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                 Test Cases for Evaluating RMCAT Proposals
                       draft-ietf-rmcat-eval-test-03

Abstract

   The Real-time Transport Protocol (RTP) is used to transmit media in
   multimedia telephony applications, these applications are typically
   required to implement congestion control. This document describes
   the test cases to be used in the performance evaluation of such
   congestion control algorithms.

Status of This Memo

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1. Introduction

   This memo describes a set of test cases for evaluating congestion
   control algorithm proposals for real-time interactive media. It is
   based on the guidelines enumerated in [I-D.ietf-rmcat-eval-criteria]
   and the requirements discussed in [I-D.ietf-rmcat-cc-requirements].
   The test cases cover basic usage scenarios and are described using a
   common structure, which allows for additional test cases to be added
   to those described herein to accommodate other topologies and/or the
   modeling of different path characteristics. The described test cases

in this memo SHOULD be used to evaluate any proposed congestion
control algorithm for real-time interactive media.

2. Terminology

The terminology defined in RTP [RFC3550], RTP Profile for Audio and
Video Conferences with Minimal Control [RFC3551], RTCP Extended
Report (XR) [RFC3611], Extended RTP Profile for RTCP-based Feedback
(RTP/AVPF) [RFC4585], and Support for Reduced-Size RTCP [RFC5506]
apply.

3. Structure of Test cases

All the test cases in this document follow a basic structure allowing
implementers to describe a new test scenario without repeatedly
explaining common attributes. The structure includes a general
description section that describes the test case and its motivation.
Additionally the test case defines a set of attributes that
characterize the testbed, for example, the network path between
communicating peers and the diverse traffic sources.

o Define the test case:

   * General description: describes the motivation and the goals of
      the test case.

   * Expected behavior: describes the desired rate adaptation
      behavior.

   * Define a list of metrics to evaluate the desired behavior: this
      indicates the minimum set of metrics (e.g., link utilization,
      media sending rate) that a proposed algorithm needs to measure
      to validate the expected rate adaptation behavior. It should
      also indicate the time granularity (e.g., averaged over 10ms,
      100ms, or 1s) for measuring certain metrics. Typical
      measurement interval is 200ms.

o Define testbed topology: every test case needs to define an
   evaluation testbed topology. Figure 1 shows such an evaluation
   topology. In this evaluation topology, S1..Sn are traffic
   sources. These sources generate media traffic and use either
   congestion control algorithm under investigation. R1..Rn are the
   corresponding receivers. A test case can have one or more such
   traffic sources (S) and their corresponding receivers (R). The
   path from the source to destination is denoted as "forward" and
   the path from a destination to a source is denoted as "backward".
   The following basic structure of the test case has been described
   from the perspective of media generating endpoints attached on the

left-hand side of Figure 1. In this setup, the media flows are
transported in forward direction and corresponding feedback/
control messages are transported in the backward direction.
However, it is also possible to set up the test with media in both
forward and backward directions. In that case, unless otherwise
specified by the test case, it is expected that the backward path
does not introduce any congestion related impairments and has
enough capacity to accommodate both media and feedback/control
messages. It should be noted that depending on the test cases it
is possible to have different path characteristics in either of
the directions.

```
+---+                                                   +---+
|S1 |====== \                 Forward -->        / ======|R1 |
+---+        \\                                 //        +---+
              \\                               //
+---+       +-----+                        +-----+       +---+
|S2 |=======|  A  |------------------------------->|  B  |======|R2 |
+---+       |     |<-----------------------------|     |       +---+
            +-----+                        +-----+
(...)          //                               \\          (...)
              //           <-- Backward          \\
+---+        //                                   \\        +---+
|Sn |====== /                                       \ ======|Rn |
+---+                                                   +---+
```
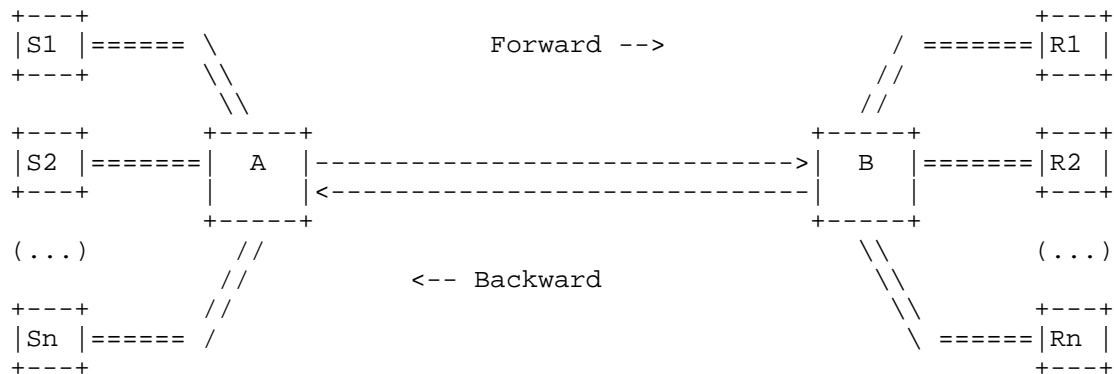
                Figure 1: Example of A Testbed Topology

   In a testbed environment where real equipments are used to create
   a laboratory, there may exist a significant amount of traffic on
   portions of the network path between the endpoints that is not
   desired for the purposes of the tests described in the document.
   Some of this traffic may be generated by other processes on the
   endpoints themselves (e.g., discovery protocols) or by other
   endpoints not presently under test. It is recommended not to
   route traffic generated by endpoints that are not under test
   through the test bed and route those traffic generated by the
   endpoints under test around the bottleneck links specified herein.

   o Define testbed attributes:

   * Duration: defines the duration of the test in seconds.

