Multi-model standard for bitstream-, pixel-based and hybrid video quality assessment of UHD/4K: ITU-T P.1204

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VQEG 2020, Stockholm, Sweden

Introduction (1/2)

- Presenting work from AVHD/P.NATS Phase 2 project
- Based on recent P.1204 IEEE Access Paper (Raake et al., 2020)
- HTTP-based adaptive streaming (HAS):
  Video and audio quality, quality switches, initial loading delay, stalling
  - Holistic view of QoE for HAS-type or other streaming see e.g. (Bampis, Li, and Bovik, 2017; Barman and Martini, 2019; Garcia et al., 2014; Robitza, Garcia, and Raake, 2015; Robitza and Raake, 2016; Seufert et al., 2014; Tavakoli et al., 2014; Tavakoli et al., 2016)
  - P.NATS Phase 1 (ITU-T Rec. P.1203.X): Focus on $[1-5]$ min sequence QoE
- P.1204: Short-term video quality (5 to 10 sec)
- Collaboration ITU-T Q14/12 + VQEG

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- Types of models
  1. Metadata-based – not considered here
  2. Bitstream-based NR – P.1204.3
  3. Pixel-based RR/FR – P.1204.4
  4. Hybrid NR – P.1204.5

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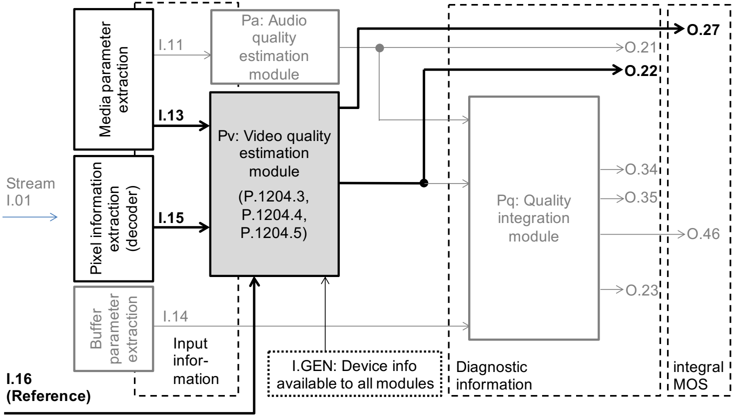
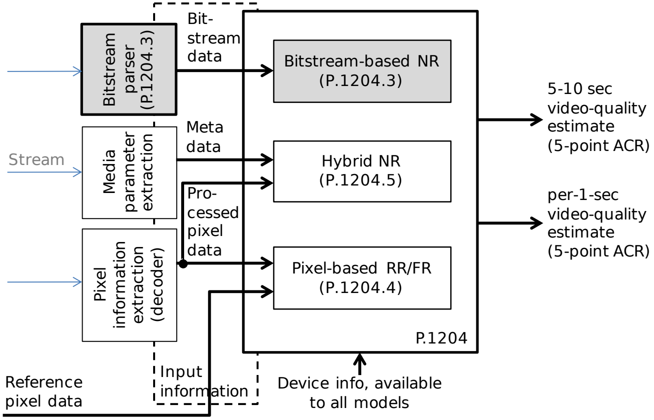
P.1204 (Phase 2) in P.1203 framework (Phase 1)



Overview of P.1204 models

- Framerates up to 60 fps
- Resolution up to 4K/UHD-1 (on 4K/UHD-1 screen)
- Codecs: H.264, H.265/HEVC, VP9
- Target devices: PC/TV, tablet, mobile



P.NATS Phase 2 development parts

1. Training database creation
2. Model training and submission
3. Validation database creation
4. Model verification/validation
5. Model merging/optimization

P.NATS Phase 2 development steps (1/2)

1. Training database creation
   - Processing chain → Talk by Werner Robitza, David Lindero et al.
   - 13 databases (5 PC, 4 TV, 4 mobile)
2. Model training and submission
   - Around 4 months for training proponents' models
   - 35 model candidates submitted: VM to dedicated ITU-T TSB server, containing all their submitted models, runnable
   - Paper & report focus on 3 finally standardized models
3. Validation database creation
   - 13 validation databases (1 PC, 8 TV, 3 mobile, 1 tablet)
   - Resulting subjective scores submitted to ITU-T TSB
   - Data needed to run models and get predictions shared among all proponents
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   - Bug fixing (if source code submitted under 2.)
   - Model score verification
   - Validation and selection
     - Share subjective scores with all parties
     - P.NATS Phase 2 approach: Only standardize models that provide actual added value in terms of prediction performance and/or model complexity
     - For example, RR model ultimately standardized as ITU-T Rec. P.1204.4, since best FR model not significantly better
5. Model merging/optimization: No merging needed for standardized models, since only one model in each winning group
   - Optimized based on cross-validation: 5 splits, re-optimized per split
   - Coefficients for split with least RMSE finally reported in P.1204.X

