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November 5, 2015

Evaluation Test Cases for Interactive Real-Time Media over Wireless Networks
draft-ietf-rmcat-wireless-tests-01

Abstract

It is evident that to ensure seamless and robust user experience across all type of access networks multimedia communication suits should adapt to the changing network conditions. There is an ongoing effort in IETF RMCAT working group to standardize rate adaptive algorithm(s) to be used in the real-time interactive communication. In this document test cases are described to evaluate the performances of the proposed endpoint adaptation solutions in LTE networks and Wi-Fi networks. The proposed algorithms should be evaluated using the test cases defined in this document to select most optimal solutions.

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1. Introduction

Wireless networks (both cellular and Wi-Fi [IEEE802.11] local area network) are an integral part of the Internet. Mobile devices connected to the wireless networks produces huge amount of media traffic in the Internet. They covers the scenarios of having a video call in the bus to media consumption sitting on a couch in a living room. It is a well known fact that the characteristic and challenges for offering service over wireless network are very different than providing the same over a wired network. Even though RMCAT basic test cases defines number of test cases that covers lots of effects of the impairments visible in the wireless networks but there are characteristics and dynamics those are unique to particular wireless environment. For example, in the LTE the base station maintains queues per radio bearer per user hence it gives different interaction when all traffic from user share the same queue. Again, the user mobility in a cellular network is different than the user mobility in a Wi-Fi network. Thus, It is important to evaluate the performance of the proposed RMCAT candidates separately in the cellular mobile networks and Wi-Fi local networks (IEEE 802.11xx protocol family).

RMCAT evaluation criteria [I-D.ietf-rmcat-eval-criteria] document provides the guideline to perform the evaluation on candidate algorithms and recognizes wireless networks to be important access link. However, it does not provides particular test cases to evaluate the performance of the candidate algorithm. In this document we describe test cases specifically targeting cellular networks such as LTE networks and Wi-Fi local networks.

2. Terminologies

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 RFC2119 [RFC2119]

3. Cellular Network Specific Test Cases

A cellular environment is more complicated than a wireline ditto since it seeks to provide services in the context of variable available bandwidth, location dependencies and user mobilities at different speeds. In a cellular network the user may reach the cell edge which may lead to a significant amount of retransmissions to deliver the data from the base station to the destination and vice versa. These network links or radio links will often act as a bottleneck for the rest of the network which will eventually lead to excessive delays or packet drops. An efficient retransmission or

link adaptation mechanism can reduce the packet loss probability but there will still be some packet losses and delay variations. Moreover, with increased cell load or handover to a congested cell, congestion in transport network will become even worse. Besides, there are certain characteristics which make the cellular network different and challenging than other types of access network such as Wi-Fi and wired network. In a cellular network -

- o The bottleneck is often a shared link with relatively few users.

  * The cost per bit over the shared link varies over time and is different for different users.

  * Left over/ unused resource can be grabbed by other greedy users.

- o Queues are always per radio bearer hence each user can have many of such queues.

- o Users can experience both Inter and Intra Radio Access Technology (RAT) handovers ("handover" definition in [HO-def-3GPP]).

- o Handover between cells, or change of serving cells (see in [HO-LTE-3GPP] and [HO-UMTS-3GPP]) might cause user plane interruptions which can lead to bursts of packet losses, delay and/or jitter. The exact behavior depends on the type of radio bearer. Typically, the default best effort bearers do not generate packet loss, instead packets are queued up and transmitted once the handover is completed.

- o The network part decides how much the user can transmit.

- o The cellular network has variable link capacity per user

  * Can vary as fast as a period of milliseconds.

  * Depends on lots of facts (such as distance, speed, interference, different flows).

  * Uses complex and smart link adaptation which makes the link behavior ever more dynamic.

  * The scheduling priority depends on the estimated throughput.

- o Both Quality of Service (QoS) and non-QoS radio bearers can be used.

Hence, a real-time communication application operating in such a cellular network need to cope with shared bottleneck link and variable link capacity, event likes handover, non-congestion related loss, abrupt change in bandwidth (both short term and long term) due to handover, network load and bad radio coverage. Even though 3GPP define QoS bearers [QoS-3GPP] to ensure high quality user experience, adaptive real-time applications are desired.