   * Path characteristics: defines the end-to-end transport level
      path characteristics of the testbed for a particular test case.
      Two sets of attributes describe the path characteristics, one
      for the forward path and the other for the backward path. The
      path characteristics for a particular path direction is

applicable to all the Sources "S" sending traffic on that path.
If only one attribute is specified, it is used for both path
directions, however, unless specified the reverse path has no
capacity restrictions and no path loss.

+ Path direction: forward or backward.

+ Bottleneck-link capacity: defines minimum capacity of the
  end-to-end path

+ Reference bottleneck capacity: defines a reference value for
  the bottleneck capacity for test cases with time-varying
  bottleneck capacities. All bottleneck capacities will be
  specified as a ratio with respect to the reference capacity
  value.

+ One-way propagation delay: describes the end-to-end latency
  along the path when network queues are empty, i.e., the time
  it takes for a packet to go from the sender to the receiver
  without encountering any queuing delay.

+ Maximum end-to-end jitter: defines the maximum jitter that
  can be observed along the path.

+ Bottleneck queue type: for example, Droptail, FQ-CoDel, or
  PIE.

+ Bottleneck queue size: defines the size of queue in terms of
  queuing time when the queue is full (in milliseconds).

+ Path loss ratio: characterizes the non-congested, additive,
  losses to be generated on the end-to-end path. MUST
  describe the loss pattern or loss model used to generate the
  losses.

* Application-related: defines the traffic source behavior for
  implementing the test case

+ Media traffic Source: defines the characteristics of the
  media sources. When using more than one media source, the
  different attributes are enumerated separately for each
  different media source.

  – Media type: Video/Voice

  – Media flow direction: forward, backward or both.

- Number of media sources: defines the total number of
  media sources

- Media codec: Constant Bit Rate (CBR) or Variable Bit Rate
  (VBR)

- Media source behavior: describes the media encoder
  behavior. It defines the main parameters that affect the
  adaptation behavior. This may include but is not limited
  to:

  o Adaptability: describes the adaptation options. For
    example, in the case of video it defines the following
    ranges of adaptation: bit rate, frame rate, video
    resolution. Similarly, in the case of voice, it
    defines the range of bit rate adaptation, the sampling
    rate variation, and the variation in packetization
    interval.

  o Output variation : for a VBR encoder it defines the
    encoder output variation from the average target rate
    over a particular measurement interval. For example,
    on average the encoder output may vary between 5% to
    15% above or below the average target bit rate when
    measured over a 100 ms time window. The time interval
    over which the variation is specified must be
    provided.

  o Responsiveness to a new bit rate request: the lag in
    time between a new bit rate request from the
    congestion control algorithm and actual rate changes
    in encoder output. Depending on the encoder, this
    value may be specified in absolute time (e.g. 10ms to
    1000ms) or other appropriate metric (e.g. next frame
    interval time).

  More detailed discussions on expected media source
  behavior, including those from synthetic video traffic
  sources, is at [I-D.ietf-rmcat-video-traffic-model].

- Media content: describes the chosen media sequences; For
  example, test sequences are available at: [xiph-seq] and
  [HEVC-seq].

- Media timeline: describes the point when the media source
  is introduced and removed from the testbed. For example,
  the media source may start transmitting immediately when
  the test case begins, or after a few seconds.

           - Startup behavior: the media starts at a defined bit rate,
             which may be the minimum, maximum bit rate, or a value in
             between (in Kbps).

        + Competing traffic source: describes the characteristics of
          the competing traffic source, the different types of
          competing flows are enumerated in
          [I-D.ietf-rmcat-eval-criteria].

           - Traffic direction: forward, backward or both.

           - Type of sources: defines the types of competing traffic
             sources. Types of competing traffic flows are listed in
             [I-D.ietf-rmcat-eval-criteria]. For example, the number
             of TCP flows connected to a web browser, the mean size
             and distribution of the content downloaded.

           - Number of sources: defines the total number of competing
             sources of each media type per traffic direction.

           - Congestion control: enumerates the congestion control
             used by each type of competing traffic.

           - Traffic timeline: describes when the competing traffic
             starts and ends in the test case.

     * Additional attributes: describes attributes essential for
       implementing a test case which are not included in the above
       structure. These attributes MUST be well defined, so that the
       other implementers of that particular test case are able to
       implement it easily.

   Any attribute can have a set of values (enclosed within "[]"). Each
   member value of such a set MUST be treated as different value for the
   same attribute. It is desired to run separate tests for each such
   attribute value.

   The test cases described in this document follow the above structure.

4. Recommended Evaluation Settings

   This section describes recommended test case settings and could be
   overwritten by the respective test cases.

4.1. Evaluation metrics

   To evaluate the performance of the candidate algorithms the
   implementers MUST log enough information to visualize the following
   metrics at a fine enough time granularity:

   1. Flow level:

       A. End-to-end delay for the congestion controlled media flow.

       B. Variation in sending bit rate and goodput. Mainly observing
           the frequency and magnitude of oscillations.

       C. Packet losses observed at the receiving endpoint.

       D. Feedback message overhead.

       E. Convergence time - time to reach steady state for the
           congestion controlled media flow(s).

   2. Transport level:

       A. Bandwidth utilization.

       B. Queue length (milliseconds at specified path capacity):

           + average over the length of the session.

           + 5 and 95 percentile.

           + median, maximum, minimum.

4.2. Path characteristics

   Each path between a sender and receiver as described in Figure 1 have
   the following characteristics unless otherwise specified in the test
   case.

   o Path direction: forward and backward.

   o Reference bottleneck capacity: 1Mbps.

   o One-Way propagation delay: 50ms. Implementers are encouraged to
      run the experiment with additional propagation delays mentioned in
      [I-D.ietf-rmcat-eval-criteria]

   o Maximum end-to-end jitter: 30ms. Jitter models are described in
      [I-D.ietf-rmcat-eval-criteria]

o Bottleneck queue type: Drop tail. Implementers are encouraged to
   run the experiment with other AQM schemes, such as FQ-CoDel and
   PIE.

o Bottleneck queue size: 300ms.

o Path loss ratio: 0%.