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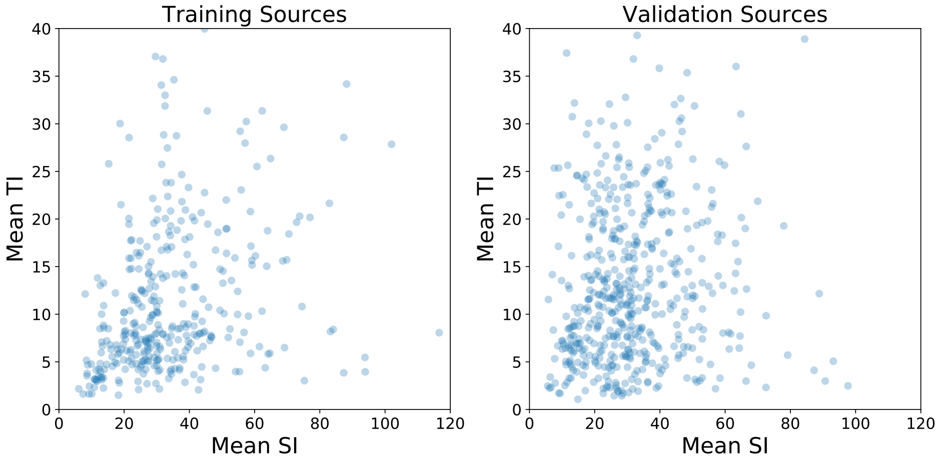
SRCs – content selection for appr. 8 s sequences

Number of unique footage and SRC files for training (TR) and validation (VL)

		TR	VL	TOT
Footages	50/60 fps	27	20	43 (4 common TR/VL)
	24/25/30 fps	32	97	129
	Total	59	117	172 (4 common TR/VL)
SRC files	50/60 fps	203	79	278 (4 common TR/VL)
	24/25/30 fps	138	294	432
	Total	341	373	710 (4 common TR/VL)