Different mobile operators deploy their own cellular network with their own set of network functionalities and policies. Usually, a mobile operator network includes 2G, EDGE, 3G and 4G radio access technologies. Looking at the specifications of such radio technologies it is evident that only 3G and 4G radio technologies can support the high bandwidth requirements from real-time interactive video applications. The future real-time interactive application will impose even greater demand on cellular network performance which makes 4G (and beyond radio technologies) more suitable access technology for such genre of application.

The key factors to define test cases for cellular network are

o Shared and varying link capacity

o Mobility

o Handover

However, for cellular network it is very hard to separate such events from one another as these events are heavily related. Hence instead of devising separate test cases for all those important events we have divided the test case in two categories. It should be noted that in the following test cases the goal is to evaluate the performance of candidate algorithms over radio interface of the cellular network. Hence it is assumed that the radio interface is the bottleneck link between the communicating peers and that the core network does not add any extra congestion in the path. Also the combination of multiple access technologies such as one user has LTE connection and another has Wi-Fi connection is kept out of the scope of this document. However, later those additional scenarios can also be added in this list of test cases. While defining the test cases we assumed a typical real-time telephony scenario over cellular networks where one real-time session consists of one voice stream and one video stream. We recommend that an LTE network simulator is used for the test cases defined in this document, for example-NS-3 LTE simulator [LTE-simulator].

3.1. Varying Network Load

The goal of this test is to evaluate the performance of the candidate congestion control algorithm under varying network load. The network load variation is created by adding and removing network users a.k.a. User Equipments (UEs) during the simulation. In this test case, each of the user/UE in the media session is an RMCAT compliant endpoint. The arrival of users follows a Poisson distribution, which is proportional to the length of the call, so that the number of users per cell is kept fairly constant during the evaluation period. At the beginning of the simulation there should be enough amount of time to warm-up the network. This is to avoid running the evaluation in an empty network where network nodes are having empty buffers, low interference at the beginning of the simulation. This network initialization period is therefore excluded from the evaluation period.

This test case also includes user mobility and competing traffic. The competing traffics includes both same kind of flows (with same adaptation algorithms) and different kind of flows (with different service and congestion control). The investigated congestion control algorithms should show maximum possible network utilization and stability in terms of rate variations, lowest possible end to end frame latency, network latency and Packet Loss Rate (PLR) at different cell load level.

3.1.1. Network Connection

Each mobile user is connected to a fixed user. The connection between the mobile user and fixed user consists of a LTE radio access, an Evolved Packet Core (EPC) and an Internet connection. The mobile user is connected to the EPC using LTE radio access technology which is further connected to the Internet. The fixed user is connected to the Internet via wired connection with no bottleneck (practically infinite bandwidth). The Internet and wired connection in this setup does not add any network impairments to the test, it only adds 10ms of one-way transport propagation delay.

The path from the fixed user to mobile user is defines as "Downlink" and the path from mobile user to the fixed user is defined as "Uplink". We assume that only uplink or downlink is congested for the mobile users. Hence, we recommend that the uplink and downlink simulations are run separately.

```
                             uplink
            ++)))        +---------------------------->
            ++-+      ((o))
            |  |       / \     +-------+     +------+    +---+
            +--+      /   \----+       +------+     +-----+  |
                     /     \   +-------+     +------+    +---+
             UE          BS        EPC        Internet    fixed
                         <---------------------------+
                                  downlink
```

Figure 1: Simulation Topology

3.1.2. Simulation Setup

The values enclosed within " [ ] " for the following simulation attributes follow the notion set in [I-D.ietf-rmcat-eval-test]. The desired simulation setup as follows-

