P(i)<0 then
                 delete flow
              else
                 S_P = S_P + P(i)
              end if
           end for
           if DR(f) < FSE_R(f) then
              TLO = TLO + (P(f)/S_P) * S_CR - DR(f))
           end if
```

(d) It calculates the sending rate, Rate.

```
           Rate = min(new_DR, (P(f)*S_CR)/S_P + TLO)

           if Rate != new_DR and TLO > 0 then
               TLO = 0  // f has 'taken' TLO
           end if
```

(e) It updates DR(f) and FSE_R(f) with Rate.

```
           if Rate > DR(f) then
               DR(f) = Rate
           end if
           FSE_R(f)  = Rate
```

The goals of the flow algorithm are to achieve prioritization,

improve network utilization in the face of application-limited flows, and impose limits on the increase behavior such that the negative impact of multiple flows trying to increase their rate together is minimized. It does that by assigning a flow a sending rate that may not be what the flow's congestion controller expected. It therefore builds on the assumption that no significant inefficiencies arise from temporary application-limited behavior or from quickly jumping to a rate that is higher than the congestion controller intended. How problematic these issues really are depends on the controllers in use and requires careful per-controller experimentation. The coupled congestion control mechanism described here also does not require all controllers to be equal; effects of heterogeneous controllers, or homogeneous controllers being in different states, are also subject to experimentation.

This algorithm gives all the leftover rate of application-limited flows to the first flow that updates its sending rate, provided that this flow needs it all (otherwise, its own leftover rate can be taken by the next flow that updates its rate). Other policies could be applied, e.g. to divide the leftover rate of a flow equally among all other flows in the FGI.

B.1. Example operation (passive)

In order to illustrate the operation of the passive coupled congestion control algorithm, this section presents a toy example of two flows that use it. Let us assume that both flows traverse a common 10 Mbit/s bottleneck and use a simplistic congestion controller that starts out with 1 Mbit/s, increases its rate by 1 Mbit/s in the absence of congestion and decreases it by 2 Mbit/s in the presence of congestion. For simplicity, flows are assumed to always operate in a round-robin fashion. Rate numbers below without units are assumed to be in Mbit/s. For illustration purposes, the actual sending rate is also shown for every flow in FSE diagrams even though it is not really stored in the FSE.

Flow #1 begins. It is a bulk data transfer and considers itself to have top priority. This is the FSE after the flow algorithm's step 1:

```
----------------------------------------
| # | FGI |  P  | FSE_R  |  DR  | Rate |
|   |     |     |        |      |      |
| 1 |  1  |  1  |   1    |   1  |   1  |
----------------------------------------
S_CR = 1, TLO = 0
```

Its congestion controller gradually increases its rate. Eventually, at some point, the FSE should look like this:

#	FGI	P	FSE_R	DR	Rate
1	1	1	10	10	10

S_CR = 10, TLO = 0

Now another flow joins. It is also a bulk data transfer, and has a lower priority (0.5):

#	FGI	P	FSE_R	DR	Rate
1	1	1	10	10	10
2	1	0.5	1	1	1

S_CR = 11, TLO = 0

Now assume that the first flow updates its rate to 8, because the total sending rate of 11 exceeds the total capacity. Let us take a closer look at what happens in step 3 of the flow algorithm.

CC_R = 8. new_DR = infinity.
3 a) new_S_CR = 11; DELTA = 8 - 10 = -2.
3 b) FSE_Rf) = 8. DELTA is negative, hence S_CR = 9;
     DR(f) = 8.
3 c) S_P = 1.5.
3 d) new sending rate = min(infinity, 1/1.5 * 9 + 0) = 6.
3 e) FSE_R(f) = 6.

The resulting FSE looks as follows:

#	FGI	P	FSE_R	DR	Rate
1	1	1	6	8	6
2	1	0.5	1	1	1

S_CR = 9, TLO = 0

The effect is that flow #1 is sending with 6 Mbit/s instead of the 8 Mbit/s that the congestion controller derived. Let us now assume that flow #2 updates its rate. Its congestion controller detects that the network is not fully saturated (the actual total sending rate is 6+1=7) and increases its rate.