SRCs – SI-TI of sources, training and validation

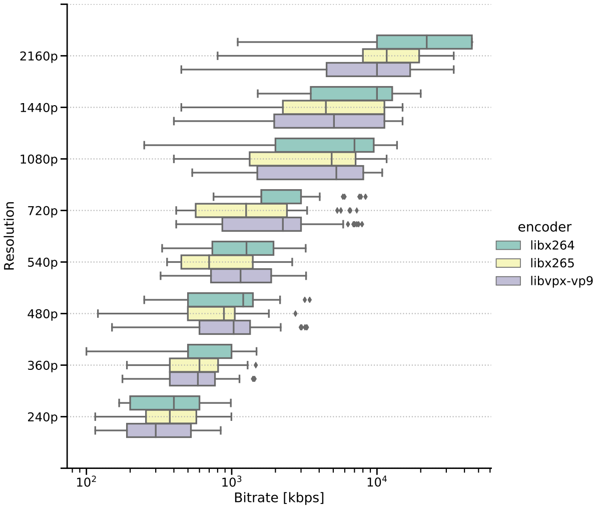


HRCs – encoder parameter ranges

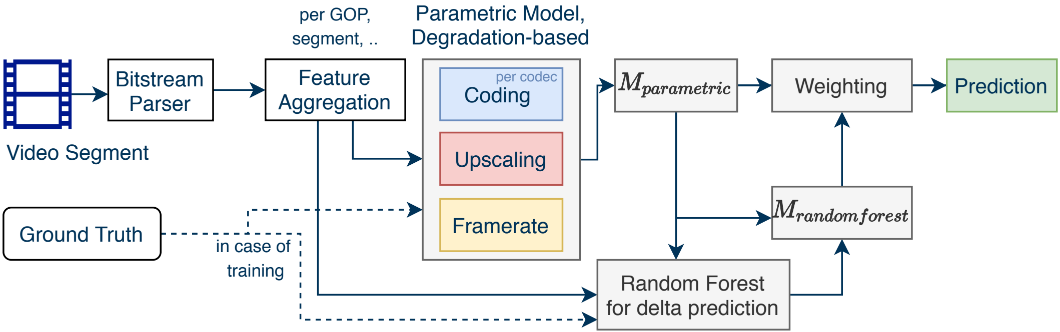
Parameter	Range
Video Codec	H.264, H.265, VP9
Encoded Resolution	TV/Monitor: 640×360 – 3840×2160, Mobile/Tablet: 426×240 – 2560×1440
Framerate	15, 24, 25, 30, 50, 60 frames per seconds
Presets	H.264/H.265: online, i.e. Youtube, Bitmovin or Vimeo; medium, ultrafast, fast, veryfast, slower, slow, veryslow. VP9: speed presets 0, 1, 2, 3, 4
GOP Size	Auto, 2, 5 seconds
Encoder Implementation	H.264: libx264 (ffmpeg), H.265: libx265 (ffmpeg), VP9:libvpx-vp9 (ffmpeg), YouTube, Bitmovin, Vimeo
Chroma Subsampling	YUV420, YUV422
Bit-depth	8,10 bits
Encoding Types	1-pass, 2-pass (with and without min max bitrate constraints), Constant rate factor (CRF) encoding. Unknown encoding recipes employed by YouTube, Vimeo, Bitmovin
Bitstream Container	mp4, webm, mkv

HRCs – bitrate distributions

Bitrate range for each encoder–resolution pair



P.1204.3 – General Model Structure



- Features used → QP, average motion statistics, framesize statistics, metadata

P.1204.3 – Core Model

- Degradation-based modeling approach
- 3 types of degradation
  - Quantization/Coding degradation (D_q): $f(QP)$
  - Upscaling degradation (D_u): $f(coding\_res, display\_res)$
  - Temporal degradation (D_t): $f(coding\_framerate, display\_framerate)$
- Degradation values expressed on a 0 to 100 scale
  - Compensates for the compression of the 5-point ACR scale at the scale ends

P.1204.3 – Core Model Prediction

$$M_{p_{0-100}} = 100 - (D_q + D_u + D_t) \quad (1)$$

$$M_{p_{1-4.5}} = MOSfromR(M_{p_{0-100}}) \quad (2)$$

$$M_{parametric} = scaleto5(M_{p_{1-4.5}}) \quad (3)$$

P.1204.3 – Machine Learning Part

- used to estimate the "residual"

$$target\_residual = MOS - M_{parametric} \tag{4}$$

- Based on Random Forests (RF)
  - Hyper-parameters: $trees = 20$ and $depth = 8$
  - One RF for PC/TV and Mobile/Tablet
- meta-features
  - QP
  - Average motion per-frame
  - Motion in the x-direction (horizontal motion)
  - Frame sizes + frame type
  - Codec, bitrate, resolution, framerate, $M_{parametric}$

P.1204.3 – Final Prediction

- Prediction of the ML-part

$$M_{randomforest} = M_{parametric} + predicted\_residual \tag{5}$$

- Final prediction

$$Prediction = w \cdot M_{parametric} + (1 - w) \cdot M_{randomforest}, \tag{6}$$

where $w = 0.5$.

P.1204.4 – Reduced Reference Model

Video v with reference v_{ref}.

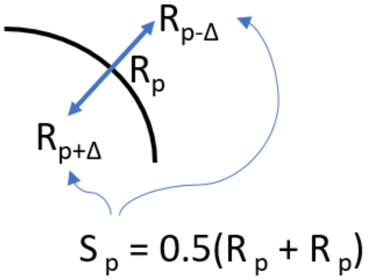
Extract feature set $\phi(v)$

Constraint: size of $\phi(v_{ref}) \leq 256\text{kbit/s}$

P.1204.4 – Normalized Edge Strength

Edge strength R, normalize

$$Z_p = \frac{\max(0, R_p - S_p)}{c + R_p + S_p}. \qquad (7)$$

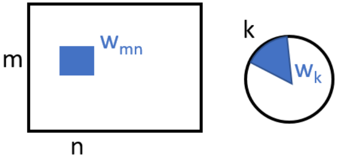


- numerator: sparseness
- $c = c(R)$: adaptation
- denominator: contrast normalization, to $[0, 1]$