1. Radio environment

    A. Deployment and propagation model : 3GPP case 1[Deployment]

    B. Antenna: Multiple-Input and Multiple-Output (MIMO), [2D, 3D]

    C. Mobility: [3km/h, 30km/h]

    D. Transmission bandwidth: 10Mhz

    E. Number of cells: multi cell deployment (3 Cells per Base Station (BS) * 7 BS) = 21 cells

    F. Cell radius: 166.666 Meters

    G. Scheduler: Proportional fair with no priority

    H. Bearer: Default bearer for all traffic.

    I. Active Queue Management (AQM) settings: AQM [on,off]

2. End to end Round Trip Time (RTT): [40, 150]

3. User arrival model: Poisson arrival model

4. User intensity:

    * Downlink user intensity: {0.7, 1.4, 2.1, 2.8, 3.5, 4.2, 4.9, 5.6, 6.3, 7.0, 7.7, 8.4, 9,1, 9.8, 10.5}

   * Uplink user intercity : {0.7, 1.4, 2.1, 2.8, 3.5, 4.2, 4.9, 5.6, 6.3, 7.0}

5. Simulation duration: 91s

6. Evaluation period : 30s-60s

7. Media traffic

   1. Media type: Video

      a. Media direction: [Uplink, Downlink]

      b. Number of Media source per user: One (1)

      c. Media duration per user: 30s

      d. Media source: same as define in section 4.3 of [I-D.ietf-rmcat-eval-test]

   2. Media Type : Audio

      a. Media direction: Uplink and Downlink

      b. Number of Media source per user: One (1)

      c. Media duration per user: 30s

      d. Media codec: Constant BitRate (CBR)

      e. Media bitrate : 20 Kbps

      f. Adaptation: off

8. Other traffic model:

   * Downlink simulation: Maximum of 4Mbps/cell (web browsing or FTP traffic)

   * Unlink simulation: Maximum of 2Mbps/cell (web browsing or FTP traffic)

3.2. Bad Radio Coverage

The goal of this test is to evaluate the performance of candidate congestion control algorithm when users visit part of the network with bad radio coverage. The scenario is created by using larger cell radius than previous test case. In this test case each of the

user/UE in the media session is an RMCAT compliant endpoint. The arrival of users follows a Poisson distribution, which is proportional to the length of the call, so that the number of users per cell is kept fairly constant during the evaluation period. At the beginning of the simulation there should be enough amount of time to warm-up the network. This is to avoid running the evaluation in an empty network where network nodes are having empty buffers, low interference at the beginning of the simulation. This network initialization period is therefore excluded from the evaluation period.

This test case also includes user mobility and competing traffic. The competing traffics includes same kind of flows (with same adaptation algorithms) . The investigated congestion control algorithms should show maximum possible network utilization and stability in terms of rate variations, lowest possible end to end frame latency, network latency and Packet Loss Rate (PLR) at different cell load level.

3.2.1. Network connection

Same as defined in Section 3.1.1

3.2.2. Simulation Setup

The desired simulation setup is same as Varying Network Load test case defined in Section 3.1 except following changes-

1. Radio environment : Same as defined in Section 3.1.2 except followings

    A. Deployment and propagation model : 3GPP case 3[Deployment]

    B. Cell radius: 577.3333 Meters

    C. Mobility: 3km/h

2. User intensity = {0.7, 1.4, 2.1, 2.8, 3.5, 4.2, 4.9, 5.6, 6.3, 7.0}

3. Media traffic model: Same as defined in Section 3.1.2

4. Other traffic model: None

3.3. Desired Evaluation Metrics for cellular test cases

RMCAT evaluation criteria document [I-D.ietf-rmcat-eval-criteria] defines metrics to be used to evaluate candidate algorithms. However, looking at the nature and distinction of cellular networks we recommend at minimum following metrics to be used to evaluate the performance of the candidate algorithms for the test cases defined in this document.

The desired metrics are-

- o Average cell throughput (for all cells), shows cell utilizations.

- o Application sending and receiving bitrate, goodput.

- o Packet Loss Rate (PLR).

- o End to end Media frame delay. For video, this means the delay from capture to display.

- o Transport delay.

- o Algorithm stability in terms of rate variation.

