# Νέες και Παλιές Προκλήσεις στα Δίκτυα Κινητών Επικοινωνιών

ΤΜΉΜΑ ΠΛΗΡΟΦΟΡΙΚΉΣ ΚΑΙ ΤΗΛΕΠΙΚΟΙΝΩΝΊΩΝ, ΕΚΠΑ

ΔΡ. ΔΗΜΗΤΡΙΟΣ ΤΣΟΛΚΑΣ & ΚΑΘ. ΛΑΖΑΡΟΣ ΜΕΡΑΚΟΣ

# Takeaways from Lectures 3 and 4

- API exposure is performed with CAPIF support
- QoS Enforcement
  - QFI concept
  - Network slice selection during the PDU session set up
- 5G New Radio (NR)
  - Deployment options: SA / NSA
  - SDAP protocol is added to realize filtering of 5G quality flows to DRB
  - The protocols stack is Split to allow central management of radio flows (concept of functional split)

- 5G New Radio (NR)
  - Channels
  - Numerology
  - Key Performance Indicators (KPIs)

# Lecture 5 Targets

- From QoS to QoE
- Qualitative and quantitative QoE evaluation
- QoE research Challenges

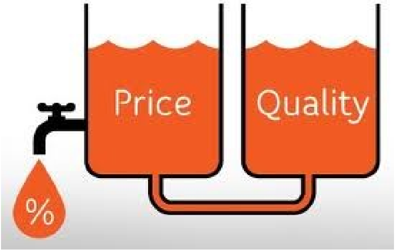
# Motivation to move from QoS to QoE

- Two "competing" entities:

**Operator/Provider vs. Customer/User**

**←→**

**min(Cost) vs. max(Quality)**




- Some facts:
  - **82%** of customer defections are due to frustration and the provider's inability to deal with this effectively
  - For 1 person who calls with a problem, **29** never will
  - 1 frustrated customer will tell **13** others
  - **90%** abandons a service without even complaining

# Motivation to move from QoS to QoE

*"Unlimited internet with speed up to 24Mbps"*

→ QoS (Quality of Service)

*"Excellent user experience guaranteed"*

→ QoE (Quality of Experience)

- **QoS** is "a set of technical quality requirements on the collective behaviours of one or more objects in order to define the required performance criteria". But:
  - It handles pure technical aspects
  - Same QoS values do not imply same customer experience
  - QoS does not reflect the end-user satisfaction

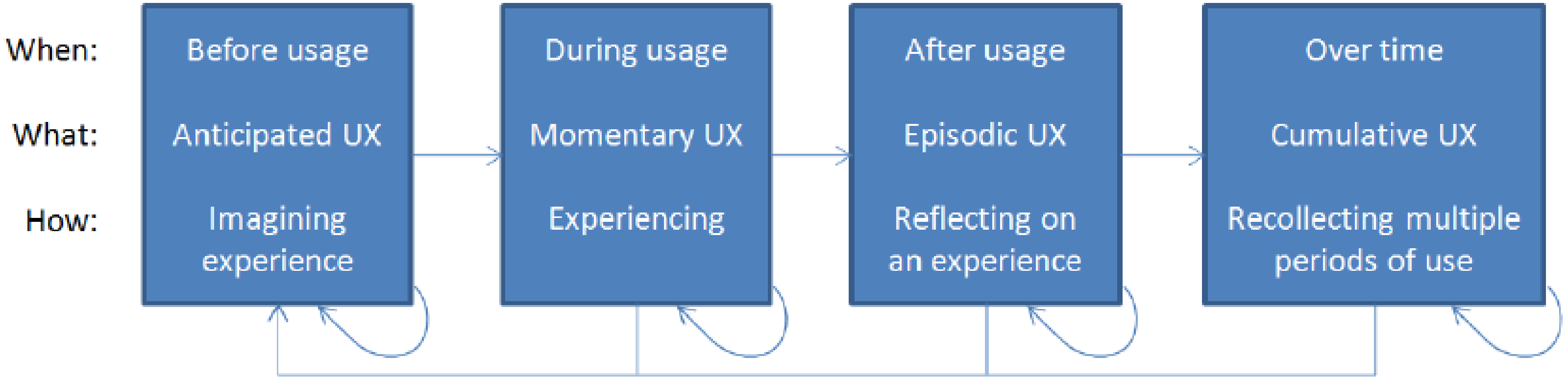
# QoE definition

ITU-T: “The overall acceptability of an application or service, as perceived subjectively by the end-user.”

ETSI: “A measure of user performance based on both objective and subjective psychological measures of using an ICT service or product.”