P.1204.4 – Patch Statistic

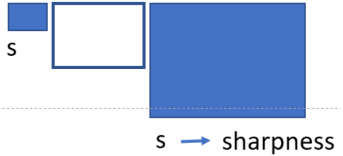
Average above quantile q

$$s_{mnk} = \sum_{p, Z_p > q} w_{mn} w_k Z_p \qquad (8)$$



Extracted video features

- Store $s = (s_{mnk})$ at medium resolution
- Aggregate to sharpness at highest resolution
- Feature set: $\phi(v) = (s, sharpness, ..)$



P.1204.4 – Degradations, Quality Prediction

$$D_0 = F_0(\max(0, s - s_{ref})) \qquad \text{coding artifacts}$$
$$D_1 = F_1(\max(0, s_{ref} - s) \qquad \text{loss in detail}$$

Similar D_i for

- relative sharpness increase
- relative sharpness decrease
- frame rate reduction

Aggregate, allow for interactions

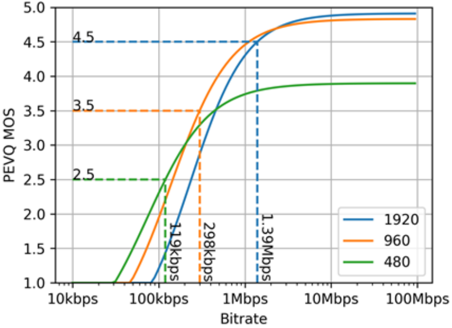
$$Q = \prod_i (1 - D_i) \quad \text{in} \quad [0, 1] \tag{9}$$

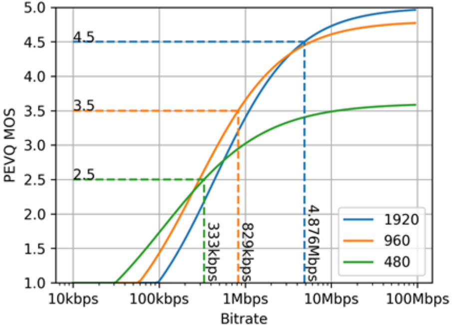
P.1204.5 – Modeling Philosophy

- Logistic a-like base quality function with saturation, decay and offset factors
  - The base function defines encoded bitrate to video quality mapping
    - Normalized bitarte to account for different chroma subsampling
    - Log bitrate domain - 10th logarithm of normalized-bitrate-in-kbps
  - Individual factors determine the quality behavior, such as:
    - Maximum achievable quality value for a certain resolution
    - How fast the quality decays w.r.t. the encoded bitrate
    - For the same encoded bitrate lower content complexity can achieve higher quality
- Individual factors of the base quality function are in-turn functions of features, such as:
  - Scaling ratio - ratio of display resolution to encoded resolution
  - Framerate ratio - ratio of display framerate to encoded framerate
  - Content complexity - an indicator that determines how hard some content is for encoding

P.1204.5 – Some visualizations of the idea

Fixed resolution variable bitrate with H.264
Left: Low complexity scene, Right: High complexity scene





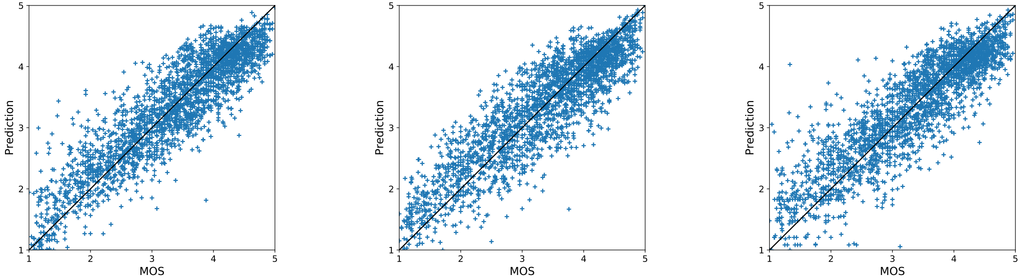
P.1204.5 – Content Complexity

- Limitations of SI/TI
  - Requires availability of the original reference signal
  - SI/TI presents a visual view of the content complexity
  - Video codecs view the content differently
    - Translational motion does not pose a big difficulty
    - Regular spatial features can be predicted using intra-prediction
- A video codec based view of the content complexity
  - Encode the degraded video using CRF encoding (pick a CRF that can result in visually losless compression)
  - The resulting bits per pixel (bpp) is used as a content complexity indicator
  - More complex content leads to higher bpp to achieve the chosen CRF quality