Examples of additional network parameters are discussed in
[I-D.ietf-rmcat-eval-criteria].

For test cases involving time-varying bottleneck capacity, all
capacity values are specified as a ratio with respect to a reference
capacity value, so as to allow flexible scaling of capacity values
along with media source rate range. There exist two different
mechanisms for inducing path capacity variation: a) by explicitly
modifying the value of physical link capacity; or b) by introducing
background non-adaptive UDP traffic with time-varying traffic rate.
Implementers are encouraged to run the experiments with both
mechanisms for test cases specified in Section 5.1, Section 5.2, and
Section 5.3.

4.3. Media source

Unless otherwise specified, each test case will include one or more
media sources as described below.

o Media type: Video

   * Media codec: VBR

   * Media source behavior:

      + Adaptability:

         - Bit rate range: 150 Kbps - 1.5 Mbps. In real-life
            applications the bit rate range can vary a lot depending
            on the provided service, for example, the maximum bit
            rate can be up to 4Mbps. However, for running tests to
            evaluate the congestion control algorithms it is more
            important to have a look at how they are reacting to
            certain amount of bandwidth change. Also it is possible
            that the media traffic generator used in a particular
            simulator or testbed is not capable of generating higher
            bit rate. Hence we have selected a suitable bit rate
            range typical of consumer-grade video conferencing
            applications in designing the test case. If a different
            bit rate range is used in the test cases, then the end-

                    to-end path capacity values will also need to be scaled
                    accordingly.

             -   Frame resolution: 144p - 720p (or 1080p). This
                 resolution range is selected based on the bit rate range.
                 If a different bit rate range is used in the test cases
                 then the frame resolution range also need to be selected
                 suitably.

             -   Frame rate: 10fps - 30fps. This frame rate range is
                 selected based on the bit rate range. If a different bit
                 rate range is used in the test cases then the frame rate
                 range also need to be adjusted suitably.

          + Variation from target bit rate: +/-5%. Unless otherwise
             specified in the test case(s), bit rate variation SHOULD be
             calculated over one (1) second period of time.

          + Responsiveness to new bit rate request: 100ms

       * Media content: The media content should represent a typical
          video conversational scenario with head and shoulder movement.
          We recommend to use Foreman video sequence.

       * Media startup behavior: 150Kbps. It should be noted that
          applications can use smart ways to select an optimal startup
          bit rate value for a certain network condition. In such cases
          the candidate proposals MAY show the effectiveness of such
          smart approach as an additional information for the evaluation
          process.

    o Media type: Audio

       * Media codec: CBR

       * Media bit rate: 20Kbps

5. Basic Test Cases

5.1. Variable Available Capacity with a Single Flow

    In this test case the bottleneck-link capacity between the two
    endpoints varies over time. This test is designed to measure the
    responsiveness of the candidate algorithm. This test tries to
    address the requirements in [I-D.ietf-rmcat-cc-requirements], which
    requires the algorithm to adapt the flow(s) and provide lower end-to-
    end latency when there exists:

o an intermediate bottleneck

o change in available capacity (e.g., due to interface change,
   routing change, abrupt arrival/departure of background non-
   adaptive traffic).

o maximum media bit rate is greater than link capacity. In this
   case, the application will attempt to ramp up to its maximum bit
   rate, since the link capacity is limited to a value lower, the
   congestion control scheme is expected to stabilize the sending bit
   rate close to the available bottleneck capacity.

It should be noted that the exact variation in available capacity due
to any of the above depends on the underlying technologies. Hence,
we describe a set of known factors, which may be extended to devise a
more specific test case targeting certain behaviors in a certain
network environment.

Expected behavior: the candidate algorithm is expected to detect the
path capacity constraint, converges to the bottleneck link's capacity
and adapt the flow to avoid unwanted oscillation when the sending bit
rate is approaching the bottleneck link's capacity. The oscillations
occur when the media flow(s) attempts to reach its maximum bit rate
but overshoots the usage of the available bottleneck capacity then to
rectify, it reduces the bit rate and starts to ramp up again.

Evaluation metrics : as described in Section 4.1.

Testbed topology: One media source S1 is connected to the
corresponding R1. The media traffic is transported over the forward
path and corresponding feedback/control traffic is transported over
the backward path.

```
                          Forward -->
+---+         +-----+                                  +-----+         +---+
|S1 |=======|  A  |--------------------------------->|  B  |=======|R1 |
+---+         |     |     |<-----------------------------|     |         +---+
              +-----+                                  +-----+
                          <-- Backward
```

        Figure 2: Testbed Topology for Limited Link Capacity

Testbed attributes:

o Test duration: 100s

o Path characteristics: as described in Section 4.2

   o Application-related:

      * Media Traffic:

         + Media type: Video

            - Media direction: forward.

            - Number of media sources: one (1)

            - Media timeline:

               o Start time: 0s.

               o End time: 99s.

         + Media type: Audio

            - Media direction: forward.

            - Number of media sources: one (1)

            - Media timeline:

               o Start time: 0s.

               o End time: 99s.

      * Competing traffic:

         + Number of sources : zero (0)

   o Test Specific Information:

      * One-way propagation delay: [50 ms, 100 ms]. on the forward
         path direction

      * This test uses bottleneck path capacity variation as listed in
         Table 1

      * When using background non-adaptive UDP traffic to induce time-
         varying bottleneck , the physical path capacity remains at
         4Mbps and the UDP traffic source rate changes over time as
         (4-x)Mbps, where x is the bottleneck capacity specified in
         Table 1

```
+-------------------+-------------+----------+------------------+
| Variation pattern | Path        | Start    | Path capacity    |
| index             | direction   | time     | ratio            |
+-------------------+-------------+----------+------------------+
| One               | Forward     | 0s       | 1.0              |
| Two               | Forward     | 40s      | 2.5              |
| Three             | Forward     | 60s      | 0.6              |
| Four              | Forward     | 80s      | 1.0              |
+-------------------+-------------+----------+------------------+
```

    Table 1: Path capacity variation pattern for forward direction

5.2. Variable Available Capacity with Multiple Flows

   This test case is similar to Section 5.1. However in addition this
   test will also consider persistent network load due to competing
   traffic.