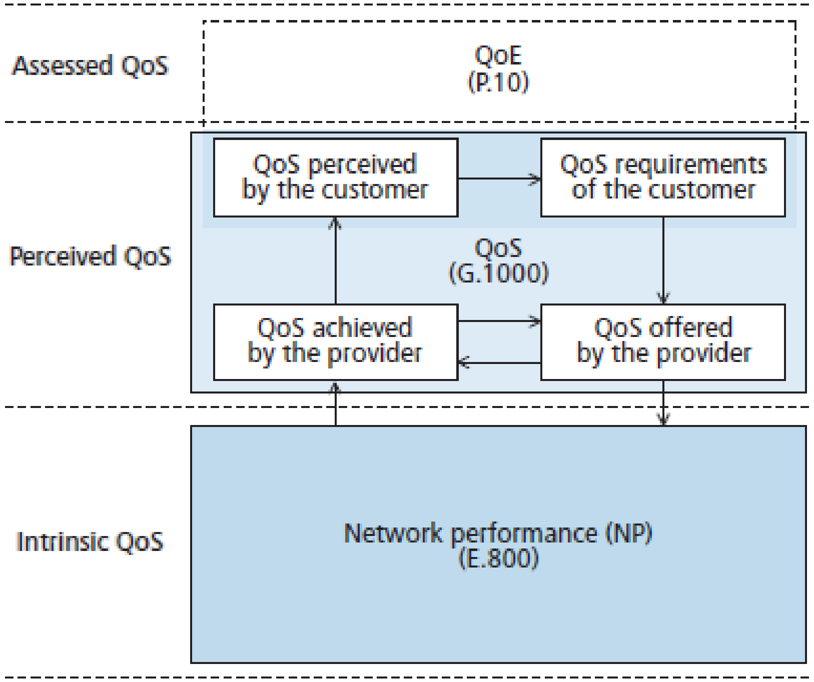
Practically: “The degree of your delight or annoyance over a product, application or service.” [Qualinet]

**Time spans of UX**




* “User Experience White Paper: Bringing clarity to the concept of user experience”, Dagstuhl Seminar

# QoE: A multidisciplinary field




Main properties:

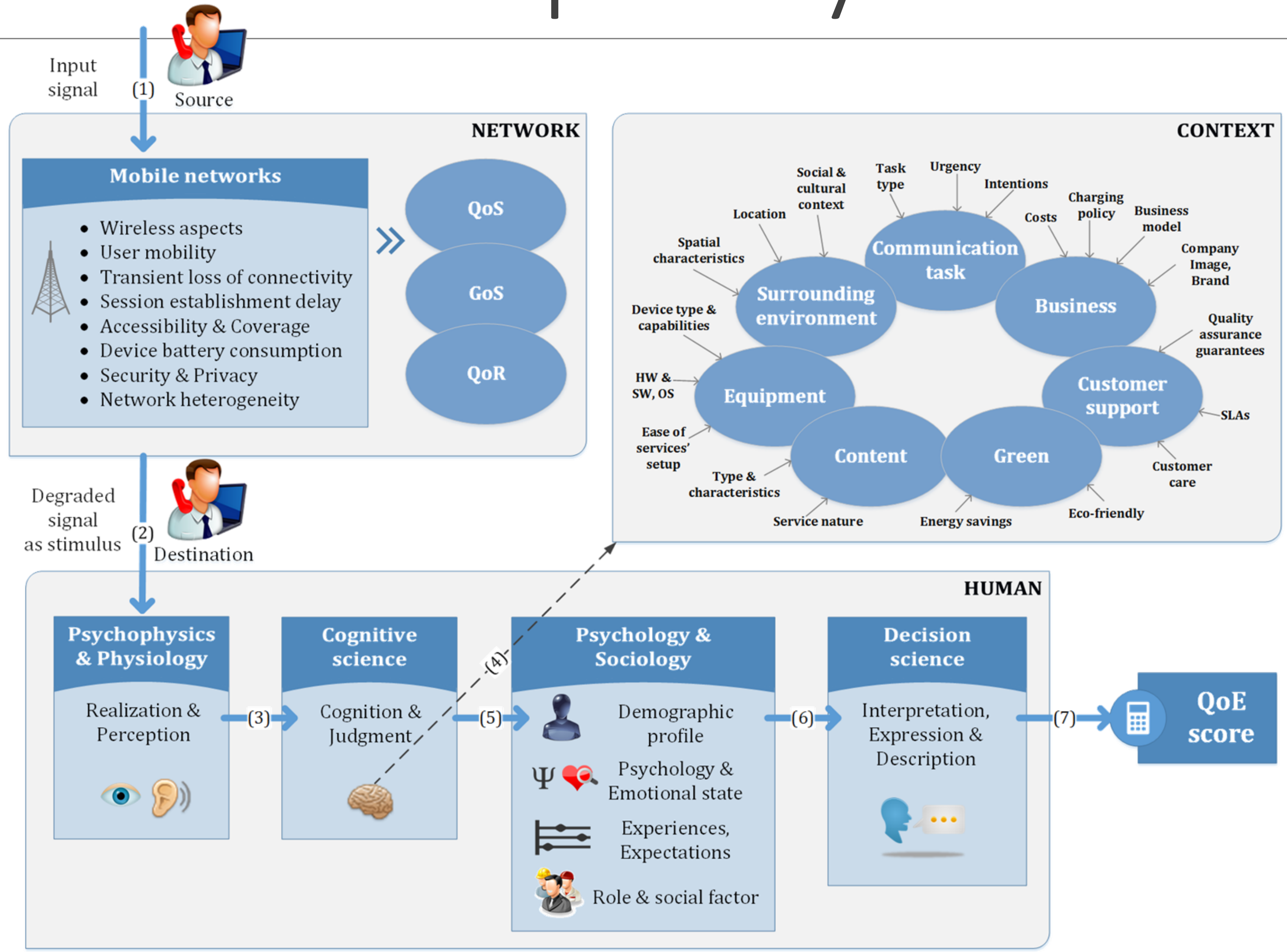
- User-dependent
- Application-dependent
- Terminal-dependent
- Time variant

➢ QoS: technology-centred

➢ QoE: user-centred

* R. Stankiewicz, P. Cholda, and A. Jajszczyk, “QoX: What is it really?,” IEEE Communications Magazine, vol. 49, no. 4, pp. 148–158, Apr-2011.