P.1204.5 – Codec and Device Handling

- Display devices split into two groups
  - Group 1: PC-Monitors, TV (3840x2160)
  - Group 2: Tablet, Smartphone (2560x1440)
- A single model trained for a device group and codec pair
  - 3 codecs x 2 device groups = 6 sets of model coefficients
- Linear mapping to differentiate between devices in a group

Performance



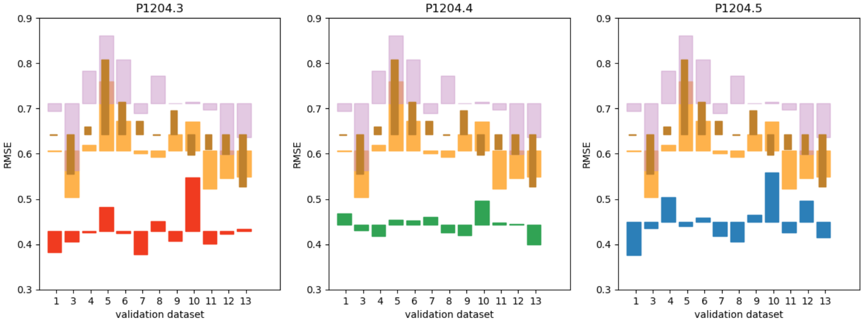
(a) P.1204.3 (b) P.1204.4 (c) P.1204.5

Performance – P.1204.X vs SoA models (P.NATS validation databases, RMSE and Correlation)

Overall model performance of different models on P.NATS Phase 2 validation databases

Model	All HRCs			HRCs using SRC fps		
	RMSE	**Pearson**	**Spearman**	**RMSE**	**Pearson**	**Spearman**
PSNR	0.716	0.630	0.615	0.688	0.625	0.609
SSIM	0.648	0.609	0.704	0.580	0.665	0.725
VMAF	0.611	0.761	0.773	0.548	0.794	0.790
P.1204.3	0.422	0.899	0.883	0.429	0.891	0.875
P.1204.4	0.441	0.889	0.872	0.440	0.884	0.864
P.1204.5	0.448	0.885	0.880	0.447	0.880	0.871

Performance – P.1204.X vs SoA models (P.NATS validation databases)



Model prediction error (RMSE) per validation dataset. Plotted is the prediction error for the submitted models P.1204.3 (red, left), P.1204.4 (green, middle), P.1204.5 (blue, right), and on all three subplots PSNR (purple), VMAF (orange), and SSIM (brown). For each model, the bars show the deviation from the mean prediction error.

Performance – P.1204.X vs SoA models (Open databases, RMSE)

Model	Test 1	Test 2	Test 3	Test 4	MCML
VMAF	0.459	0.448	0.588	0.631	0.340
P.1204.3	0.270	0.222	0.328	0.501	0.378
P.1204.4	0.341	0.334	0.380	0.420	0.322
P.1204.5	0.239	0.458	0.327	0.371	0.395

Conclusion and Future Work

- P.1204: Versatile set of models for different appliations with highly competetive prediction performance
- Amendment of P.1204.X standards by individual Appendices for long-term integration underway
- Extension of P.1204 models towards further codecs: AV1, H.266/VVC, ...
- P.NATS Phase 3: Prediction of MOS and quitting probability for longer sessions (30 s to 5 min) based on HTTP-based adaptive streaming session data (audio, video quality; initial loading delay, stalling; integration with P.1203.X and P.1204.X)
- P.DiAQoSE: Diagnostic information extraction from P.1203 and P.1204 models, identifying main causes for low QoE
- P.BBQCG: Cloud gaming quality prediction, passive and interactive scenarios, checking usage of existing P.1203 and P.1204 models

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- P.NATS Phase 3: Prediction of MOS and quitting probability for longer sessions (30 s to 5 min) based on HTTP-based adaptive streaming session data (audio, video quality; initial loading delay, stalling; integration with P.1203.X and P.1204.X)
- P.DiAQoSE: Diagnostic information extraction from P.1203 and P.1204 models, identifying main causes for low QoE
- P.BBQCG: Cloud gaming quality prediction, passive and interactive scenarios, checking usage of existing P.1203 and P.1204 models

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Thank you for your attention

...... are there any questions?