   Expected behavior: the candidate algorithm is expected to detect the
   variation in available capacity and adapt the media stream(s)
   accordingly. The flows stabilize around their maximum bit rate as
   the maximum link capacity is large enough to accommodate the flows.
   When the available capacity drops, the flows adapt by decreasing
   their sending bit rate, and when congestion disappears, the flows are
   again expected to ramp up.

   Evaluation metrics : as described in Section 4.1.

   Testbed Topology: Two (2) media sources S1 and S2 are connected to
   their corresponding destinations R1 and R2. The media traffic is
   transported over the forward path and corresponding feedback/control
   traffic is transported over the backward path.
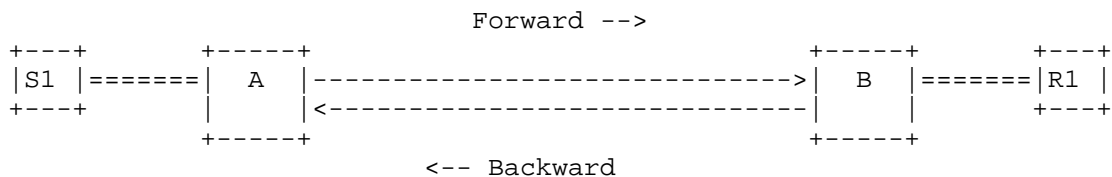
```
+---+                                                +---+
|S1 |===== \                                / ======|R1 |
+---+     \\              Forward -->       //       +---+
           \\                              //
          +-----+                        +-----+
          |  A  |------------------------------->|  B  |
          |     |<-------------------------------|     |
          +-----+                        +-----+
            //                              \\
            //           <-- Backward        \\
+---+     //                                   \\    +---+
|S2 |===== /                              \ =====|R2 |
+---+                                                +---+
```

    Figure 3: Testbed Topology for Variable Available Capacity

Testbed attributes:

Testbed attributes are similar as described in Section 5.1 except the test specific capacity variation setup.

Test Specific Information: This test uses path capacity variation as listed in Table 2 with a corresponding end time of 125 seconds. The reference bottleneck capacity is 2Mbps. When using background non-adaptive UDP traffic to induce time-varying bottleneck for congestion controlled media flows, the physical path capacity is 4Mbps and the UDP traffic source rate changes over time as (4-x)Mbps, where x is the bottleneck capacity specified in Table 2.

Variation pattern index	Path direction	Start time	Path capacity ratio
One	Forward	0s	2.0
Two	Forward	25s	1.0
Three	Forward	50s	1.75
Four	Forward	75s	0.5
Five	Forward	100s	1.0

Table 2: Path capacity variation pattern for forward direction

5.3. Congested Feedback Link with Bi-directional Media Flows

Real-time interactive media uses RTP hence it is assumed that RTCP, RTP header extension or such would be used by the congestion control algorithm in the backchannel. Due to asymmetric nature of the link between communicating peers it is possible for a participating peer to not receive such feedback information due to an impaired or congested backchannel (even when the forward channel might not be impaired). This test case is designed to observe the candidate congestion control behavior in such an event.

It is expected that the candidate algorithms are able to cope with the lack of feedback information and adapt to minimize the performance degradation of media flows in the forward channel.

It should be noted that for this test case: logs are compared with the reference case, i.e, when the backward channel has no impairments.

Evaluation metrics : as described in Section 4.1.

Testbed topology: One (1) media source S1 is connected to
corresponding R1, but both endpoints are additionally receiving and
sending data, respectively. The media traffic (S1->R1) is
transported over the forward path and corresponding feedback/control
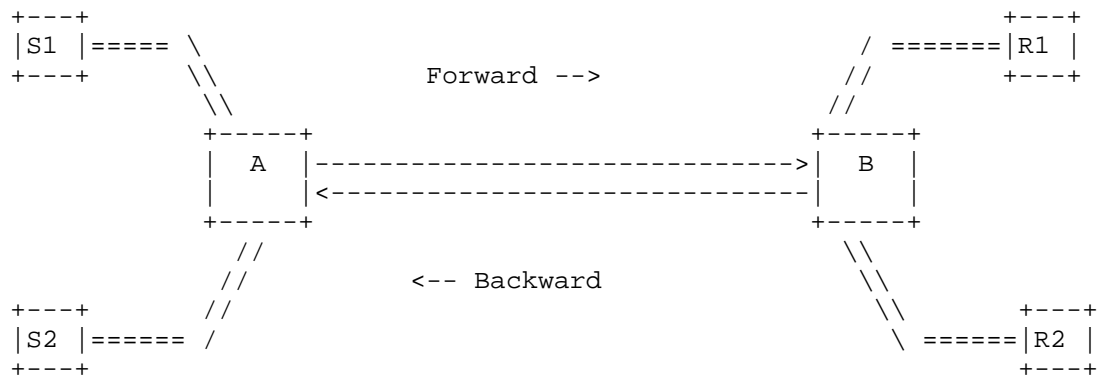traffic is transported over the backward path. Likewise media
traffic (S2->R2) is transported over the backward path and
corresponding feedback/control traffic is transported over the
forward path.

```
 +---+                                                      +---+
 |S1 |===== \            Forward -->           / ======|R1 |
 +---+      \\                                 //       +---+
             \\                               //
        +-----+                         +-----+
        |  A  |------------------------------->|  B  |
        |     |<-----------------------------|     |
        +-----+                         +-----+
          //                               \\
         //              <-- Backward        \\
 +---+  //                                   \\   +---+
 |R2 |===== /                              \ ======|S2 |
 +---+                                               +---+
```
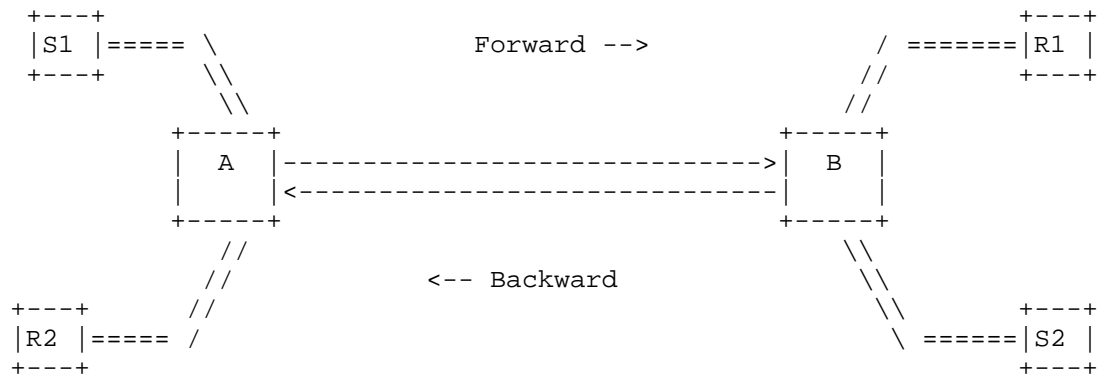
          Figure 4: Testbed Topology for Congested Feedback Link