# QoE: A multidisciplinary field



# 1. Network (Key Performance Indicators - KPIs)

| Aspect | Quality Influence Factors | Aspect | Quality Influence Factors |
|---|---|---|---|
| **Video specific** | - Frame Rate<br>- Video bit rate<br>- Video content<br>- Terminal type<br>- Display size, type and resolution<br>- Codec type and implementation<br>- Video resolution and video format | **Transport/ Network** | - Round trip / one-way delay<br>- Jitter<br>- Packet loss ratio<br>- Delay burstiness distribution<br>- Loss burstiness distribution<br>- Bottleneck bandwidth<br>- Congestion period |
| **Video on Demand** | - Number of stalling events<br>- Duration of stalling events<br>- Total video duration<br>- Initial delay (start-up delay)<br>- Time on highest layer (HTTP Adaptive Streaming - HAS)<br>- Number of switches (HAS)<br>- Altitude (HAS) | **Physical** | - SNR / SIR / SINR<br>- Bit rate<br>- BLER<br>- Outage probability<br>- Packet / Symbol / Bit Error probability<br>- Outage capacity<br>- Ergodic capacity / throughput<br>- Diversity order / coding gain<br>- Area spectral efficiency<br>- Energy efficiency |

# 2. Human

Age, gender, education level, cultural background, sociological and psychological factors, cognitive and perceptual abilities, user expectations, experiences, emotion, mood, perception, preferences

# 3. Context

Energy consumption

Terminal type

Human role

Communication task, Urgency

Customer support, ease of setup & use

Charging policy & price

Environment

**Content**

# Context-based approaches

Two users are in proximity based on GPS data:

- Then, any call initiated between them is automatically treated as a D2D connection (Device-to-Device)

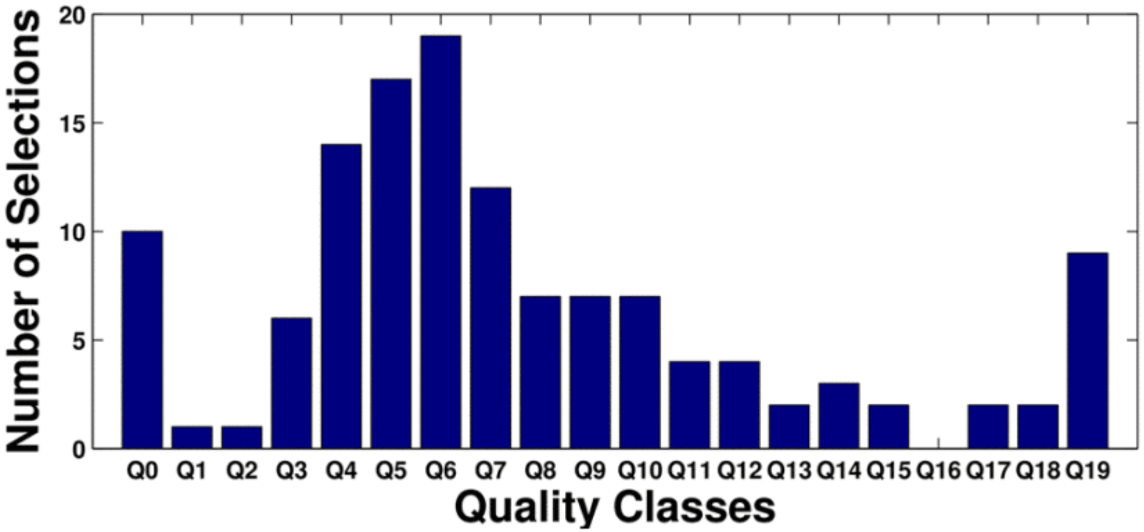
A user has limited battery level:

- Then, an incoming or outgoing call is switched to the closest access point (e.g. Wi-Fi instead of 4G)

A user checks his/her Facebook account at more or less the same time every date at his home:

- Then, the network pre-fetches (caches) the news feed on location instead of waiting for the user to update

