3GPP TR 26.922 V16.1.0 (2020-07)

Technical Report

3rd Generation Partnership Project;

Technical Specification Group Services and System Aspects;

Video telephony robustness improvements extensions; Performance evaluation

(Release 16)

** 

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Keywords

GSM, UMTS, codec, LTE

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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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where:

x the first digit:

1 presented to TSG for information;

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

# 1 Scope

The present document reports the study on video telephony robustness improvements extensions in Multimedia Telephony Service for IMS (MTSI) and provides recommendation on their applicability for MTSI video telephony applications.

# 2 References

The following documents contain provisions, which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 22.105: "Services and service capabilities".

[3] 3GPP TS 26.114: "IP Multimedia Subsystem (IMS); Multimedia telephony; Media handling and interaction".

[4] IETF RFC 4588: "RTP Retransmission Payload Format", July 2006.

[5] IETF RFC 6865: "Simple Reed-Solomon Forward Error Correction (FEC) Scheme for FECFRAME", February 2013.

[6] IETF RFC 5109: "RTP Payload Format for Generic Forward Error Correction", December 2007.

[7] IETF RFC 4585: "Extended RTP Profile for Real-time Transport Control Protocol (RTCP)-Based Feedback (RTP/AVPF)", July 2006.

[8] K. Yamagishi, T. Hayashi, "Parametric Packet-Layer Model for Monitoring Video Quality of IPTV Services", IEEE ICC 2008, pp. 110-114, May 2008.

[9] Q. Huynh-Thu, M. Ghanbari, "Impact of Jitter and Jerkiness on Perceived Video Quality", Proc. of the Second International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM), 2006.

[10] C. Wang, X. Jiang, Y. Wang, "Video Quality Assessment Models for IPTV Services", JDCTA, April 2013.

[11] Pierre Ferre, Dimitris Agrafiotis, Tuan Kiang Chiew, Angela Doufexi, Andrew Nix, David Bull, "Packet Loss Modelling for H.264 Video Transmission over IEEE 802.11g Wireless LANs", IEEE WIAMIS 2005.

[12] S. Holmer, M. Shemer, M. Paniconi, "Handling Packet Loss in WebRTC", pp. 1860-1864, ICIP, 2013.

# 3 Definitions and abbreviations

## 3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] apply.

## 3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply.

AV Audio Video

AVC Advanced Video Coding

AVPF Audio-Video Profile with Feedback

ER Error Resiliency

FPS Frames Per Second

HEVC High Efficiency Video Coding

IMS-VT IP Multimedia Subsystem Video Telephony

KB Kilo Byte

MTSI Multimedia Telephony Service for IMS

OTT Over The Top

PLI Picture Loss Indication

PLR Packet Loss Rate

QVGA Quarter Video Graphics Array

RPS Reference Picture Selection

RPSI Reference Picture Selection Indication

RTT Round Trip Time

VGA Video Graphics Array

VT Video Telephony

VTRI\_EXT Video Robustness Improvements Extensions

Wifi Wireless Fidelity

Note: Wifi is synonymous with Wi-Fi as defined by the Wi-Fi Allicance

# 4 Background

The present document reports the study on video telephony robustness improvements extensions in Multimedia Telephony Service for IMS and provides recommendation on their applicability for MTSI video telephony applications. These extensions target error robustness for higher bitrate MTSI video telephony as well as inter-working with WLAN use cases where error resiliency is more important. In order to be technically competitive, e.g. to some proprietary systems, MTSI should have the capability to employ mechanisms that can offer different trade-offs between rendering delay, video rendering jitter (smoothness) and video quality that can adapt to varying channel conditions for better user experience. Retransmission, Forward Error Correction (FEC), and complementary reference picture selection indication (RPSI) AVPF feedback mechanisms offer these trade-offs. The present document first provides an overview of the additional error resiliency (ER) tools that could improve the performance of the Multimedia Telephony Service for IMS (TS 26.114 [3]). Then test conditions representative of error conditions experienced in IMS Video Telephony are presented. Following the description of the test conditions, evaluation criteria for determining the benefits of proposed tools and mechanisms is presented. Performance of the proposed ER tools is evaluated under the defined testing conditions that take into account packet loss rate/pattern, end to end delay, bitrate overhead and video smoothness (dropped frames, rendering jitter). Based on the performance results, conclusions are made in terms of recommendations for support of proposed ER tools and mechanisms for Multimedia Telephony Service for IMS.

# 5 Overview of video robustness improvements extensions (VTRI\_EXT) tools

## 5.1 Introduction

Multimedia Telephony Service for IMS (MTSI 3GPP TS 26.114 [3]) defines MTSI clients' sender and receiver behaviour utilizing IETF RFC 4585 [7] AVPF Generic NACK and Picture Loss Indication (PLI) feedback messages for ER. Current error correction scheme provides basic error correction through codec level error resiliency (ER) mechanisms. Transport and application level error resiliency schemes such as Retransmission (NACK), Forward Error Correction (FEC) along with advanced codec level ER schemes such as Reference Picture Selection (RPS) provide alternative error correction mechanisms that offer different performance trade-offs. The performance of error correction schemes varies with end-to-end delay, channel bandwidth and packet loss rate.

## 5.2 Retransmission

Retransmission (NACK) scheme [4] provides efficient error correction in terms of bandwidth under short round-trip-time (RTT) cases with low packet loss rates. The efficiency of retransmission scheme becomes more pronounced at higher bitrates since selective retransmission of lost packets instead of entire pictures are needed. Under low RTT scenarios it can provide low video rendering jitter dependent on the de-jittering mechanism at the cost of additional delay. If additional delay cannot be accommodated, then retransmission can still provide recovery from error with video freezes during recovery similar to the existing error resiliency scheme in TS 26.114.

## 5.3 Forward error correction

Forward Error Correction (FEC) schemes [5] and [6] provide a mechanism that balances video quality and end-to-end delay. FEC schemes can adapt to varying channel error conditions. FEC is suitable for high RTT channels with high packet loss rates where retransmission leads to high video rendering delay and codec based recovery mechanisms like RPSI, PLI lead to frequent video freezes and/or corruptions. FEC schemes are complemented by retransmission (NACK) or RPSI, PLI feedback mechanisms to address FEC failure cases.

## 5.4 Reference picture selection

Reference picture selection indication (RPSI) feedback message in AVPF [7] that is currently not supported in TS 26.114 offers establishment of common reference point for recovery between the sender and the receiver. In essence it provides codec level ER mechanism similar to the transport layer ER mechanism supported by the generic NACK message in TS 26.114.

# 6 Test cases and conditions

## 6.1 QoS requirements for conversational video services

Specification TS 22.105 [2] defines the range of QoS requirements and end user QoS requirements for conversational video services. According to TS 22.105, the following requirements should be supported.

Table 6.1-1: Range of QoS requirements copied from TS 22.105 (clause 5.4)

|  |  |  |
| --- | --- | --- |
|  | Real Time (Constant Delay) | Non Real Time (Variable Delay) |
| **Operating environment** | **BER/Max Transfer Delay** | **BER/Max Transfer Delay** |
| **Satellite**  **(Terminal relative speed to ground up to 1000 km/h for plane)** | Max Transfer Delay less than 400 ms  BER 10-3 - 10-7  (NOTE 1) | Max Transfer Delay 1200 ms or more  (NOTE 2)  BER = 10-5 to 10-8 |
| **Rural outdoor**  **(Terminal relative speed to ground up to 500 km/h) (NOTE 3)** | Max Transfer Delay 20 - 300 ms  BER 10-3 - 10-7  (NOTE 1) | Max Transfer Delay 150 ms or more  (NOTE 2)  BER = 10-5 to 10-8 |
| **Urban/ Suburban outdoor**  **(Terminal relative speed to ground up to 120 km/h)** | Max Transfer Delay 20 - 300 ms  BER 10-3 - 10-7  (NOTE 1) | Max Transfer Delay 150 ms or more  (Note 2)  BER = 10-5 to 10-8 |
| **Indoor/ Low range outdoor**  **(Terminal relative speed to ground up to 10 km/h)** | Max Transfer Delay 20 - 300 ms  BER 10-3 - 10-7  (NOTE 1) | Max Transfer Delay 150 ms or more  (NOTE 2)  BER = 10-5 to 10-8 |
| NOTE 1: There is likely to be a compromise between BER and delay.  NOTE 2: The Max Transfer Delay should be here regarded as the target value for 95% of the data.  NOTE 3: The value of 500 km/h as the maximum speed to be supported in the rural outdoor environment was selected in order to provide service on high speed vehicles (e.g. trains). This is not meant to be the typical value for this environment (250 km/h is more typical). | | |

And the requirements for end user QoS as performance expectations for conversational/real-time services is shown in table 6.1-2.