4. Wi-Fi Networks Specific Test Cases

Given the prevalence of Internet access links over Wi-Fi, it is important to evaluate candidate RMCAT congestion control solutions over Wi-Fi test cases. Such evaluations should also highlight the inherent different characteristics of Wi-Fi networks in contrast to Wired networks:

- o The wireless radio channel is subject to interference from nearby transmitters, multi-path fading, and shadowing, causing fluctuations in link throughput and sometimes an error-prone communication environment

- o Available network bandwidth is not only shared over the air between concurrent users, but also between uplink and downlink traffic due to the half duplex nature of wireless transmission medium.

- o Packet transmissions over Wi-Fi are susceptible to contentions and collisions over the air. Consequently, traffic load beyond a certain utilization level over a Wi-Fi network can introduce frequent collisions and significant network overhead. This, in turn, leads to excessive delay, retransmission, loss and lower effective bandwidth for applications.

o The IEEE 802.11 standard (i.e., Wi-Fi) supports multi-rate transmission capabilities by dynamically choosing the most appropriate modulation scheme for a given received signal strength. A different choice of Physical-layer rate will lead to different application-layer throughput.

o Presence of legacy 802.11b networks can significantly slow down the rest of a modern Wi-Fi Network, since it takes longer to transmit the same packet over a slower link than over a faster link. [Editor's note: maybe include a reference here instead.]

o Handover from one Wi-Fi Access Point (AP) to another may cause packet delay and loss.

o IEEE 802.11e defined EDCA/WMM (Enhanced DCF Channel Access/Wi-Fi Multi-Media) to give voice and video streams higher priority over pure data applications (e.g., file transfers).

As we can see here, presence of Wi-Fi network in different network topologies and traffic arrival can exert different impact on the network performance in terms of video transport rate, packet loss and delay that, in turn, effect end-to-end real-time multimedia congestion control.

Throughout this draft, unless otherwise mentioned, test cases are described using 802.11g due to its wide availability in network simulation platform. In practice, however, statistics collected from enterprise networks show that the dominant physical modes are 802.11n and 802.11ac, accounting for 73.6% and 22.5% of enterprise network users, respectively. Whenever possible, it is recommended to extend some of the experiments to 802.11n and 802.11ac, so as to reflect a more modern Wi-Fi network setting.

Since Wi-Fi network normally connects to a wired infrastructure, either the wired network or the Wi-Fi network could be the bottleneck. In the following section, we describe basic test cases for both scenarios separately. The same set of performance metrics as in [I-D.ietf-rmcat-eval-test]) should be collected for each test case.

While all test cases described below can be carried out using simulations, e.g. based on [ns-2] or [ns-3], it is also recommended to perform testbed-based evaluations using Wi-Fi access points and endpoints running up-to-date IEEE 802.11 protocols. [Editor's Note: need to add some more discussions on the pros and cons of simulation-based vs. testbed-based evaluations. It will be good to provide recommended testbed configurations.]

4.1. Bottleneck in Wired Network

The test scenarios below are intended to mimic the set up of video conferencing over Wi-Fi connections from the home. Typically, the Wi-Fi home network is not congested and the bottleneck is present over the wired home access link. Although it is expected that test evaluation results from this section are similar to those from test cases defined for wired networks (see [I-D.ietf-rmcat-eval-test]), it is worthwhile to run through these tests as sanity checks.

4.1.1. Network topology

Figure 2 shows topology of the network for Wi-Fi test cases. The test contains multiple mobile nodes (MNs) connected to a common Wi-Fi access point (AP) and their corresponding wired clients on fixed nodes (FNs). Each connection carries either RMCAT or TCP traffic flow. Directions of the flows can be uplink, downlink, or bi-directional.

```
                                   uplink
                             +----------------->+
            +------+                                       +------+
            | MN_1 |))))                             /=====| FN_1 |
            +------+    ))                          //     +------+
                .        ))                        //         .
                .         ))                      //          .
                .          ))                    //           .
            +------+         +----+         +-----+        +------+
            | MN_N | ))))))) |    |         |     |========| FN_N |
            +------+         |    |         |     |        +------+
                             | AP |=========| FN0 |
           +----------+      |    |         |     |      +----------+
           | MN_tcp_1 | )))) |    |         |     |======| MN_tcp_1 |
           +----------+      +----+         +-----+      +----------+
                 .          ))                 \\             .
                 .         ))                   \\            .
                 .        ))                     \\           .
           +----------+  ))                       \\     +----------+
           | MN_tcp_M |)))                         \=====| MN_tcp_M |
           +----------+                                  +----------+
                            +<-----------------+
                                    downlink
```