   Testbed attributes:

   o Test duration: 100s

   o Path characteristics:

      * Reference bottleneck capacity: 1Mbps.

   o Application-related:

      * Media Source:

         + Media type: Video

            - Media direction: forward and backward

            - Number of media sources: two (2)

            - Media timeline:

               o Start time: 0s.

               o End time: 99s.

+ Media type: Audio

    - Media direction: forward and backward

    - Number of media sources: two (2)

    - Media timeline:

        o Start time: 0s.

        o End time: 99s.

* Competing traffic:

    + Number of sources : zero (0)

o Test Specific Information: this test uses path capacity variations
  to create congested feedback link. Table 3 lists the variation
  patterns applied to the forward path and Table 4 lists the
  variation patterns applied to the backward path. When using
  background non-adaptive UDP traffic to induce time-varying
  bottleneck for congestion controlled media flows, the physical
  path capacity is 4Mbps for both directions and the UDP traffic
  source rate changes over time as $(4-x)$Mbps in each direction,
  where x is the bottleneck capacity specified in Table 4.

Variation pattern index	Path direction	Start time	Path capacity ratio
One	Forward	0s	2.0
Two	Forward	20s	1.0
Three	Forward	40s	0.5
Four	Forward	60s	2.0

Table 3: Path capacity variation pattern for forward direction

Variation pattern index	Path direction	Start time	Path capacity ratio
One	Backward	0s	2.0
Two	Backward	35s	0.8
Three	Backward	70s	2.0

Table 4: Path capacity variation pattern for backward direction

5.4. Competing Media Flows with same Congestion Control Algorithm

   In this test case, more than one media flows share the bottleneck
   link and each of them uses the same congestion control algorithm.
   This is a typical scenario where a real-time interactive application
   sends more than one media flow to the same destination and these
   flows are multiplexed over the same port. In such a scenario it is
   likely that the flows will be routed via the same path and need to
   share the available bandwidth amongst themselves. For the sake of
   simplicity it is assumed that there are no other competing traffic
   sources in the bottleneck link and that there is sufficient capacity
   to accommodate all the flows individually. While this appears to be
   a variant of the test case defined in Section 5.2, it focuses on the
   capacity sharing aspect of the candidate algorithm. The previous
   test case, on the other hand, measures adaptability, stability, and
   responsiveness of the candidate algorithm.

   Expected behavior: It is expected that the competing flows will
   converge to an optimum bit rate to accommodate all the flows with
   minimum possible latency and loss. Specifically, the test introduces
   three media flows at different time instances, when the second flow
   appears there should still be room to accommodate another flow on the
   bottleneck link. Lastly, when the third flow appears the bottleneck
   link should be saturated.

   Evaluation metrics : as described in Section 4.1.

   Testbed topology: Three media sources S1, S2, S3 are connected to R1,
   R2, R3 respectively. The media traffic is transported over the
   forward path and corresponding feedback/control traffic is
   transported over the backward path.

```
+---+                                                       +---+
|S1 |===== \                 Forward -->          / ======|R1 |
+---+       \\                                    //        +---+
             \\                                  //
+---+       +-----+                          +-----+       +---+
|S2 |======|  A  |------------------------------->|  B  |======|R2 |
+---+      |     |<-----------------------------|     |       +---+
           +-----+                          +-----+
            //                                 \\
           //          <-- Backward             \\
+---+     //                                      \\      +---+
|S3 |===== /                                       \ =====|R3 |
+---+                                                      +---+
```

             Figure 5: Testbed Topology for Multiple congestion controlled media
                                 Flows

Testbed attributes:

o Test duration: 120s

o Path characteristics:

   * Reference bottleneck capacity: 3.5Mbps

   * Path capacity ratio: 1.0

o Application-related:

   * Media Source:

      + Media type: Video

         - Media direction: forward.

         - Number of media sources: three (3)

         - Media timeline: new media flows are added sequentially,
            at short time intervals. See test specific setup below.

      + Media type: Audio

         - Media direction: forward.

         - Number of media sources: three (3)

         - Media timeline: new media flows are added sequentially,
            at short time intervals. See test specific setup below.