```
CC_R=2. new_DR = infinity.
3 a) new_S_CR = 7; DELTA = 2 - 1 = 1.
3 b) FSE_R(f) = 2. DELTA is positive, hence S_CR = 9 + 1 = 10;
     DR(f) = 2.
3 c) S_P = 1.5.
3 d) new sending rate = min(infinity, 0.5/1.5 * 10 + 0) = 3.33.
3 e) DR(f) = FSE_R(f) = 3.33.
```

The resulting FSE looks as follows:

#	FGI	P	FSE_R	DR	Rate
1	1	1	6	8	6
2	1	0.5	3.33	3.33	3.33

S_CR = 10, TLO = 0

The effect is that flow #2 is now sending with 3.33 Mbit/s, which is close to half of the rate of flow #1 and leads to a total utilization of 6(#1) + 3.33(#2) = 9.33 Mbit/s. Flow #2's congestion controller has increased its rate faster than the controller actually expected. Now, flow #1 updates its rate. Its congestion controller detects that the network is not fully saturated and increases its rate. Additionally, the application feeding into flow #1 limits the flow's sending rate to at most 2 Mbit/s.

CC_R=7. new_DR=2.
3 a) new_S_CR = 9.33; DELTA = 1.
3 b) FSE_R(f) = 7, DELTA is positive, hence S_CR = 10 + 1 = 11;
     DR = min(2, 7) = 2.
3 c) S_P = 1.5; DR(f) < FSE_R(f), hence TLO = 1/1.5 * 11 - 2 = 5.33.
3 d) new sending rate = min(2, 1/1.5 * 11 + 5.33) = 2.
3 e) FSE_R(f) = 2.

The resulting FSE looks as follows:

#	FGI	P	FSE_R	DR	Rate
1	1	1	2	2	2
2	1	0.5	3.33	3.33	3.33

S_CR = 11, TLO = 5.33

Now, the total rate of the two flows is 2 + 3.33 = 5.33 Mbit/s, i.e. the network is significantly underutilized due to the limitation of flow #1. Flow #2 updates its rate. Its congestion controller detects that the network is not fully saturated and increases its rate.

CC_R=4.33. new_DR = infinity.
3 a) new_S_CR = 5.33; DELTA = 1.
3 b) FSE_R(f) = 4.33. DELTA is positive, hence S_CR = 12;
     DR(f) = 4.33.
3 c) S_P = 1.5.
3 d) new sending rate: min(infinity, 0.5/1.5 * 12 + 5.33) = 9.33.
3 e) FSE_R(f) = 9.33, DR(f) = 9.33.

The resulting FSE looks as follows:

#	FGI	P	FSE_R	DR	Rate
1	1	1	2	2	2
2	1	0.5	9.33	9.33	9.33

S_CR = 12, TLO = 0

Now, the total rate of the two flows is 2 + 9.33 = 11.33 Mbit/s. Finally, flow #1 terminates. It sets P to -1 and DR to 0. Let us

assume that it terminated late enough for flow #2 to still experience the network in a congested state, i.e. flow #2 decreases its rate in the next iteration.

```
CC_R = 7.33. new_DR = infinity.
3 a) new_S_CR = 11.33; DELTA = -2.
3 b) FSE_R(f) = 7.33. DELTA is negative, hence S_CR = 9.33;
     DR(f) = 7.33.
3 c) Flow 1 has P = -1, hence it is deleted from the FSE.
     S_P = 0.5.
3 d) new sending rate: min(infinity, 0.5/0.5*9.33 + 0) = 9.33.
3 e) FSE_R(f) = DR(f) = 9.33.
```

The resulting FSE looks as follows:

#	FGI	P	FSE_R	DR	Rate
2	1	0.5	9.33	9.33	9.33

S_CR = 9.33, TLO = 0

Appendix C. Change log

C.1. draft-welzl-rmcat-coupled-cc

C.1.1. Changes from -00 to -01

- Added change log.

- Updated the example algorithm and its operation.

C.1.2. Changes from -01 to -02

- Included an active version of the algorithm which is simpler.

- Replaced "greedy flow" with "bulk data transfer" and "non-greedy" with "application-limited".

- Updated new_CR to CC_R, and CR to FSE_R for better understanding.

C.1.3. Changes from -02 to -03

- Included an active conservative version of the algorithm which reduces queue growth and packet loss; added a reference to a technical report that shows these benefits with simulations.

- Moved the passive variant of the algorithm to appendix.

C.1.4. Changes from -03 to -04

- Extended SBD section.

- Added a note about window-based controllers.

C.1.5. Changes from -04 to -05

- Added a section about applying the FSE to specific congestion control algorithms, with a subsection specifying its use with NADA.

C.2. draft-ietf-rmcat-coupled-cc

C.2.1. Changes from draft-welzl-rmcat-coupled-cc-05

- Moved scheduling section to the appendix.

C.2.2. Changes from -00 to -01

- Included how to apply the algorithm to GCC.

- Updated variable names of NADA to be in line with the latest version.

- Added a reference to [I-D.ietf-rtcweb-transports] to make a connection to the prioritization text there.

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