# Willingness to pay

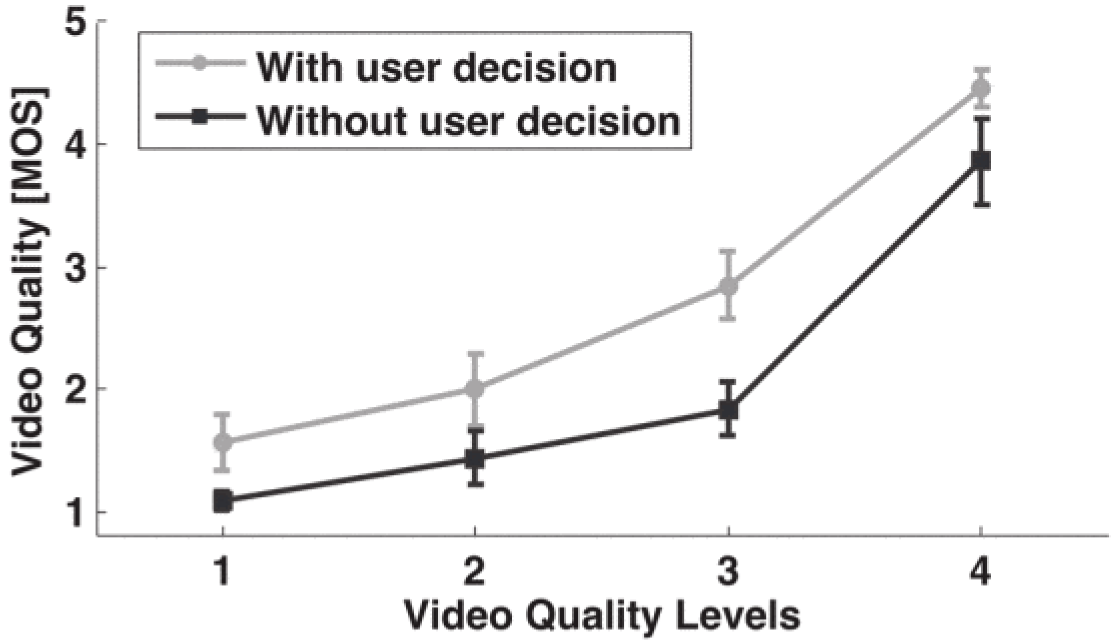



| Quality Class | Q0 | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 | Q13 | Q14 | Q15 | Q16 | Q17 | Q18 | Q19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VBR [kBit/s] | 128 | 181 | 256 | 362 | 512 | 724 | 1024 | 1448 | 2048 | 2896 | 4096 | 5793 | 8192 | 11585 | 16384 | 23170 | 32768 | 32768 | 32768 | 32768 |
| Priceplan A [€] | 0 | 0.105 | 0.211 | 0.316 | 0.421 | 0.526 | 0.632 | 0.737 | 0.842 | 0.947 | 1.053 | 1.158 | 1.263 | 1.368 | 1.474 | 1.579 | 1.684 | 1.789 | 1.895 | 2 |

* A. Sackl, P. Zwickl , et al. "The trouble with choice: An empirical study to investigate the influence of charging strategies and content selection on QoE", IEEE CNSM, 2013.

# Willingness to pay and QoE

Users who decide to choose (and pay for) high quality multimedia services tend to evaluate this quality in a different way than if they are simply offered the same quality levels for consumption

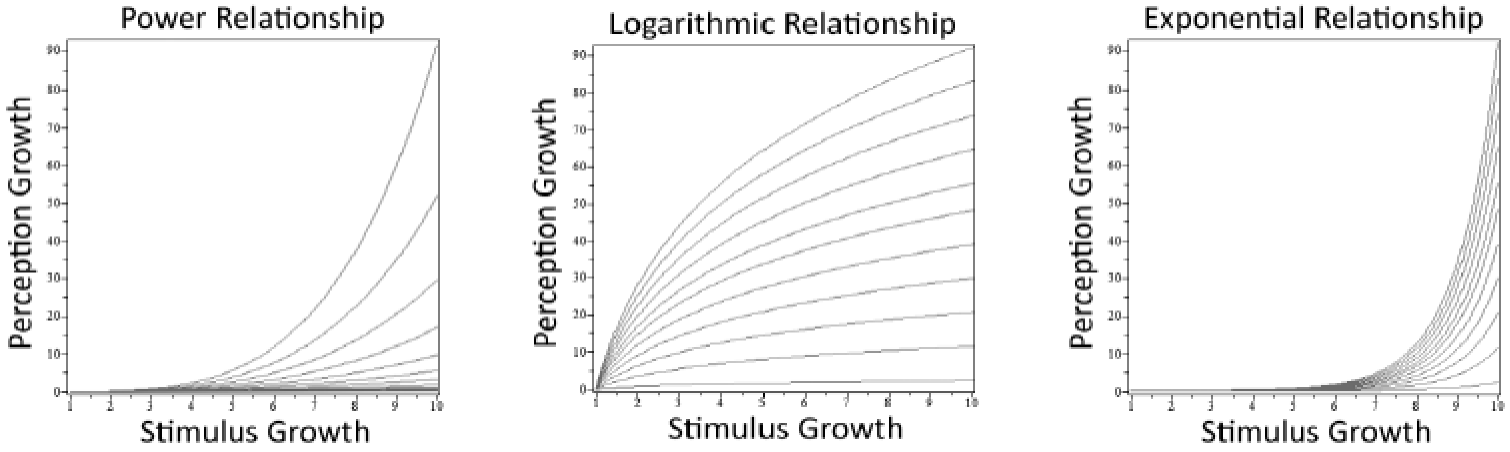



Quality is evaluated more positively when preceded by a *monetary* decision

* A. Sackl, P. Zwickl , et al. "The role of cognitive dissonance for QoE evaluation of multimedia services", IEEE Globecom Workshops, 2012.