Figure 2: Network topology for Wi-Fi test cases

4.1.2. Test setup

- o Test duration: 120s

- o Wi-Fi network characteristics:

  - * Radio propagation model: Log-distance path loss propagation model [NS3WiFi]

  - * PHY- and MAC-layer configuration: IEEE 802.11g

  - * PHY-layer link rate: 54 Mbps

- o Wired path characteristics:

  - * Path capacity: 1Mbps

  - * One-Way propagation delay: 50ms.

  - * Maximum end-to-end jitter: 30ms

  - * Bottleneck queue type: Drop tail.

  - * Bottleneck queue size: 300ms.

  - * Path loss ratio: 0%.

- o Application characteristics:

  - * Media Traffic:

    - + Media type: Video

    - + Media direction: See Section 4.1.3

    - + Number of media sources (N): See Section 4.1.3

    - + Media timeline:

      - - Start time: 0s.

      - - End time: 119s.

  - * Competing traffic:

    - + Type of sources: long-lived TCP

    - + Traffic direction: See Section 4.1.3

  + Number of sources (M): See Section 4.1.3

  + Congestion control: Default TCP congestion control [TBD]

  + Traffic timeline:

    - Start time: 0s

    - End time: 119s

4.1.3. Typical test scenarios

- Single uplink RMCAT flow: N=1 with uplink direction and M=0.

- One pair of bi-directional RMCAT flows: N=2 (with one uplink flow and one downlink flow); M=0.

- One RMCAT flow competing against one long-live TCP flow over uplink: N=1 (uplink) and M = 1(uplink).

4.1.4. Expected behavior

- Single uplink RMCAT flow: the candidate algorithm is expected to detect the path capacity constraint, converges to bottleneck link's capacity and adapt the flow to avoid unwanted oscillation when the sending bit rate is approaching the bottleneck link's capacity. No excessive rate oscillations.

- Bi-directional RMCAT flows: It is expected that the candidate algorithms is able to converge to the bottleneck capacity of the wired path on both directions despite of the presence of measurement noise over the Wi-Fi connection.

- One RMCAT flow competing with long-live TCP flow over uplink: the candidate algorithm should be able to avoid congestion collapse, and stabilize at a fair share of the bottleneck capacity over the wired path.

4.2. Bottleneck in Wi-Fi Network

These test cases assume that the wired portion along the media path are well-provisioned. The bottleneck is in the Wi-Fi network over wireless. This is to mimic the enterprise/coffee-house scenarios.

4.2.1. Network topology

Same as defined in Section 4.1.1

4.2.2. Test setup

- o Test duration: 120s
- o Wi-Fi network characteristics:
  - * Radio propagation model: Log-distance path loss propagation model [NS3WiFi]
  - * PHY- and MAC-layer configuration: IEEE 802.11g
  - * PHY-layer link rate: 54 Mbps
- o Wired path characteristics:
  - * Path capacity: 100Mbps
  - * One-Way propagation delay: 50ms.
  - * Maximum end-to-end jitter: 30ms
  - * Bottleneck queue type: Drop tail.
  - * Bottleneck queue size: 300ms.
  - * Path loss ratio: 0%.
- o Application characteristics:
  - * Media Traffic:
    - + Media type: Video
    - + Media direction: See Section 4.2.3
    - + Number of media sources (N): See Section 4.2.3
    - + Media timeline:
      - - Start time: 0s.
      - - End time: 119s.
  - * Competing traffic:

+ Type of sources: long-lived TCP

+ Number of sources (M): See Section 4.2.3

+ Traffic direction: See Section 4.2.3

+ Congestion control: Default TCP congestion control [TBD]