Table 6.1-2: End-user performance expectations (copied from TS 22.105 clause 5.5)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Medium | Application | Degree of symmetry | Data rate | Key performance parameters and target values | | |
|  |  |  |  | End-to-end One-way  Delay | Delay  Variation within a call | Information loss |
| Audio | Conversational voice | Two-way | 4-25 kb/s | <150 msec  preferred  <400 msec limit NOTE 1 | < 1 msec | < 3% FER |
| Video | Videophone | Two-way | 32-384 kb/s | < 150 msec preferred  <400 msec limit  Lip-synch: < 100 msec |  | < 1% FER |
| Data | Telemetry  - two-way control | Two-way | <28.8 kb/s | < 250 msec | N.A | Zero |
| Data | realtime games | Two-way | < 60 kb/s  NOTE 2 | < 75 msec preferred | N.A | < 3% FER preferred,  < 5% FER limit  NOTE 2 |
| Data | Telnet | Two-way  (asymmetric) | < 1 KB | < 250 msec | N.A | Zero |
| NOTE 1: The overall one way delay in the mobile network (from UE to PLMN border) is approximately 100msec.  NOTE 2: Thesevalues are considered the most demanding ones with respect to delay requirements (e.g. supporting First Person Shooter games). Other types of games may require higher or lower data rates and more or less information loss but can tolerate longer end-to-end delay | | | | | | |

QoS test conditions used to evaluate the proposed tools should follow the service requirements described in TS 22.105. In addition to QoS networks, test conditions addressing interworking with non-QoS networks should be considered for the following reasons:

- Interworking with non-QoS networks is a relevant deployment use case and may result in losses in the non-managed part of the delivery.

- Despite QoS, there may be circumstances for which the QoS guarantees fail and service continuity is relevant.

## 6.2 Channel conditions

Channels conditions from QoS LTE, best effort over the top (OTT) LTE and WiFi channels are logged from video telephony calls for video configurations defined in clause 6.4. Packet captures are conducted on video telephony (VT) calls under mobile and stationary test conditions. Sending and receiving rates, delay (RTT/2), packet loss patterns are derived from captures sending and receiving times, timestamps and sequence numbers. The sources of the packet losses are from the physical channel as well as congestion. During the channel capturing process, the operating rate of the VT calls targeted rates below the available bandwidth for avoiding congestion. It is not always possible to avoid congestion during the capturing process. Logs exhibiting frequent large variations in rate due to congestion are filtered out.

Packet losses are characterized by the burst patterns. A packet *loss-free* burst of order *k0* is observed in the loss pattern when at least *k0* consecutive packets are correctly received. A packet loss burst order *k0* starts and finishes with a missing packet ("1") and is composed of at most *k0 -*1 consecutive received packets [11]. In the analysis presented in the present document, *k0 =*1 is used for simplicity. Sequences of *m* (total number of logged packets) loss indicators are divided into *p* alternating loss-free burst (*Xj*) and packet loss bursts (*Yj*). Average packet loss rate *PLRavg*, average loss free duration *Xavg* and average loss duration *Yavg* are computed as:

, (6.2-1)

, (6.2-2)

. (6.2-3)

## 6.3 Error profiles

### 6.3.1 Introduction

Error profiles representing guaranteed QoS and best effort (non-QoS) cases are used for evaluation. A number of real channel capture logs from QoS and non-QoS services are provided for emulation of channel conditions and/or derivation of channel models for simulation of channel conditions. Captured channel logs are used in the simulations of channel conditions for evaluation of proposed error resiliency tools.

### 6.3.2 QoS LTE

IMS-VT QoS calls conducted under low speed mobile conditions covering near cell and edge cell conditions were logged for analysis. QVGA (320x240), 15 fps, 350 kbps (maximum bitrate) H.264 video is used during the IMS-VT call. 17 MO to MT and 17 MT to MO logs selected from ~100 short duration calls (less than 1 minute) are used. In Table 6.3-1, MO to MT (IMS-QoS Test1) and likewise MT to MO (IMS-QoS Test2) call statistics are consolidated into one due to short duration of the calls. Packet loss statistics are tabulated in Table 6.3-1. Clause A.1 provides packet loss patterns for the consolidated logs.

### 6.3.3 LTE-OTT

Video telephony calls over LTE-OTT were conducted under driving conditions. One of the UEs is positioned in a stationary office environment with good LTE signal and the other UE in a moving vehicle. VGA (640x480) 30 fps 600 kbps (VT-LTE OTT Test1 & Test2) and QVGA 15 fps 300 kbps (VT-LTE OTT Test3 & Test4) videos were used for collecting channel logs. Packet loss statistics are tabulated in Table 6.3-1. Clause A.2 provides packet loss patterns for LTE-OTT tests.

### 6.3.4 WiFi

Video telephony calls over WiFi are conducted in office environment. Stationary office to office call and office to walking UE calls are logged. 720p (1 280x720) 30 fps 1 000 kbps video is used for collecting channel logs. Total of 8 logs (VT-Wifi Test1-8) are collected. Packet loss statistics are tabulated in Table 6.3-1. Clause A.3 provides packet loss patterns for WiFi tests.

### 6.3.5 Summary

Table 6.3-1 summarizes error profiles used during the evaluation process.

Table 6.3-1: Summary of error pattern statistics

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Test | Condition | Bit -rate (kbps) | Frame Rate (fps) | Resolution | Duration (sec) | No. of packets | Avg loss free duration (pkts) | Avg. loss duration (pkts) | Avg PLR (%) |
| IMS-QoS Test1 | Low mobility | 350 | 15 | 320x240 | 309 | 12032 | 2 007 | 1,5 | 0,07% |
| IMS-QoS Test2 | Low mobility | 350 | 15 | 320x240 | 309 | 11870 | 627 | 4,1 | 0,66% |
| VT-LTE OTT Test1 | High mobility | 600 | 30 | 640x480 | 2 291 | 158 699 | 1 521 | 4,6 | 0,30% |
| VT-LTE OTT Test2 | High mobility | 600 | 30 | 640x480 | 2 290 | 145 352 | 1 305 | 5,7 | 0,43% |
| VT-LTE OTT Test3 | Walk & High mobility | 300 | 15 | 320x240 | 982 | 40 305 | 2 672 | 15,1 | 0,56% |
| VT-LTE OTT Test4 | Walk & High mobility | 300 | 15 | 320x240 | 981 | 39 222 | 2 440 | 11,8 | 0,48% |
| VT-Wifi Test1 | Stationary | 1 000 | 30 | 1 280x720 | 766 | 93 771 | 1 801 | 1,9 | 0,10% |
| VT-Wifi Test2 | Stationary | 1 000 | 30 | 1 280x720 | 765 | 92 795 | 1 685 | 1,9 | 0,11% |
| VT-Wifi Test3 | Stationary | 1 000 | 30 | 1 280x720 | 715 | 53 698 | 292 | 2,7 | 0,92% |
| VT-Wifi Test4 | Stationary | 1 000 | 30 | 1 280x720 | 717 | 72 244 | 36 | 1,9 | 5,02% |
| VT-Wifi Test5 | Stationary | 1 000 | 30 | 1 280x720 | 620 | 75 946 | 1 724 | 2,2 | 0,13% |
| VT-Wifi Test6 | Stationary | 1 000 | 30 | 1 280x720 | 620 | 75 472 | 1 477 | 3,2 | 0,21% |
| VT-Wifi Test7 | Walk | 1 000 | 30 | 1 280x720 | 381 | 24 045 | 607 | 9,8 | 1,60% |
| VT-Wifi Test8 | Walk | 1 000 | 30 | 1 280x720 | 381 | 37 093 | 67 | 3,4 | 4,75% |
| VT-Wifi Test9 | Walk | 1 000 | 30 | 1 280x720 | 913 | 54 260 | 39 | 2,7 | 7,19% |
| VT-Random | Random | 1 000 | 30 | 1 280x720 | 1 013 | 98 634 | - | - | 10,04% |

## 6.4 Test Content

For evaluation of ER tools, the two main factors that have impact on the overall performance is the video bitrate and the frame rate. It is assumed that the video is coded in low delay configuration, i.e. IPPPPP… or IBBBB…. configuration. The video resolution, content, and codec type (AVC, HEVC) have minimal impact since as described in clause 7, the corrupted pictures will be considered as non-rendered pictures. The following video resolutions, bitrate and frame rates are used during the evaluation process.