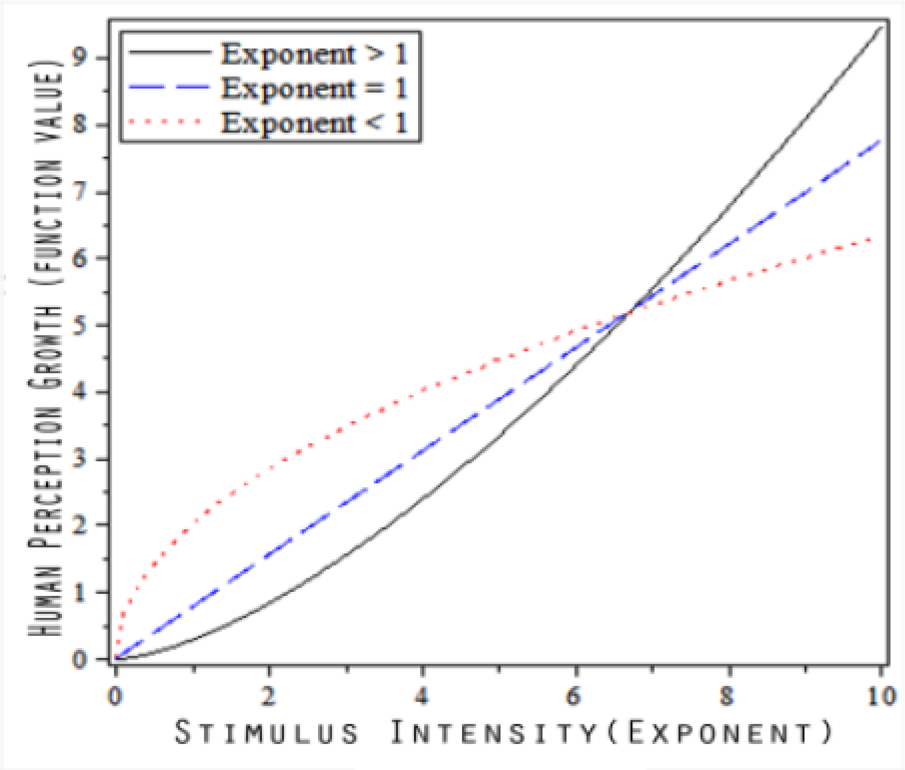
# QoS - QoE qualitative relationship

| | Name | Trend | Relation | Form |
|---|---|---|---|---|
| Adopted from Psychophysics | Stevens' Power Law | Stimulus-centric | $QoE = K.QoS^{b}$ | Power |
| | Weber-Fechner Law | Stimulus-centric | $QoE = k.\ln(QoS)$ | Logarithmic |
| Adopted from a Hypothesis | IQX | Perception-centric | $QoE = \alpha.e^{-\beta.QoS} + \gamma$ | Exponential |




* S. Khorsandroo, et al, "A Generic Quantitative Relationship to Assess Interdependency of QoE and QoS", Ksii Transactions on Internet and Information Systems, 2013.

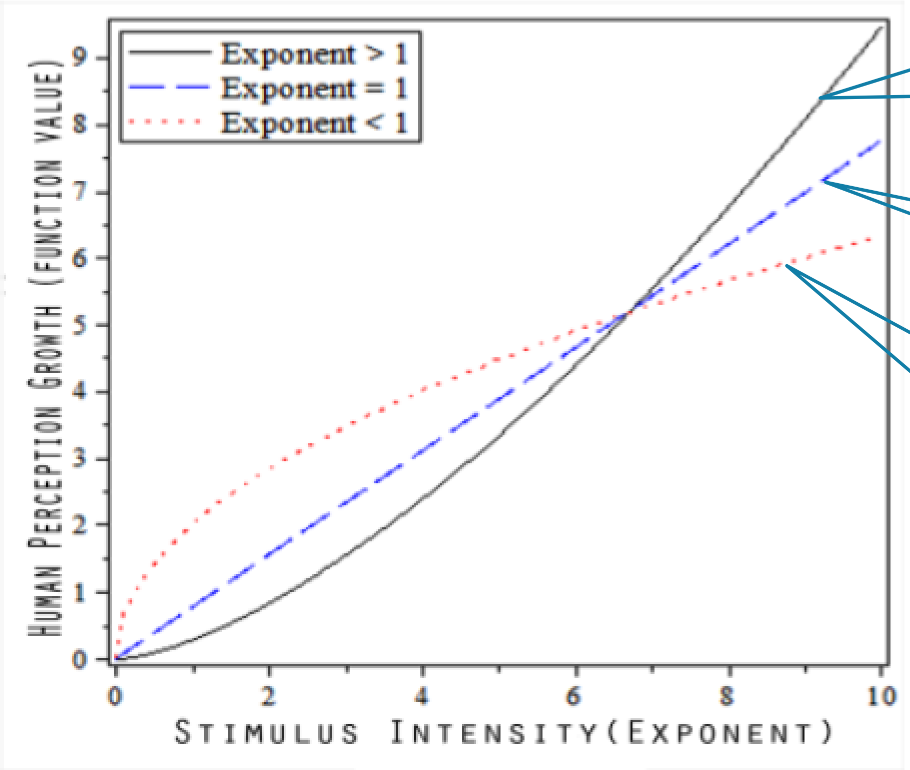
# Steven’s law




$$P(S) = K * S^b$$

* S. Khorsandroo, et al, “A Generic Quantitative Relationship to Assess Interdependency of QoE and QoS”, Ksii Transactions on Internet and Information Systems, 2013.