   * Competing traffic:

      + Number of sources : zero (0)

o Test Specific Information: Table 5 defines the media timeline for
   both media type.

```
+---------+-----------+------------+----------+
| Flow ID | Media type | Start time | End time |
+---------+-----------+------------+----------+
| 1       | Video     | 0s         | 119s     |
| 2       | Video     | 20s        | 119s     |
| 3       | Video     | 40s        | 119s     |
| 4       | Audio     | 0s         | 119s     |
| 5       | Audio     | 20s        | 119s     |
| 6       | Audio     | 40s        | 119s     |
+---------+-----------+------------+----------+
```

          Table 5: Media Timeline for Video and Audio media sources

5.5. Round Trip Time Fairness

   In this test case, multiple media flows share the bottleneck link,
   but the end-to-end path latency for each flow is different. For the
   sake of simplicity it is assumed that there are no other competing
   traffic sources in the bottleneck link and that there is sufficient
   capacity to accommodate all the flows. While this appears to be a
   variant of test case 5.2, it focuses on the capacity sharing aspect
   of the candidate algorithm under different RTTs.

   It is expected that the competing flows will converge to bit rates to
   accommodate all the flows with minimum possible latency and loss.
   Specifically, the test introduces five media flows at the same time
   instance.

   Evaluation metrics : as described in Section 4.1.

   Testbed Topology: Five (5) media sources S1,S2,..,S5 are connected to
   their corresponding media sinks R1,R2,..,R5. The media traffic is
   transported over the forward path and corresponding feedback/control
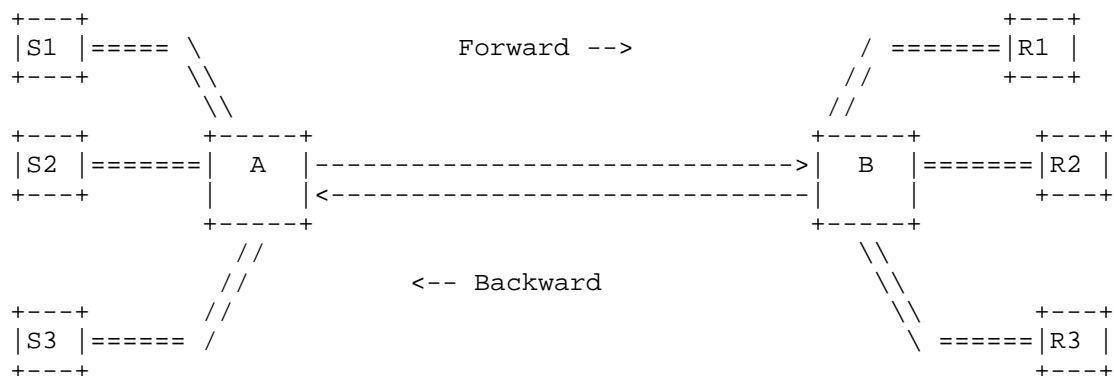   traffic is transported over the backward path. The topology is the
   same as in Section 5.4. The end-to-end path delays are: 10ms for
   S1-R1, 25ms for S2-R2, 50ms for S3-R3, 100ms for S4-R4, and 150ms
   S5-R5, respectively.

   Testbed attributes:

   o Test duration: 300s

   o Path characteristics:

      * One-Way propagation delay for each flow: 10ms, 25ms, 50ms,
         100ms, 150ms.

   o Application-related:

* Media Source:

  + Media type: Video

    - Media direction: forward

    - Number of media sources: five (5)

    - Media timeline: new media flows are added sequentially,
      at short time intervals. See test specific setup below.

  + Media type: Audio

    - Media direction: forward.

    - Number of media sources: five (5)

    - Media timeline: new media flows are added sequentially,
      at short time intervals. See test specific setup below.

* Competing traffic:

  + Number of sources : zero (0)

o Test Specific Information: Table 6 defines the media timeline for
  both media type.

```
+---------+-----------+------------+----------+
| Flow IF | Media type | Start time | End time |
+---------+-----------+------------+----------+
| 1       | Video     | 0s         | 299s     |
| 2       | Video     | 10s        | 299s     |
| 3       | Video     | 20s        | 299s     |
| 4       | Video     | 30s        | 299s     |
| 5       | Video     | 40s        | 299s     |
| 6       | Audio     | 0          | 299s     |
| 7       | Audio     | 10s        | 299s     |
| 8       | Audio     | 20s        | 299s     |
| 9       | Audio     | 30s        | 299s     |
| 10      | Audio     | 40s        | 299s     |
+---------+-----------+------------+----------+
```

Table 6: Media Timeline for Video and Audio media sources

5.6. Media Flow Competing with a Long TCP Flow

   In this test case, one or more media flows share the bottleneck link
   with at least one long lived TCP flow. Long lived TCP flows download
   data throughout the session and are expected to have infinite amount
   of data to send and receive. This is a scenario where a multimedia
   application co-exists with a large file download. The test case
   measures the adaptivity of the candidate algorithm to competing
   traffic. It addresses the requirement 3 in
   [I-D.ietf-rmcat-cc-requirements].

   Expected behavior: depending on the convergence observed in test case
   5.1 and 5.2, the candidate algorithm may be able to avoid congestion
   collapse. In the worst case, the media stream will fall to the
   minimum media bit rate.

   Evaluation metrics : following metrics in addition to as described in
   Section 4.1.