Table 6.4-1: Test content configuration

|  |  |  |
| --- | --- | --- |
| Resolution | Bitrate (kbps) | Frame rate (fps) |
| 320x240 | 300 & 350 | 15 |
| 640x480 | 600 | 30 |
| 1 280x720 | 1 000 | 30 |

# 7 Evaluation criteria

## 7.1 Testing configuration

In order to simplify the evaluation process, it will be assumed that corrupted video frames will not be rendered. When an error occurs, corrective action based on retransmission, RPSI or FEC will be taken. These proposed tools can be used alone or in combination. For example FEC and RPSI or FEC and NACK can be used in combination to complement each other (i.e. when FEC fails, NACK or RPSI can achieve recovery).

Video bitstreams are packetized into maximum packet length of 1 400 bytes. Packetization byte overhead is ignored. Packet loss patterns are applied only in one direction according to the error profiles defined in clause 6.3, i.e. feedback channel is assumed to be error free. Sender and receiver side processing (encoding/decoding + various other tasks) times are ignored. Frames are generated at uniform time interval according to the frame rate. Transmission delay of packets in each direction is equal to RTT/2. Frames are packetized and sent as soon as they are encoded (i.e. at frame timestamps) at the sender, and removed from the packet de-jitter buffer as soon as complete frame data is available.

Decoding delay (*delayD*) is computed as the difference between the time of removal from the de-jitter buffer for decoding and the capture timestamp (RTP timestamp). End-to-end rendering delay (*delaye2e*) is determined as:

, (7.1-1)

where, *avg\_delayD* is the average decoding delay and *std\_delayD* is standard deviation of decoding delay. This is to accommodate variation in arrival time of frames that can be rendered due retransmission. Frames that are late by more than *delaye2e* are not rendered. A hard limit of 400 ms is also imposed according to requirements of TS 22.105. Only perfectly reconstructed frames are rendered.

Every lost packet is reported to the sender side. For RPSI based recovery, it is assumed that the recovery frame size is same as the frame size in the bitstream that occurs at the recovery point and it generates an identical picture to the picture occurring at the recovery point. This simplified assumption is necessary for simplifying the simulations. It has negligible effect on the simulation results (without this assumption, the recovery frame size will be larger than the frame size occurring at the recovery point). For NACK based recovery, missing packets are retransmitted. For FEC based recovery an adaptive perfect FEC scheme (Reed Solomon) targeting 0,95 minimum recovery probability for maximum loss rate occurring during the 10 second history window is used. There is no interleaving of packets used and FEC packets do not cross frame boundaries, i.e. FEC packets protect source data that belongs to one frame. FEC overhead rate can be adjusted according to RTT time to minimize frequency of freezes when RTT is large. In the simulation environment, this method was not used.

## 7.2 Performance metrics

Assuming that there will be no corrupted pictures will be rendered, then the parameters that affect the perceived video quality are:

1. Bitrate overhead

2. End-to-end rendering delay

3. Number of frames not rendered

4. Rendering smoothness measure (standard deviation of rendering time from the target rendering time), i.e.

. (7.2-1)

's are the time intervals between consecutively rendered frames and is the average of for *N* frames [12].

In terms of bitrate overhead, FEC and retransmission are the tools that have bitrate overhead impact, FEC being the one that may have significant overhead. Given a limited channel bandwidth, full channel utilization, bitrate overhead impacts spatial video quality. The final effect of the overhead is the reduction of effective video source rate. Although it is content dependent, generally, bitrate reductions of 15% or more are perceivable. Bitrate overhead is measured with respect to the video source rate.

End-to-end rendering delay for video, which impacts audio delay, is critical for conversational services. The upper limit for tolerable delay is 400 ms. Delays of 150 ms or below are not noticeable. During a call end-to-end delay may vary. Among the proposed tools, retransmission is the only tool that may have impact on the end-to-end delay.

Number frames not rendered convey information on the temporal video quality. A frame will not be rendered if it has a packet that is missing or it is dependent on past frames that had missing packets. It is related to ER failure rate for frames. In general the higher it is, the worse the perceived video quality is. However the distribution of non-rendered frames also impact the visual quality. In [8], [9] and [10], it is reported that the frequent short video freezes result in lower MOS scores than long infrequent video freezes. Rendering smoothness measure in combination with number of not rendered frames conveys distribution information of video freezes. These two metrics are applicable to all proposed ER tools.

During the testing process, audio-video (AV) synchronization is assumed to be preserved, i.e. long term delay in video forces audio to be delayed. End to end delay in evaluation setup remains within the bounds specified in TS 22.105.

# 8 Results

## 8.1 Test cases

The performance of proposed tools under channel conditions defined in clause 6.3 are evaluated according to metrics defined for video quality in clause 7.2. Video test content defined in clause 6.4 is generated offline using an H.264 encoder. A test setup that simulates channel conditions according to conditions defined in clause 6.3 as well as error resiliency behavior of the proposed tools is used. Evaluations of the proposed tools are conducted under different round-trip-time (RTT) conditions with the captured channel logs.

Captured channel logs are used for simulating packet losses under RTT of (100 ms, 200 ms, 300 ms, 400 ms). The proposed metrics defined in clause 7.2 are logged to characterize behavior of each tool. Each tool is tested individually and in combination with other tools. The following test cases are run:

Table 8.1-1: Test cases

|  |
| --- |
| Test Cases |
| TS 26.114 NACK or RPSI |
| FEC+RPSI |
| Retransmission (NACK) |
| FEC+ retransmission |

## 8.2 Simulation (RTT= 100 ms)

Table 8.2-1 shows the evaluation results for RTT = 100 ms.