# Steven’s law




Human perception growth as a function of muscle force

How humans can perceive changes in visual length

Human perception as a function of smell

$$P(S) = K * S^b$$

* S. Khorsandroo, et al, “A Generic Quantitative Relationship to Assess Interdependency of QoE and QoS”, Ksii Transactions on Internet and Information Systems, 2013.

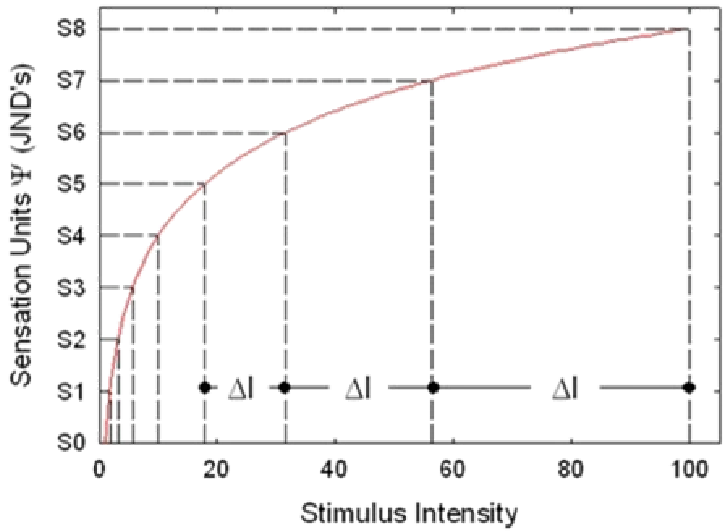
# Weber Fechner Law

"Just noticeable differences" concept - jnd:

Weight: 100gr distinguished from 105 gr, 200gr distinguished from 210gr => 5% is the "Weber fraction"

Observed values: need to change by at least some small but constant proportion of the current value to ensure humans will reliably detect it -- Brightness, loudness, numerical cognition, etc.

$$dP = k * \frac{dS}{S} \Rightarrow P = k * ln(\frac{S}{S_0})$$

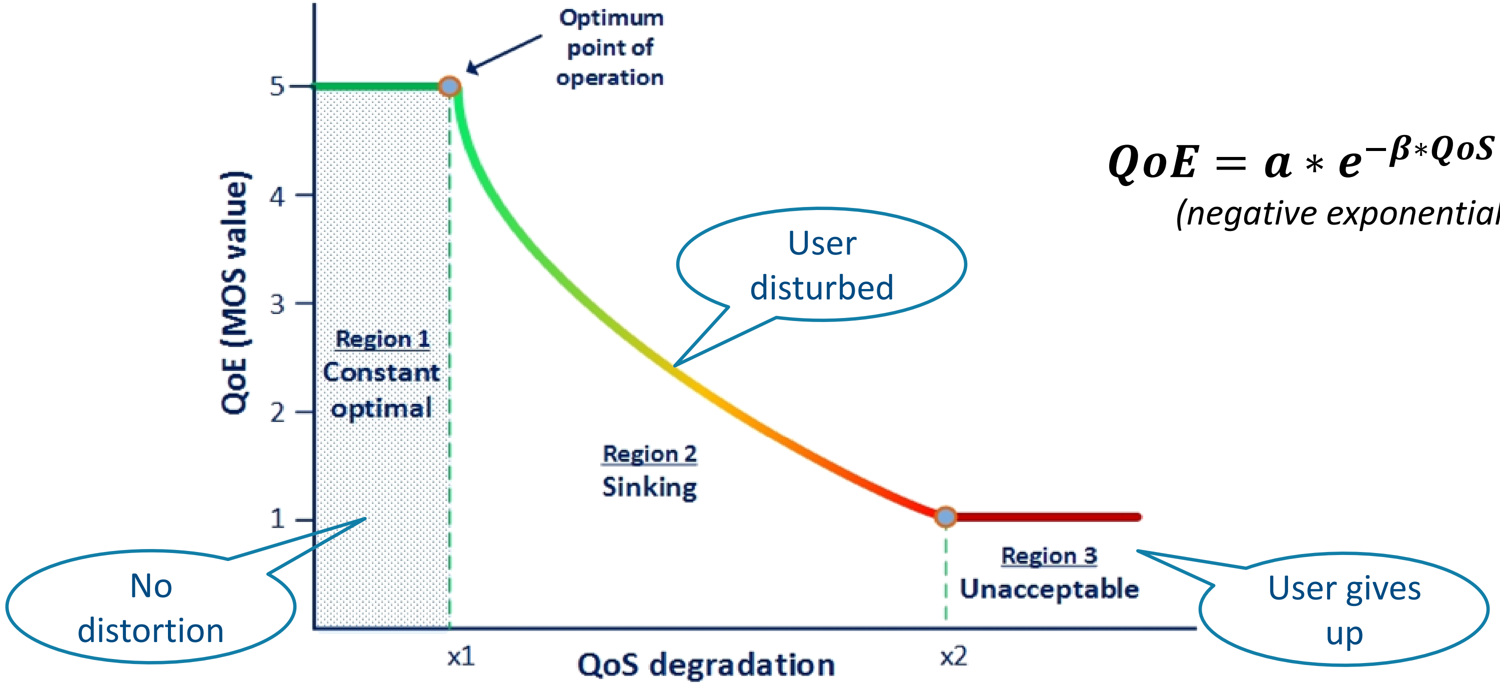



- $dP$ = differential change in perception
- $dS$ = differential increase in the stimulus
- $S$ = instantaneous stimulus
- $S_0$ = stimulus threshold
- $k$ = constant, experimentally found