   1. Flow level:

       A. TCP throughput.

       B. Loss for the TCP flow

   Testbed topology: One (1) media source S1 is connected to the
   corresponding media sink, R1. In addition, there is a long-live TCP
   flow sharing the same bottleneck link. The media traffic is
   transported over the forward path and corresponding feedback/control
   traffic is transported over the backward path. The TCP traffic goes
   over the forward path from, S_tcp with acknowledgment packets go over
   the backward path from, R_tcp.

```
    +--+                                              +--+
    |S1|===== \           Forward -->       / ======|R1|
    +--+       \\                           //        +--+
                \\                         //
       +-----+   \\                  +-----+
       | A   |------------------------->|  B  |
       |     |<-------------------------|     |
       +-----+                         +-----+
            //                              \\
           //            <-- Backward        \\
   +-----+  //                                \\   +-----+
   |S_tcp|=== /                                \ ===|R_tcp|
   +-----+                                          +-----+
```

           Figure 6: Testbed Topology for TCP vs congestion controlled media
                                    Flows

   Testbed attributes:

   o Test duration: 120s

   o Path characteristics:

      * Reference bottleneck capacity: 2Mbps

      * Path capacity ratio: 1.0

      * Bottleneck queue size: [300ms, 1000ms]

   o Application-related:

      * Media Source:

         + Media type: Video

            - Media direction: forward

            - Number of media sources: one (1)

            - Media timeline:

               o Start time: 5s.

               o End time: 119s.

         + Media type: Audio

            - Media direction: forward

                    - Number of media sources: one (1)

                    - Media timeline:

                       o Start time: 5s.

                       o End time: 119s.

             * Additionally, implementers are encouraged to run the experiment
                with multiple media sources.

             * Competing traffic:

                + Number and Types of sources : one (1) and long-lived TCP

                + Traffic direction : forward

                + Congestion control: default TCP congestion control[RFC5681].

                + Traffic timeline:

                   - Start time: 0s.

                   - End time: 119s.

      o Test Specific Information: none

5.7. Media Flow Competing with Short TCP Flows

   In this test case, one or more congestion controlled media flow
   shares the bottleneck link with multiple short-lived TCP flows.
   Short-lived TCP flows resemble the on/off pattern observed in the web
   traffic, wherein clients (browsers) connect to a server and download
   a resource (typically a web page, few images, text files, etc.) using
   several TCP connections (up to 4). This scenario shows the
   performance of a multimedia application when several browser windows
   are active. The test case measures the adaptivity of the candidate
   algorithm to competing web traffic, it addresses the requirements 1.E
   in [I-D.ietf-rmcat-cc-requirements].

   Depending on the number of short TCP flows, the cross-traffic either
   appears as a short burst flow or resembles a long TCP flow. The
   intention of this test is to observe the impact of short-term burst
   on the behavior of the candidate algorithm.

   Evaluation metrics : following metrics in addition to as described in
   Section 4.1.

   1. Flow level:

       A. Variation in the sending rate of the TCP flow.

       B. TCP throughput.

   Testbed topology: The topology described here is same as the one
   described in Figure 6.

   Testbed attributes:

   o Test duration: 300s

   o Path characteristics:

      * Reference bottleneck capacity: 2.0Mbps

      * Path capacity ratio: 1.0

   o Application-related:

      * Media source:

         + Media type: Video

            - Media direction: forward

            - Number of media sources: two (2)

            - Media timeline:

               o Start time: 5s.

               o End time: 299s.

         + Media type: Audio

            - Media direction: forward

            - Number of media sources: two (2)

            - Media timeline:

               o Start time: 5s.

               o End time: 299s.

      * Competing traffic:

+ Number and Types of sources : ten (10), short-lived TCP
  flows.

+ Traffic direction : forward

+ Congestion algorithm: default TCP Congestion control
  [RFC5681].

+ Traffic timeline: each short TCP flow is modeled as a
  sequence of file downloads interleaved with idle periods.
  See test specific setup. Not all short TCP flows start at
  the same time, 2 of them start in the ON state while rest on
  the 8 flows start in an OFF stats. The model for the idle
  times for the OFF state is discussed in
  [I-D.ietf-rmcat-eval-criteria].

o Test Specific Information:

  * Short-TCP traffic model:

    + File sizes: uniform distribution between 100KB to 1MB

    + Idle period: the duration of the OFF state is derived from
       an exponential distribution with the mean value of 10
       seconds.

5.8. Media Pause and Resume

In this test case, more than one real-time interactive media flows
share the link bandwidth and all flows reach to a steady state by
utilizing the link capacity in an optimum way. At this stage one of
the media flows is paused for a moment. This event will result in
more available bandwidth for the rest of the flows as they are on a
shared link. When the paused media flow resumes it would no longer
have the same bandwidth share on the link. It has to make it's way
through the other existing flows in the link to achieve a fair share
of the link capacity. This test case is important specially for
real-time interactive media which consists of more than one media
flows and can pause/resume media flows at any point of time during
the session. This test case directly addresses the requirement
number 5 in [I-D.ietf-rmcat-cc-requirements]. One can think it as a
variation of test case defined in Section 5.4. However, it is
different as the candidate algorithms can use different strategies to
increase its efficiency, for example in terms of fairness,
convergence time, reduce oscillation etc, by capitalizing the fact
that they have previous information of the link.

Evaluation metrics : following metrics in addition to as described in Section 4.1.

1. Flow level:

    A. Variation in sending bit rate and goodput. Mainly observing the frequency and magnitude of oscillations.

Testbed Topology: Same as test case defined in Section 5.4

Testbed attributes: The general description of the testbed parameters are same as Section 5.4 with changes in the test specific setup as below-

o Other test specific setup:

   * Media flow timeline:

      + Flow ID: one (1)

      + Start time: 0s

      + Flow duration: 119s

      + Pause time: not required

      + Resume time: not required

   * Media flow timeline:

      + Flow ID: two (2)

      + Start time: 0s

      + Flow duration: 119s

      + Pause time: at 40s

      + Resume time: at 60s

   * Media flow timeline:

      + Flow ID: three (3)

      + Start time: 0s

      + Flow duration:119s

        + Pause time: not required

        + Resume time: not required

6. Other potential test cases

   It has been noticed that there are other interesting test cases
   besides the basic test cases listed above. In many aspects, these
   additional test cases can help further evaluation of the candidate
   algorithm. They are listed as below.