Table 8.2-1: RTT = 100 ms

| Tool | Test(RTT = 100 ms) | PLR% | Bitrate Overhead% | Total Frames | e2e Delay (ms) | Std Render Delta(ms) | Rendered Frames | Rendered Frame% |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TS 26.114 NACK or RPSI | IMS-QoS Test1 | 0,07% | 0,00% | 4561 | 50 | 5 | 4 550 | 99,76% |
| IMS-QoS Test2 | 0,66% | 0,00% | 4497 | 50 | 24 | 4 453 | 99,02% |
| VT-LTE OTT Test1 | 0,30% | 0,00% | 77 793 | 50 | 9 | 77 389 | 99,48% |
| VT-LTE OTT Test2 | 0,43% | 0,00% | 71 249 | 50 | 12 | 70 820 | 99,40% |
| VT-LTE OTT Test3 | 0,56% | 0,00% | 19 072 | 50 | 34 | 18 947 | 99,34% |
| VT-LTE OTT Test4 | 0,48% | 0,00% | 18 560 | 50 | 24 | 18 458 | 99,45% |
| VT-Wifi Test1 | 0,10% | 0,00% | 28 884 | 50 | 6 | 28 677 | 99,28% |
| VT-Wifi Test2 | 0,11% | 0,00% | 28 583 | 50 | 6 | 28 364 | 99,23% |
| VT-Wifi Test3 | 0,92% | 0,00% | 16 540 | 50 | 13 | 15 948 | 96,42% |
| VT-Wifi Test4 | 5,02% | 0,00% | 22 253 | 50 | 62 | 17 584 | 79,02% |
| VT-Wifi Test5 | 0,13% | 0,00% | 23 393 | 50 | 6 | 23 223 | 99,27% |
| VT-Wifi Test6 | 0,21% | 0,00% | 23 247 | 50 | 7 | 23 028 | 99,06% |
| VT-Wifi Test7 | 1,60% | 0,00% | 7 407 | 50 | 23 | 7 198 | 97,18% |
| VT-Wifi Test8 | 4,75% | 0,00% | 11 425 | 50 | 62 | 9 797 | 85,75% |
| VT-Wifi Test9 | 7,19% | 0,00% | 16 714 | 50 | 68 | 13 142 | 78,63% |
| VT-Random | 10,04% | 0,00% | 30 381 | 50 | 79 | 13 791 | 45,39% |
| FEC+RPSI | IMS-QoS Test1 | 0,07% | 6,11% | 4 300 | 50 | 5 | 4 290 | 99,77% |
| IMS-QoS Test2 | 0,66% | 7,48% | 4 186 | 50 | 27 | 4 141 | 98,93% |
| VT-LTE OTT Test1 | 0,30% | 4,30% | 74 587 | 50 | 7 | 74 269 | 99,57% |
| VT-LTE OTT Test2 | 0,43% | 2,83% | 69 292 | 50 | 13 | 68 925 | 99,47% |
| VT-LTE OTT Test3 | 0,56% | 2,06% | 18 688 | 50 | 31 | 18 579 | 99,42% |
| VT-LTE OTT Test4 | 0,48% | 2,13% | 18 173 | 50 | 14 | 18 110 | 99,65% |
| VT-Wifi Test1 | 0,10% | 9,74% | 26 328 | 50 | 6 | 26 141 | 99,29% |
| VT-Wifi Test2 | 0,11% | 10,84% | 25 799 | 50 | 6 | 25 595 | 99,21% |
| VT-Wifi Test3 | 0,92% | 26,54% | 13 097 | 50 | 12 | 12 746 | 97,32% |
| VT-Wifi Test4 | 5,02% | 43,16% | 15 566 | 50 | 26 | 14 422 | 92,65% |
| VT-Wifi Test5 | 0,13% | 11,17% | 21 063 | 50 | 6 | 20 917 | 99,31% |
| VT-Wifi Test6 | 0,21% | 13,04% | 20 588 | 50 | 7 | 20 391 | 99,04% |
| VT-Wifi Test7 | 1,60% | 14,02% | 6 502 | 50 | 22 | 6 331 | 97,37% |
| VT-Wifi Test8 | 4,75% | 32,00% | 8 669 | 50 | 42 | 8 051 | 92,87% |
| VT-Wifi Test9 | 7,19% | 36,46% | 12 261 | 50 | 47 | 11 047 | 90,10% |
| VT-Random | 10,04% | 62,92% | 18 724 | 50 | 11 | 18 177 | 97,08% |
| Retransmit (NACK) | IMS-QoS Test1 | 0,07% | 0,08% | 4 557 | 73 | 8 | 4 540 | 99,63% |
| IMS-QoS Test2 | 0,66% | 0,64% | 4 468 | 146 | 16 | 4 440 | 99,37% |
| VT-LTE OTT Test1 | 0,30% | 0,31% | 77 555 | 133 | 9 | 77 213 | 99,56% |
| VT-LTE OTT Test2 | 0,43% | 0,44% | 70 939 | 131 | 9 | 70 661 | 99,61% |
| VT-LTE OTT Test3 | 0,56% | 0,57% | 18 964 | 400 | 31 | 18 871 | 99,51% |
| VT-LTE OTT Test4 | 0,48% | 0,48% | 18 470 | 243 | 19 | 18 414 | 99,70% |
| VT-Wifi Test1 | 0,10% | 0,10% | 28 853 | 76 | 6 | 28 631 | 99,23% |
| VT-Wifi Test2 | 0,11% | 0,11% | 28 550 | 76 | 6 | 28 318 | 99,19% |
| VT-Wifi Test3 | 0,92% | 0,92% | 16 388 | 130 | 13 | 15 965 | 97,42% |
| VT-Wifi Test4 | 5,02% | 5,31% | 21 134 | 339 | 18 | 20 804 | 98,44% |
| VT-Wifi Test5 | 0,13% | 0,13% | 23 363 | 77 | 6 | 23 172 | 99,18% |
| VT-Wifi Test6 | 0,21% | 0,21% | 23 197 | 91 | 6 | 23 011 | 99,20% |
| VT-Wifi Test7 | 1,60% | 1,54% | 7 295 | 331 | 19 | 7 206 | 98,78% |
| VT-Wifi Test8 | 4,75% | 4,90% | 10 892 | 400 | 44 | 10 620 | 97,50% |
| VT-Wifi Test9 | 7,19% | 7,76% | 15 525 | 400 | 35 | 14 975 | 96,46% |
| VT-Random | 10,04% | 11,16% | 27 330 | 366 | 7 | 27 029 | 98,90% |
| FEC + NACK | IMS-QoS Test1 | 0,07% | 5,53% | 4 319 | 72 | 7 | 4 303 | 99,63% |
| IMS-QoS Test2 | 0,66% | 8,34% | 4 159 | 151 | 14 | 4 134 | 99,40% |
| VT-LTE OTT Test1 | 0,30% | 4,75% | 74 265 | 125 | 8 | 73 983 | 99,62% |
| VT-LTE OTT Test2 | 0,43% | 2,97% | 69 196 | 133 | 9 | 68 948 | 99,64% |
| VT-LTE OTT Test3 | 0,56% | 2,13% | 18 675 | 400 | 29 | 18 590 | 99,54% |
| VT-LTE OTT Test4 | 0,48% | 2,78% | 18 062 | 185 | 16 | 18 012 | 99,72% |
| VT-Wifi Test1 | 0,10% | 9,85% | 26 299 | 75 | 6 | 26 097 | 99,23% |
| VT-Wifi Test2 | 0,11% | 10,97% | 25 769 | 77 | 6 | 25 552 | 99,16% |
| VT-Wifi Test3 | 0,92% | 27,68% | 12 983 | 112 | 11 | 12 686 | 97,71% |
| VT-Wifi Test4 | 5,02% | 43,03% | 15 577 | 241 | 16 | 15 322 | 98,36% |
| VT-Wifi Test5 | 0,13% | 11,32% | 21 034 | 76 | 6 | 20 869 | 99,22% |
| VT-Wifi Test6 | 0,21% | 13,73% | 20 468 | 91 | 7 | 20 304 | 99,20% |
| VT-Wifi Test7 | 1,60% | 17,01% | 6 340 | 249 | 15 | 6 260 | 98,74% |
| VT-Wifi Test8 | 4,75% | 36,77% | 8 363 | 400 | 33 | 8 191 | 97,94% |
| VT-Wifi Test9 | 7,19% | 45,28% | 11 533 | 400 | 25 | 11 258 | 97,62% |
| VT-Random | 10,04% | 63,51% | 18 654 | 108 | 10 | 18 183 | 97,48% |

## 8.3 Simulation (RTT= 200 ms)

Table 8.3-1 shows the evaluation results for RTT = 200 ms.