+ Traffic timeline:

  - Start time: 0s

  - End time: 119s

4.2.3. Typical test scenarios

This sections describes a few specific test scenarios that are deemed as important for understanding behavior of a RMCAT candidate solution over a Wi-Fi network.

o Multiple RMCAT Flows Sharing the Wireless Downlink: N=16 (all downlink); M = 0; This test case is for studying the impact of contention on competing RMCAT flows. Specifications for IEEE 802.11g with a physical-layer transmission rate of 54 Mbps is chosen. Note that retransmission and MAC-layer headers and control packets may be sent at a lower link speed. The total application-layer throughput (reasonable distance, low interference and small number of contention stations) for 802.11g is around 20 Mbps. Consequently, a total of N=16 RMCAT flows are needed for saturating the wireless interface in this experiment. Evaluation of a given candidate solution should focus on whether downlink RMCAT flows can stabilize at a fair share of bandwidth.

o Multiple RMCAT Flows Sharing the Wireless Uplink: N = 16 (all downlink); M = 0; When multiple clients attempt to transmit video packets uplink over the wireless interface, they introduce more frequent contentions and potentially collisions. Per-flow throughput is expected to be lower than that in the previous downlink-only scenario. Evaluation of a given candidate solution should focus on whether uplink flows can stabilize at a fair share of bandwidth.

o Multiple Bi-directional RMCAT Flows: N = 16 (8 uplink and 8 downlink); M = 0. The goal of this test is to evaluate performance of the candidate solution in terms of bandwidth fairness between uplink and downlink flow.

- o Multiple RMCAT flows in the presence of background TCP traffic: the goal of this test is to evaluate how RMCAT flows compete against TCP over a congested Wi-Fi network for a given candidate solution. [Editor's Note: more detailed description will be added in the next version in terms of directoin/number of RMCAT and TCP flows.]

- o Varying number of RMCAT flows: the goal of this test is to evaluate how a candidate RMCAT solution responds to varying traffic load/demand over a congested Wi-Fi network. [Editor's Note: more detailed description will be added in the next version in terms of arrival/departure pattern of the flows.]

4.2.4. Expected behavior

- o Multiple downlink RMCAT flows: All RMCAT flows should get fair share of the bandwidth. Overall bandwidth usage should be no less than same case with TCP flows (using TCP as performance benchmark). The delay and loss should be within acceptable range for real-time multimedia flow.

- o Multiple uplink RMCAT flows: overall bandwidth usage shared by all RMCAT flows should be no less than those shared by the same number of TCP flows (i.e., benchmark performance using TCP flows).

- o Multiple bi-directional RMCAT flows: overall bandwidth usage shared by all RMCAT flows should be no less than those shared by the same number of TCP flows (i.e., benchmark performance using TCP flows). All downlink RMCAT flows are expected to obtain similar bandwidth with respect to each other.

4.3. Potential Potential Test Cases

4.3.1. EDCA/WMM usage

EDCA/WMM is prioritized QoS with four traffic classes (or Access Categories) with differing priorities. RMCAT flow should have better performance (lower delay, less loss) with EDCA/WMM enabled when competing against non-interactive background traffic (e.g., file transfers). When most of the traffic over Wi-Fi is dominated by media, however, turning on WMM may actually degrade performance. This is a topic worthy of further investigation.

4.3.2. Legacy 802.11b Effects

When there is 802.11b devices connected to modern 802.11 network, it may affect the performance of the whole network. Additional test

cases can be added to evaluate the affects of legacy devices on the performance of RMCAT congestion control algorithm.

5. Conclusion

This document defines a collection of test cases that are considered important for cellular and Wi-Fi networks. Moreover, this document also provides a framework for defining additional test cases over wireless cellular/Wi-Fi networks.

6. Acknowledgements

We would like to thank Tomas Frankkila, Magnus Westerlund, Kristofer Sandlund for their valuable comments while writing this draft.

7. IANA Considerations

This memo includes no request to IANA.

8. Security Considerations

Security issues have not been discussed in this memo.

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9.1. Normative References

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