6.1. Media Flows with Priority

   In this test case media flows will have different priority levels.
   This will be an extension of Section 5.4 where the same test will be
   run with different priority levels imposed on each of the media
   flows. For example, the first flow (S1) is assigned a priority of 2
   whereas the remaining two flows (S2 and S3) are assigned a priority
   of 1. The candidate algorithm MUST reflect the relative priorities
   assigned to each media flow. In the previous example, the first flow
   (S1) MUST arrive at a steady-state rate approximately twice of that
   of the other two flows (S2 and S3).

   The candidate algorithm can use a coupled congestion control
   mechanism for the bandwidth distribution according to the respective
   media flow priority.

6.2. Explicit Congestion Notification Usage

   This test case requires to run all the basic test cases with the
   availability of Explicit Congestion Notification (ECN) [RFC6679]
   feature enabled. The goal of this test is to exhibit that the
   candidate algorithms do not fail when ECN signals are available.
   With ECN signals enabled the algorithms are expected to perform
   better than their delay based variants.

6.3. Multiple Bottlenecks

   In this test case one congestion controlled media flow, S1->R2,
   traverses a path with multiple bottlenecks. As illustrated in
   Figure 7, the first flow (S1->R1) competes with the second congestion
   controlled media flow (S2->R2) over the link between A and B which is
   close to the sender side; again, that flow (S1->R1) competes with the
   third congestion controlled media flow (S3->R3) over the link between
   C and D which is close to the receiver side. The goal of this test
   is to ensure that the candidate algorithms work properly in the
   presence of multiple bottleneck links on the end to end path.

Expected behavior: the candidate algorithm is expected to achieve
full utilization at both bottleneck links without starving any of the
three congestion controlled media flows.

```
                        Forward ---->


        +---+           +---+           +---+           +---+
        |S2 |           |R2 |           |S3 |           |R3 |
        +---+           +---+           +---+           +---+
          |               |               |               |
          |               |               |               |
+---+   +-----+         +-----+         +-----+         +-----+   +---+
|S1 |===|  A  |------->|  B  |----->|  C  |---->|  D  |===|R1 |
+---+   |     |<------|     |<-----|     |<----|     |       +---+
        +-----+         +-----+         +-----+         +-----+

              1st                           2nd
        Bottleneck (A->B)             Bottleneck (C->D)


              <------ Backward
```
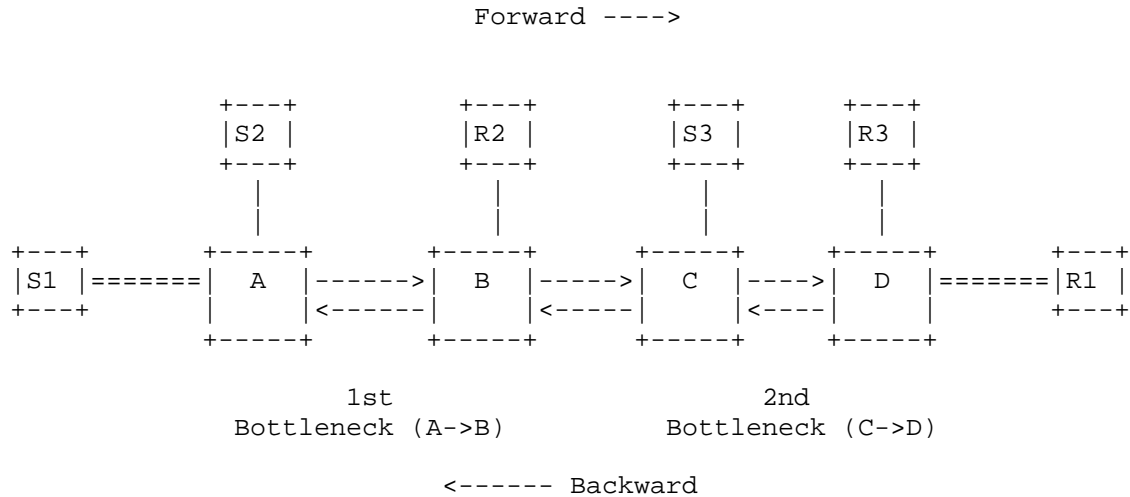
Figure 7: Testbed Topology for Multiple Bottlenecks

Testbed topology: Three media sources S1, S2, and S3 are connected to
respective destinations R1, R2, and R3. For all three flows the
media traffic is transported over the forward path and corresponding
feedback/control traffic is transported over the backward path.

Testbed attributes:

o Test duration: 300s

o Path characteristics:

   * Reference bottleneck capacity: 2Mbps.

   * Path capacity ratio between A and B: 1.0

   * Path capacity ratio between B and C: 4.0.

   * Path capacity ratio between C and D: 0.75.

   * One-Way propagation delay:

      1. Between S1 and R1: 100ms

      2. Between S2 and R2: 40ms

      3. Between S3 and R3: 40ms

   o Application-related:

   * Media Source:

      + Media type: Video

         - Media direction: Forward

         - Number of media sources: Three (3)

         - Media timeline:

            o Start time: 0s.

            o End time: 299s.

      + Media type: Audio

         - Media direction: Forward

         - Number of media sources: Three (3)

         - Media timeline:

            o Start time: 0s.

            o End time: 299s.

   * Competing traffic:

      + Number of sources : Zero (0)

7. Wireless Access Links

   Additional wireless network (both cellular network and WiFi network)
   specific test cases are defined in [I-D.ietf-rmcat-wireless-tests].

8. Security Considerations

   Security issues have not been discussed in this memo.

9. IANA Considerations

   There are no IANA impacts in this memo.

10. Acknowledgements

   Much of this document is derived from previous work on congestion
   control at the IETF.

   The content and concepts within this document are a product of the
   discussion carried out in the Design Team.

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