Table 8.3-1: RTT = 200 ms

| Tool | Test(RTT = 200 ms) | PLR% | Bitrate Overhead% | Total Frames | e2e Delay (ms) | Std Render Delta(ms) | Rendered Frames | Rendered Frame% |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TS 26.114 NACK or RPSI | IMS-QoS Test1 | 0,07% | 0,00% | 4 561 | 100 | 9 | 4 540 | 99,54% |
| IMS-QoS Test2 | 0,66% | 0,00% | 4 497 | 100 | 25 | 4 448 | 98,91% |
| VT-LTE OTT Test1 | 0,30% | 0,00% | 77 793 | 100 | 11 | 77 293 | 99,36% |
| VT-LTE OTT Test2 | 0,43% | 0,00% | 71 249 | 100 | 15 | 70 747 | 99,30% |
| VT-LTE OTT Test3 | 0,56% | 0,00% | 19 072 | 100 | 35 | 18 929 | 99,25% |
| VT-LTE OTT Test4 | 0,48% | 0,00% | 18 560 | 100 | 25 | 18 448 | 99,40% |
| VT-Wifi Test1 | 0,10% | 0,00% | 28 884 | 100 | 10 | 28 524 | 98,75% |
| VT-Wifi Test2 | 0,11% | 0,00% | 28 583 | 100 | 10 | 28 202 | 98,67% |
| VT-Wifi Test3 | 0,92% | 0,00% | 16 540 | 100 | 23 | 15 602 | 94,33% |
| VT-Wifi Test4 | 5,02% | 0,00% | 22 253 | 100 | 76 | 16 164 | 72,64% |
| VT-Wifi Test5 | 0,13% | 0,00% | 23 393 | 100 | 10 | 23 098 | 98,74% |
| VT-Wifi Test6 | 0,21% | 0,00% | 23 247 | 100 | 12 | 22 885 | 98,44% |
| VT-Wifi Test7 | 1,60% | 0,00% | 7 407 | 100 | 27 | 7 135 | 96,33% |
| VT-Wifi Test8 | 4,75% | 0,00% | 11 425 | 100 | 81 | 9 220 | 80,70% |
| VT-Wifi Test9 | 7,19% | 0,00% | 16 714 | 100 | 83 | 12 141 | 72,64% |
| VT-Random | 10,04% | 0,00% | 30 381 | 100 | 137 | 10 052 | 33,09% |
| FEC+RPSI | IMS-QoS Test1 | 0,07% | 6,10% | 4 301 | 100 | 8 | 4 285 | 99,63% |
| IMS-QoS Test2 | 0,66% | 7,44% | 4 186 | 100 | 36 | 4 133 | 98,73% |
| VT-LTE OTT Test1 | 0,30% | 4,40% | 74 515 | 100 | 10 | 74 083 | 99,42% |
| VT-LTE OTT Test2 | 0,43% | 2,41% | 69 577 | 100 | 14 | 69 123 | 99,35% |
| VT-LTE OTT Test3 | 0,56% | 2,10% | 18 679 | 100 | 28 | 18 568 | 99,41% |
| VT-LTE OTT Test4 | 0,48% | 2,14% | 18 172 | 100 | 18 | 18 099 | 99,60% |
| VT-Wifi Test1 | 0,10% | 9,67% | 26 344 | 100 | 10 | 26 012 | 98,74% |
| VT-Wifi Test2 | 0,11% | 10,88% | 25 790 | 100 | 10 | 25 448 | 98,67% |
| VT-Wifi Test3 | 0,92% | 26,53% | 13 097 | 100 | 18 | 12 570 | 95,98% |
| VT-Wifi Test4 | 5,02% | 40,87% | 15 813 | 100 | 35 | 14 037 | 88,77% |
| VT-Wifi Test5 | 0,13% | 11,75% | 20 958 | 100 | 9 | 20 718 | 98,85% |
| VT-Wifi Test6 | 0,21% | 13,03% | 20 590 | 100 | 12 | 20 258 | 98,39% |
| VT-Wifi Test7 | 1,60% | 14,44% | 6 480 | 100 | 23 | 6 262 | 96,64% |
| VT-Wifi Test8 | 4,75% | 32,10% | 8 661 | 100 | 49 | 7 814 | 90,22% |
| VT-Wifi Test9 | 7,19% | 37,19% | 12 196 | 100 | 55 | 10 612 | 87,01% |
| VT-Random | 10,04% | 62,92% | 18 723 | 100 | 20 | 17 814 | 95,15% |
| Retransmit (NACK) | IMS-QoS Test1 | 0,07% | 0,08% | 4 557 | 141 | 10 | 4 535 | 99,52% |
| IMS-QoS Test2 | 0,66% | 0,64% | 4 468 | 262 | 20 | 4 434 | 99,24% |
| VT-LTE OTT Test1 | 0,30% | 0,31% | 77 555 | 215 | 13 | 77 114 | 99,43% |
| VT-LTE OTT Test2 | 0,43% | 0,44% | 70 939 | 211 | 11 | 70 584 | 99,50% |
| VT-LTE OTT Test3 | 0,56% | 0,56% | 18 964 | 400 | 34 | 18 863 | 99,47% |
| VT-LTE OTT Test4 | 0,48% | 0,47% | 18 470 | 368 | 22 | 18 404 | 99,64% |
| VT-Wifi Test1 | 0,10% | 0,10% | 28 853 | 154 | 9 | 28 529 | 98,88% |
| VT-Wifi Test2 | 0,11% | 0,11% | 28 550 | 156 | 9 | 28 210 | 98,81% |
| VT-Wifi Test3 | 0,92% | 0,93% | 16 388 | 264 | 19 | 15 816 | 96,51% |
| VT-Wifi Test4 | 5,02% | 5,31% | 21 134 | 400 | 34 | 20 189 | 95,53% |
| VT-Wifi Test5 | 0,13% | 0,13% | 23 363 | 156 | 9 | 23 086 | 98,81% |
| VT-Wifi Test6 | 0,21% | 0,21% | 23 197 | 171 | 9 | 22 911 | 98,77% |
| VT-Wifi Test7 | 1,60% | 1,50% | 7 297 | 400 | 20 | 7 197 | 98,63% |
| VT-Wifi Test8 | 4,75% | 4,89% | 10 892 | 400 | 53 | 10 411 | 95,58% |
| VT-Wifi Test9 | 7,19% | 7,75% | 15 528 | 400 | 53 | 14 364 | 92,50% |
| VT-Random | 10,04% | 11,15% | 27 331 | 400 | 44 | 22 540 | 82,47% |
| FEC + NACK | IMS-QoS Test1 | 0,07% | 6,19% | 4 298 | 140 | 10 | 4 277 | 99,51% |
| IMS-QoS Test2 | 0,66% | 8,35% | 4 158 | 286 | 22 | 4 122 | 99,13% |
| VT-LTE OTT Test1 | 0,30% | 4,75% | 74 264 | 208 | 12 | 73 886 | 99,49% |
| VT-LTE OTT Test2 | 0,43% | 3,06% | 69 134 | 208 | 11 | 68 798 | 99,51% |
| VT-LTE OTT Test3 | 0,56% | 2,13% | 18 676 | 400 | 31 | 18 583 | 99,50% |
| VT-LTE OTT Test4 | 0,48% | 2,69% | 18 075 | 278 | 18 | 18 017 | 99,68% |
| VT-Wifi Test1 | 0,10% | 9,86% | 26 297 | 154 | 9 | 25 996 | 98,86% |
| VT-Wifi Test2 | 0,11% | 11,00% | 25 763 | 157 | 9 | 25 438 | 98,74% |
| VT-Wifi Test3 | 0,92% | 27,29% | 13 022 | 240 | 14 | 12 702 | 97,54% |
| VT-Wifi Test4 | 5,02% | 44,57% | 15 411 | 400 | 23 | 15 099 | 97,98% |
| VT-Wifi Test5 | 0,13% | 11,81% | 20 947 | 155 | 9 | 20 710 | 98,87% |
| VT-Wifi Test6 | 0,21% | 13,22% | 20 558 | 171 | 9 | 20 305 | 98,77% |
| VT-Wifi Test7 | 1,60% | 15,29% | 6 430 | 346 | 17 | 6 342 | 98,63% |
| VT-Wifi Test8 | 4,75% | 35,68% | 8 433 | 400 | 38 | 8 183 | 97,04% |
| VT-Wifi Test9 | 7,19% | 44,90% | 11 552 | 400 | 35 | 11 047 | 95,63% |
| VT-Random | 10,04% | 63,75% | 18 626 | 215 | 13 | 18 069 | 97,01% |

## 8.4 Simulation (RTT= 300 ms)

Table 8.4-1 shows the evaluation results for RTT = 300 ms.