# The IQX hypothesis

The change of QoE depends on its current level

High QoE => small disturbances strong impact ≠ small QoE => unperceived




$$QoE = a * e^{-\beta * QoS} + \gamma$$

*(negative exponential)*

* M. Fiedler, T. Hossfeld, and P. Tran-Gia, “A generic quantitative relationship between quality of experience and quality of service,” IEEE Network, vol. 24, no. 2, pp. 36–41, Mar-2010.

# QoE - importance

- Why the study of QoE is important?
  - The QoE encompasses the issue of the user's decision on retaining a service (and keep paying for it) or giving it up
  - It is more efficient to focus on guaranteeing QoE than promising high QoS
    - Obviously, high QoS results in high QoE, however the quantification of this relation may be useful from the perspective of saving network resources or providing QoE-centric services (and charges)
  - QoE is the most reliable way to evaluate real time services such as VoIP and video which are currently used by more and more people

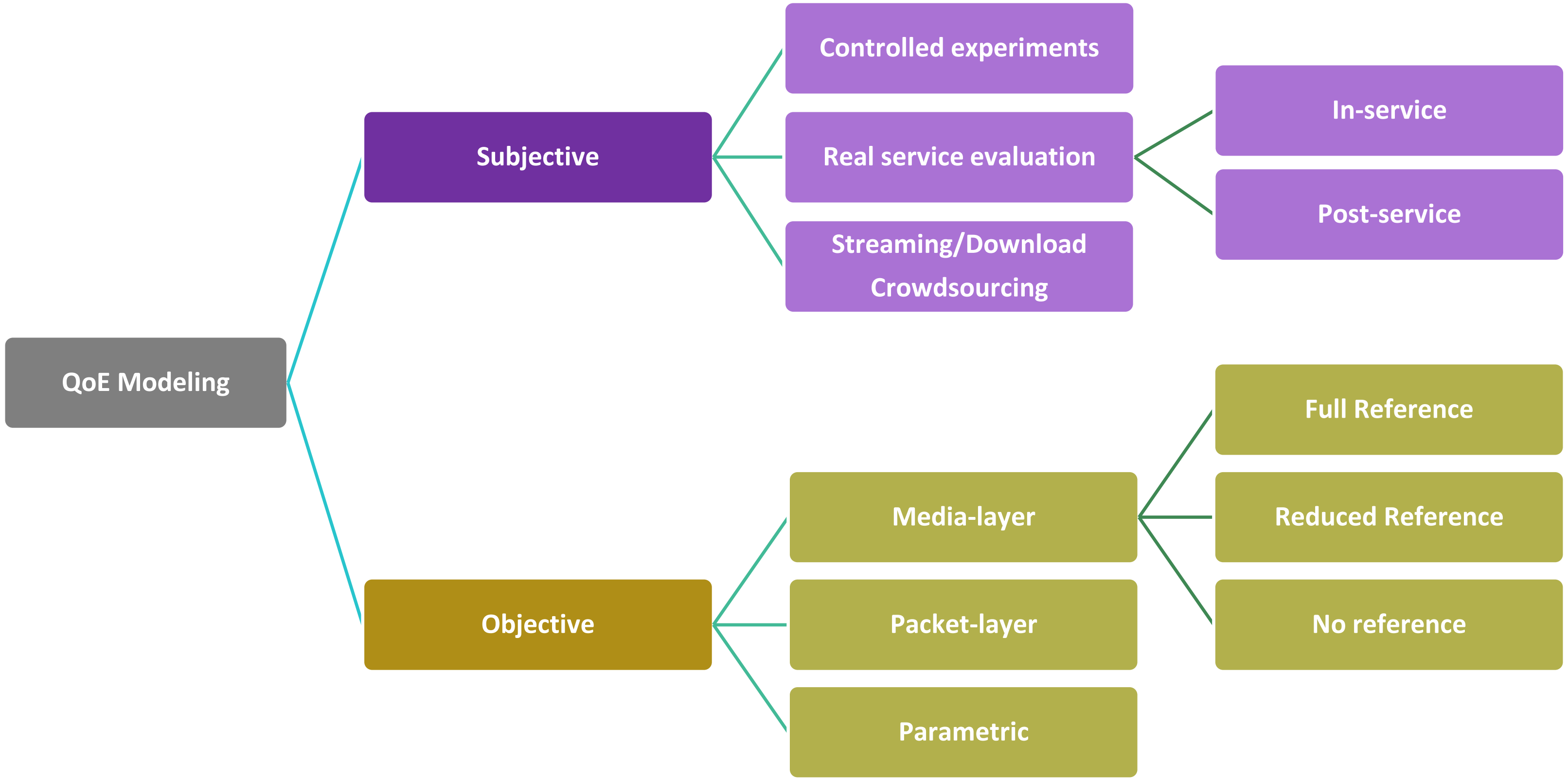
# QoE - challenges

Can we measure QoE?