Table 8.4-1: RTT = 300 ms

| Tool | Test(RTT = 300 ms) | PLR% | Bitrate Overhead% | Total Frames | e2e Delay (ms) | Std Render Delta(ms) | Rendered Frames | Rendered Frame% |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TS 26.114 NACK or RPSI | IMS-QoS Test1 | 0,07% | 0,00% | 4 561 | 150 | 11 | 4 535 | 99,43% |
| IMS-QoS Test2 | 0,66% | 0,00% | 4 497 | 150 | 34 | 4 442 | 98,78% |
| VT-LTE OTT Test1 | 0,30% | 0,00% | 77 793 | 150 | 14 | 77 181 | 99,21% |
| VT-LTE OTT Test2 | 0,43% | 0,00% | 71 249 | 150 | 18 | 70 701 | 99,23% |
| VT-LTE OTT Test3 | 0,56% | 0,00% | 19 072 | 150 | 36 | 18 920 | 99,20% |
| VT-LTE OTT Test4 | 0,48% | 0,00% | 18 560 | 150 | 26 | 18 442 | 99,36% |
| VT-Wifi Test1 | 0,10% | 0,00% | 28 884 | 150 | 14 | 28 371 | 98,22% |
| VT-Wifi Test2 | 0,11% | 0,00% | 28 583 | 150 | 14 | 28 045 | 98,12% |
| VT-Wifi Test3 | 0,92% | 0,00% | 16 540 | 150 | 32 | 15 317 | 92,61% |
| VT-Wifi Test4 | 5,02% | 0,00% | 22 253 | 150 | 94 | 14 940 | 67,14% |
| VT-Wifi Test5 | 0,13% | 0,00% | 23 393 | 150 | 14 | 22 972 | 98,20% |
| VT-Wifi Test6 | 0,21% | 0,00% | 23 247 | 150 | 16 | 22 744 | 97,84% |
| VT-Wifi Test7 | 1,60% | 0,00% | 7 407 | 150 | 31 | 7 078 | 95,56% |
| VT-Wifi Test8 | 4,75% | 0,00% | 11 425 | 150 | 95 | 8 786 | 76,90% |
| VT-Wifi Test9 | 7,19% | 0,00% | 16 714 | 150 | 103 | 11 258 | 67,36% |
| VT-Random | 10,04% | 0,00% | 30 381 | 150 | 191 | 7 890 | 25,97% |
| FEC+RPSI | IMS-QoS Test1 | 0,07% | 6,12% | 4 300 | 150 | 11 | 4 275 | 99,42% |
| IMS-QoS Test2 | 0,66% | 7,42% | 4 187 | 150 | 35 | 4 134 | 98,73% |
| VT-LTE OTT Test1 | 0,30% | 4,36% | 74 547 | 150 | 12 | 74 056 | 99,34% |
| VT-LTE OTT Test2 | 0,43% | 2,80% | 69 310 | 150 | 14 | 68 862 | 99,35% |
| VT-LTE OTT Test3 | 0,56% | 2,06% | 18 687 | 150 | 32 | 18 560 | 99,32% |
| VT-LTE OTT Test4 | 0,48% | 2,14% | 18 171 | 150 | 20 | 18 091 | 99,56% |
| VT-Wifi Test1 | 0,10% | 9,74% | 26 328 | 150 | 14 | 25 855 | 98,20% |
| VT-Wifi Test2 | 0,11% | 10,84% | 25 798 | 150 | 15 | 25 290 | 98,03% |
| VT-Wifi Test3 | 0,92% | 26,53% | 13 097 | 150 | 26 | 12 360 | 94,37% |
| VT-Wifi Test4 | 5,02% | 41,43% | 15 749 | 150 | 49 | 13 495 | 85,69% |
| VT-Wifi Test5 | 0,13% | 11,26% | 21 046 | 150 | 14 | 20 702 | 98,37% |
| VT-Wifi Test6 | 0,21% | 13,08% | 20 584 | 150 | 17 | 20 114 | 97,72% |
| VT-Wifi Test7 | 1,60% | 14,03% | 6 501 | 150 | 28 | 6 227 | 95,79% |
| VT-Wifi Test8 | 4,75% | 32,97% | 8 608 | 150 | 56 | 7 569 | 87,93% |
| VT-Wifi Test9 | 7,19% | 35,88% | 12 312 | 150 | 66 | 10 340 | 83,98% |
| VT-Random | 10,04% | 62,90% | 18 726 | 150 | 28 | 17 421 | 93,03% |
| Retransmit (NACK) | IMS-QoS Test1 | 0,07% | 0,08% | 4 557 | 212 | 12 | 4 530 | 99,41% |
| IMS-QoS Test2 | 0,66% | 0,64% | 4 468 | 332 | 21 | 4 429 | 99,13% |
| VT-LTE OTT Test1 | 0,30% | 0,31% | 77 555 | 302 | 14 | 77 032 | 99,33% |
| VT-LTE OTT Test2 | 0,43% | 0,44% | 70 939 | 305 | 15 | 70 512 | 99,40% |
| VT-LTE OTT Test3 | 0,56% | 0,57% | 18 964 | 400 | 36 | 18 843 | 99,36% |
| VT-LTE OTT Test4 | 0,48% | 0,47% | 18 470 | 400 | 25 | 18 389 | 99,56% |
| VT-Wifi Test1 | 0,10% | 0,10% | 28 853 | 239 | 12 | 28 427 | 98,52% |
| VT-Wifi Test2 | 0,11% | 0,11% | 28 550 | 242 | 12 | 28 102 | 98,43% |
| VT-Wifi Test3 | 0,92% | 0,92% | 16 388 | 385 | 18 | 15 819 | 96,53% |
| VT-Wifi Test4 | 5,02% | 5,30% | 21 134 | 400 | 77 | 16 388 | 77,54% |
| VT-Wifi Test5 | 0,13% | 0,13% | 23 363 | 242 | 12 | 23 002 | 98,45% |
| VT-Wifi Test6 | 0,21% | 0,21% | 23 197 | 268 | 13 | 22 807 | 98,32% |
| VT-Wifi Test7 | 1,60% | 1,50% | 7 297 | 400 | 25 | 7 102 | 97,33% |
| VT-Wifi Test8 | 4,75% | 4,90% | 10 892 | 400 | 73 | 9 348 | 85,82% |
| VT-Wifi Test9 | 7,18% | 7,73% | 15 544 | 400 | 93 | 12 119 | 77,97% |
| VT-Random | 10,04% | 11,15% | 27 331 | 400 | 233 | 7 393 | 27,05% |
| FEC + NACK | IMS-QoS Test1 | 0,07% | 5,55% | 4 318 | 211 | 12 | 4 292 | 99,40% |
| IMS-QoS Test2 | 0,66% | 8,28% | 4 160 | 358 | 23 | 4 119 | 99,01% |
| VT-LTE OTT Test1 | 0,30% | 4,61% | 74 367 | 293 | 14 | 73 904 | 99,38% |
| VT-LTE OTT Test2 | 0,43% | 3,05% | 69 141 | 310 | 15 | 68 732 | 99,41% |
| VT-LTE OTT Test3 | 0,56% | 2,13% | 18 675 | 400 | 33 | 18 563 | 99,40% |
| VT-LTE OTT Test4 | 0,48% | 2,56% | 18 099 | 358 | 20 | 18 032 | 99,63% |
| VT-Wifi Test1 | 0,10% | 9,85% | 26 299 | 238 | 11 | 25 920 | 98,56% |
| VT-Wifi Test2 | 0,11% | 10,97% | 25 769 | 242 | 12 | 25 357 | 98,40% |
| VT-Wifi Test3 | 0,92% | 26,86% | 13 061 | 346 | 17 | 12 615 | 96,59% |
| VT-Wifi Test4 | 5,02% | 46,46% | 15 214 | 400 | 44 | 14 018 | 92,14% |
| VT-Wifi Test5 | 0,13% | 11,31% | 21 036 | 238 | 12 | 20 731 | 98,55% |
| VT-Wifi Test6 | 0,21% | 13,72% | 20 468 | 270 | 13 | 20 115 | 98,28% |
| VT-Wifi Test7 | 1,60% | 15,44% | 6 423 | 400 | 21 | 6 262 | 97,49% |
| VT-Wifi Test8 | 4,75% | 35,77% | 8 425 | 400 | 51 | 7 816 | 92,77% |
| VT-Wifi Test9 | 7,19% | 44,42% | 11 591 | 400 | 53 | 10 534 | 90,88% |
| VT-Random | 10,04% | 63,95% | 18 602 | 359 | 16 | 17 962 | 96,56% |

## 8.5 Simulation (RTT= 400 ms)

Table 8.5-1 shows the evaluation results for RTT = 400 ms.

Table 8.5-1: RTT = 400 ms

| Tool | Test(RTT = 400 ms) | PLR% | Bitrate Overhead% | Total Frames | e2e Delay (ms) | Std Render Delta(ms) | Rendered Frames | Rendered Frame% |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TS 26.114 NACK or RPSI | IMS-QoS Test1 | 0,07% | 0,00% | 4 561 | 200 | 16 | 4 525 | 99,21% |
| IMS-QoS Test2 | 0,66% | 0,00% | 4 497 | 200 | 34 | 4 435 | 98,62% |
| VT-LTE OTT Test1 | 0,30% | 0,00% | 77 793 | 200 | 15 | 77 097 | 99,11% |
| VT-LTE OTT Test2 | 0,43% | 0,00% | 71 249 | 200 | 20 | 70 648 | 99,16% |
| VT-LTE OTT Test3 | 0,56% | 0,00% | 19 072 | 200 | 38 | 18 905 | 99,12% |
| VT-LTE OTT Test4 | 0,48% | 0,00% | 18 560 | 200 | 27 | 18 431 | 99,31% |
| VT-Wifi Test1 | 0,10% | 0,00% | 28 884 | 200 | 18 | 28 218 | 97,69% |
| VT-Wifi Test2 | 0,11% | 0,00% | 28 583 | 200 | 19 | 27 880 | 97,54% |
| VT-Wifi Test3 | 0,92% | 0,00% | 16 540 | 200 | 39 | 15 035 | 90,90% |
| VT-Wifi Test4 | 5,02% | 0,00% | 22 253 | 200 | 109 | 13 972 | 62,79% |
| VT-Wifi Test5 | 0,13% | 0,00% | 23 393 | 200 | 18 | 22 846 | 97,66% |
| VT-Wifi Test6 | 0,21% | 0,00% | 23 247 | 200 | 20 | 22 606 | 97,24% |
| VT-Wifi Test7 | 1,60% | 0,00% | 7 407 | 200 | 36 | 7 012 | 94,67% |
| VT-Wifi Test8 | 4,75% | 0,00% | 11 425 | 200 | 95 | 8 522 | 74,59% |
| VT-Wifi Test9 | 7,19% | 0,00% | 16 714 | 200 | 122 | 10 630 | 63,60% |
| VT-Random | 10,04% | 0,00% | 30 381 | 200 | 268 | 6 013 | 19,79% |
| FEC+RPSI | IMS-QoS Test1 | 0,07% | 6,11% | 4 300 | 200 | 16 | 4 265 | 99,19% |
| IMS-QoS Test2 | 0,66% | 7,40% | 4 188 | 200 | 41 | 4 120 | 98,38% |
| VT-LTE OTT Test1 | 0,30% | 4,88% | 74 181 | 200 | 13 | 73 605 | 99,22% |
| VT-LTE OTT Test2 | 0,43% | 2,43% | 69 566 | 200 | 17 | 68 993 | 99,18% |
| VT-LTE OTT Test3 | 0,56% | 2,11% | 18 678 | 200 | 31 | 18 542 | 99,27% |
| VT-LTE OTT Test4 | 0,48% | 2,07% | 18 183 | 200 | 21 | 18 095 | 99,52% |
| VT-Wifi Test1 | 0,10% | 9,70% | 26 336 | 200 | 18 | 25 724 | 97,68% |
| VT-Wifi Test2 | 0,11% | 10,91% | 25 782 | 200 | 19 | 25 133 | 97,48% |
| VT-Wifi Test3 | 0,92% | 26,55% | 13 095 | 200 | 33 | 12 179 | 93,01% |
| VT-Wifi Test4 | 5,02% | 43,78% | 15 498 | 200 | 59 | 12 918 | 83,35% |
| VT-Wifi Test5 | 0,13% | 11,75% | 20 957 | 200 | 18 | 20 511 | 97,87% |
| VT-Wifi Test6 | 0,21% | 13,11% | 20 575 | 200 | 21 | 19 987 | 97,14% |
| VT-Wifi Test7 | 1,60% | 14,12% | 6 494 | 200 | 30 | 6 183 | 95,21% |
| VT-Wifi Test8 | 4,75% | 32,81% | 8 614 | 200 | 64 | 7 405 | 85,96% |
| VT-Wifi Test9 | 7,19% | 36,66% | 12 248 | 200 | 75 | 10 004 | 81,68% |
| VT-Random | 10,04% | 62,70% | 18 752 | 200 | 37 | 17 127 | 91,33% |
| Retransmit (NACK) | IMS-QoS Test1 | 0,07% | 0,08% | 4 557 | 286 | 14 | 4 525 | 99,30% |
| IMS-QoS Test2 | 0,66% | 0,65% | 4 468 | 400 | 26 | 4 418 | 98,88% |
| VT-LTE OTT Test1 | 0,30% | 0,31% | 77 555 | 389 | 16 | 76 953 | 99,22% |
| VT-LTE OTT Test2 | 0,43% | 0,44% | 70 939 | 400 | 17 | 70 445 | 99,30% |
| VT-LTE OTT Test3 | 0,56% | 0,57% | 18 964 | 400 | 39 | 18 817 | 99,22% |
| VT-LTE OTT Test4 | 0,48% | 0,47% | 18 470 | 400 | 27 | 18 374 | 99,48% |
| VT-Wifi Test1 | 0,10% | 0,10% | 28 853 | 330 | 15 | 28 325 | 98,17% |
| VT-Wifi Test2 | 0,11% | 0,11% | 28 550 | 333 | 15 | 27 994 | 98,05% |
| VT-Wifi Test3 | 0,92% | 0,92% | 16 388 | 400 | 36 | 15 175 | 92,60% |
| VT-Wifi Test4 | 5,02% | 5,30% | 21 134 | 400 | 142 | 12 805 | 60,59% |
| VT-Wifi Test5 | 0,13% | 0,13% | 23 363 | 333 | 15 | 22 918 | 98,10% |
| VT-Wifi Test6 | 0,21% | 0,21% | 23 197 | 353 | 16 | 22 711 | 97,90% |
| VT-Wifi Test7 | 1,60% | 1,50% | 7 297 | 400 | 33 | 6 983 | 95,70% |
| VT-Wifi Test8 | 4,75% | 4,89% | 10 892 | 400 | 108 | 8 158 | 74,90% |
| VT-Wifi Test9 | 7,19% | 7,53% | 15 547 | 400 | 169 | 9 860 | 63,42% |
| VT-Random | 10,04% | 11,15% | 27 331 | 400 | 1756 | 1 478 | 5,41% |
| FEC + NACK | IMS-QoS Test1 | 0,07% | 6,18% | 4 298 | 286 | 14 | 4 267 | 99,28% |
| IMS-QoS Test2 | 0,66% | 8,28% | 4 161 | 400 | 29 | 4 108 | 98,73% |
| VT-LTE OTT Test1 | 0,30% | 4,77% | 74 251 | 364 | 15 | 73 719 | 99,28% |
| VT-LTE OTT Test2 | 0,43% | 3,06% | 69 138 | 395 | 16 | 68 668 | 99,32% |
| VT-LTE OTT Test3 | 0,56% | 2,13% | 18 676 | 400 | 36 | 18 542 | 99,28% |
| VT-LTE OTT Test4 | 0,48% | 2,55% | 18 101 | 400 | 22 | 18 023 | 99,57% |
| VT-Wifi Test1 | 0,10% | 9,86% | 26 297 | 330 | 15 | 25 806 | 98,13% |
| VT-Wifi Test2 | 0,11% | 10,99% | 25 765 | 341 | 14 | 25 301 | 98,20% |
| VT-Wifi Test3 | 0,92% | 27,34% | 13 014 | 400 | 25 | 12 338 | 94,81% |
| VT-Wifi Test4 | 5,02% | 45,79% | 15 281 | 400 | 65 | 13 056 | 85,44% |
| VT-Wifi Test5 | 0,13% | 11,81% | 20 946 | 329 | 15 | 20 569 | 98,20% |
| VT-Wifi Test6 | 0,21% | 13,72% | 20 469 | 360 | 16 | 20 043 | 97,92% |
| VT-Wifi Test7 | 1,60% | 16,09% | 6 386 | 400 | 30 | 6 131 | 96,01% |
| VT-Wifi Test8 | 4,75% | 35,68% | 8 436 | 400 | 74 | 7 382 | 87,51% |
| VT-Wifi Test9 | 7,19% | 43,94% | 11 624 | 400 | 77 | 9 845 | 84,70% |
| VT-Random | 10,04% | 64,48% | 18 543 | 400 | 34 | 17 111 | 92,28% |

## 8.6 Summary

Results in the previous clauses illustrates the behaviour of each tool under different channel conditions. As a reference the performance of RPSI tool can be taken since the behaviour of RPSI tool by itself is equivalent to the error resilience behaviour in TS 26.114 that utilizes PLI and generic NACK messages. The weakness of this tool is that for every loss point there is a freeze (not rendered frames) of at least RTT duration. As RTT increases and PLR increases, the amount of non-rendered frames increases. This can be observed in VT-Wifi Test4 and Test8 where there is around 5% packet loss. As RTT increases from 100 ms to 400 ms, the percentage of rendered frames decreases from 79 - 85% to 63 - 75%. Since no retransmission is involved in this mechanism end to end delay is preserved. The main strength of this tool is its efficient handling of large burst losses that cannot be handled efficiently with other mechanisms such as FEC and retransmission.

FEC can handle random losses and short burst losses in a way that RPSI, retransmission cannot handle by introducing bitrate overhead. This becomes more important as RTT and loss rate increases. By trading of spatial video quality to temporal smoothness (i.e. less freezes) it can provide a very robust way of handling errors. For the VT-Wifi Test4 and Test8 cases it can provide rendered frame percentage of 93% and ~84% for RTT of 100 ms and 400 ms, respectively. FEC overhead can be modulated adaptively to adapt to the channel conditions, i.e. loss rate and RTT.

Retransmission is an efficient recovery tool for low loss rates and low RTT. Under these circumstances it can provide the most efficient recovery and maintain smooth rendering without introducing high delay. This can be seen in less than 1% packet loss cases with low RTT like 100 ms. In the higher RTT cases, the end to end delay increases but can be kept under 400 ms cut off if the loss rate is low.

FEC cannot recover all error cases. It needs a backup mechanism to handle the error cases that cannot be recovered by FEC. This mechanism can be retransmission, PLI or RPSI. It can also be combined with the current generic NACK mechanism specified in TS 26.114.

# 9 Conclusions and recommendations

Results in clause 8 show the trade-offs of each proposed tool under various channel conditions. FEC and selective retransmission offer benefits that cannot be achieved by the existing ER tools supported in TS 26.114.

- FEC provides robustness against moderate packet loss rates at high delay scenario. FEC can especially handle random losses and short burst losses and be beneficial in environments with high packet loss rates and/or high delay (RTT). Use of FEC may however not be appropriate when packet losses are caused by insufficient throughput (over radio access or due to congestions in network) since it introduces some bit rate overhead. In order to compensate for bit rate overhead, FEC may require to be used with efficient rate adaptation mechanisms to reduce the source bit rate according to channel conditions and not increase the total RTP bitrate. FEC will be used in combination with other mechanisms to handle the error cases that cannot be recovered by FEC (like PLI or RPSI or the current generic NACK mechanism specified in TS 26.114):

- For low RTT case with relatively high packet loss, using retransmission in combination with FEC is beneficial since retransmission can efficiently handle the FEC failure case.

- For high RTT, relatively high packet loss conditions, using generic NACK based recovery in combination with FEC is beneficial since generic NACK based recovery does not introduce additional delay.

- Selective retransmission offers efficient recovery mechanism under low delay (RTT) and low failure (loss) rate conditions. Retransmission needs to ensure that retransmitted packets arrive in time to meet delay requirements of the end to end system. Higher packet loss rates may cause loss of retransmitted packets, hence leading to larger end to end delay.

- Existing generic NACK, PLI or RPSI based error correction mechanism can provide an efficient recovery for low packet loss rates with high RTT conditions. Generic NACK message can be used for indication of packets to be retransmitted as well as informing the sender of loss of particular RTP packets for sender to take necessary actions to recover from errors. These two behaviours of the system for generic NACK message should be differentiated by signalling or some other means. RPSI is a similar mechanism operating at codec level that offers, in addition, establishment of common reference point for recovery between the sender and the receiver. If retransmission based ER is being used, the support for additional RPSI or existing NACK based error correction mechanism is not essential since the failure cases for retransmission based scheme would be rare. In that case PLI message can be used to recover from errors.

FEC and retransmission provides ER mechanisms that are effective under different channel conditions that can be encountered. These tools are beneficial under non-QoS environments that are becoming more widely used with IMS-VT terminals. In order to be competitive with non-IMS based solutions, these tools should be supported. Although RPSI provides a clean mechanism to address cases where FEC or retransmission fails, the existing generic NACK based ER scheme can provide similar functionality. It is recommended that FEC and retransmission should be supported in TS 26.114. Support for these proposed tools should be negotiable during a call or at session setup.

NOTE 1: Proper implementation and usage of these different tools (e.g. trade-off between quality & delay) are still left to the MTSI client implementers taking into account the above recommendations. This has to be done according to the service requirements and expected channel conditions that may differ from the set of test cases and related error profiles defined in section 6 and used for evaluation purpose. It is recommended to update TS 26.114 to include the above text relevant for the mechanisms to recover from packet losses included in TS 26.114 to provide additional information and guidelines on usage and benefits under various channel conditions of these mechanisms.

Annex A:  
Error patterns

# A.1 IMS-QoS

Packet loss statistics are plotted vs. packet index (X-axis).

IMS-QoS Test1 error pattern.

Figure A.1-1: Packet loss pattern PLR = 0,07%

IMS-QoS Test2 error pattern.

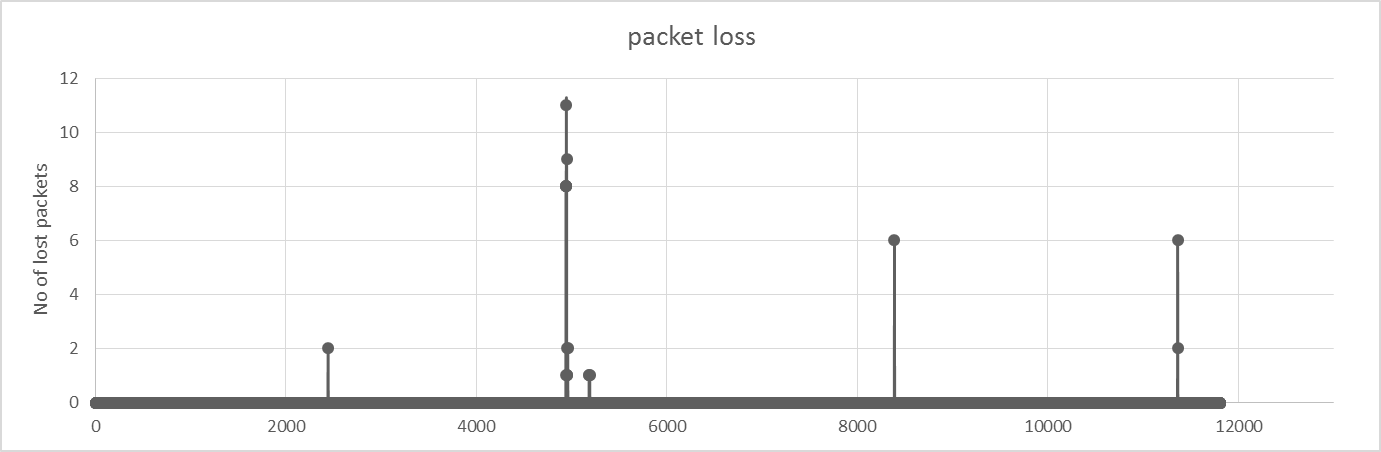


Figure A.1-2: Packet loss pattern PLR = 0,66%

# A.2 VT-LTE OTT

Packet loss statistics are plotted vs. packet index (X-axis).

VT-LTE OTT Test1 error pattern.

Figure A.2-1: Packet loss pattern PLR = 0,30%

VT-LTE OTT Test2 error pattern.

Figure A.2-2: Packet loss pattern PLR = 0,43%

VT-LTE OTT Test3 error pattern.

Figure A.2-3: Packet loss pattern PLR = 0,56%

VT-LTE OTT Test4 error pattern.

Figure A.2-4: Packet loss pattern PLR = 0,48%

# A.3 VT-Wifi

Packet loss statistics are plotted vs. packet index (X-axis).

VT-Wifi Test1 error pattern.

Figure A.3-1: Packet loss pattern PLR = 0,10%

VT-Wifi Test2 error pattern.

Figure A.3-2: Packet loss pattern PLR = 0,11%

VT-Wifi Test3 error pattern.

Figure A.3-3: Packet loss pattern PLR = 0,92%

VT-Wifi Test4 error pattern.

Figure A.3-4: Packet loss pattern PLR = 5,02%

VT-Wifi Test5 error pattern.

Figure A.3-5: Packet loss pattern PLR = 0,13%

VT-Wifi Test6 error pattern.

Figure A.3-6: Packet loss pattern PLR = 0,21%

VT-Wifi Test7 error pattern.

Figure A.3-7: Packet loss pattern PLR = 1,60%

VT-Wifi Test8 error pattern.

Figure A.3-8: Packet loss pattern PLR = 4,75%

VT-Wifi Test9 error pattern.

Figure A.3-9: Packet loss pattern PLR = 7,19%

Annex B:  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **TSG SA#** | **TSG Doc.** | **CR** | **Rev** | **Subject/Comment** | **Old** | **New** |
| 2015-06 | 68 | SP-150219 |  |  | Version 1.0.0 presented at TSG SA#68 for information | n/a | 1.0.0 |
| 2015-09 | 69 | SP-150452 |  |  | Version 2.0.0 presented at TSG SA#69 for approval | 1.0.0 | 2.0.0 |
| 2015-09 | 69 |  |  |  | Version 13.0.0 | 2.0.0 | 13.0.0 |
| 2016-12 |  |  |  |  | LTE logo updated | 13.0.0 | 13.0.1 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2017-03 | 75 |  |  |  |  | Version for Release 14 | 14.0.0 |
| 2018-06 | 80 |  |  |  |  | Version for Release 15 | 15.0.0 |
| 2020-07 | 88-e |  |  |  |  | Version for Relelase 16 | 16.1.0 |