Highly subjective metric - there is a long list of dependences

we cannot measure it, but we can, to some degree, estimate it

# QoE estimation/ how to measure



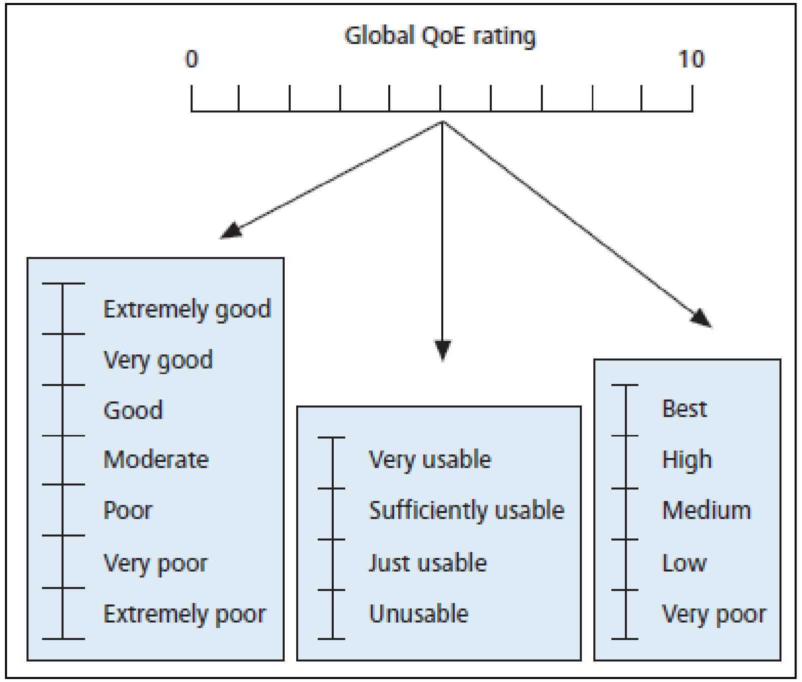
# Subjective Vs Objective models

| Model | Advantages | Disadvantages | Restrictions |
|---|---|---|---|
| **Subjective (controlled)** | + The most reliable QoE measurement model, highly accurate and valid<br>+ Ensures uniformity between subjective scores from different laboratories | - Not real-time (requires lab setting), not reproducible on demand<br>- Time consuming and expensive<br>- Needs thorough planning => complex<br>- May be biased by user opinion, assumptions or unconscious psychological factors<br>- Users may be greedy on their QoE demands and hence evaluations<br>- Users' tiredness and lack/loss of concentration<br>- Participants may just want to earn money and not be concise<br>- Difficult for users to discriminate between e.g. "Bad" and "Poor" values in MOS scale | -> Experiments need to be conducted under strict requirements and controlled conditions: isolated sound room, dedicated equipment, suitably selected panel and number of participants, specific duration of signals, etc. |
| **Objective (in general)** | + Automatically predict QoE<br>+ Same input always gives same output<br>+ Bypass the need for a human panel (the majority)<br>+ May be real-time, may be proactive | - Complexity<br>- May not always highly correlate to reality<br>- No universal generic quality model available, each one has a specific application scope<br>- Need continuous validation against subjective data | -> Differ per application/service |

# Quality scales

## Absolute Mean Opinion Scores (**MOS**) / comparative

| MOS | Quality | Impairment |
|---|---|---|
| 5 | Excellent | Imperceptible |
| 4 | Good | Perceptible |
| 3 | Fair | Slightly annoying |
| 2 | Poor | Annoying |
| 1 | Bad | Very annoying |


| Score | Description |
|---|---|
| 3 | Much Better |
| 2 | Better |
| 1 | Slightly Better |
| 0 | About the Same |
| –1 | Slightly Worse |
| –2 | Worse |
| –3 | Much Worse |

# SOS – The MOS is not enough

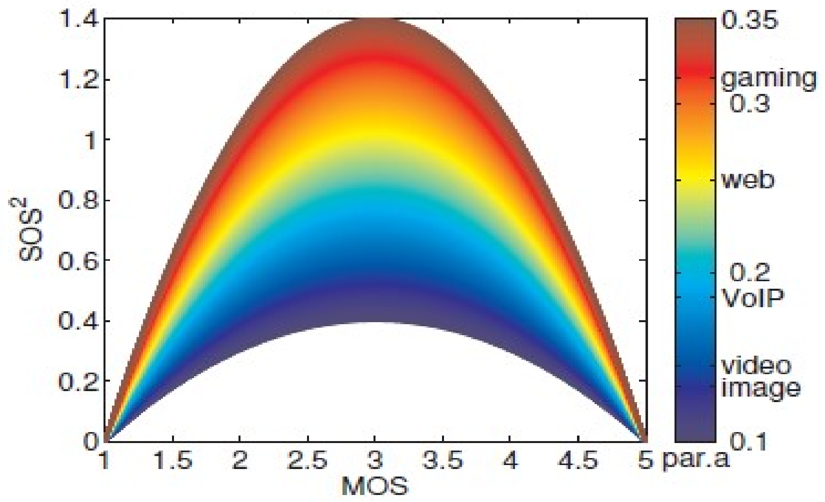
Standard deviation of Opinion Scores (SOS)

Statistical summary of subjective user tests

Reflects the level of rating diversity

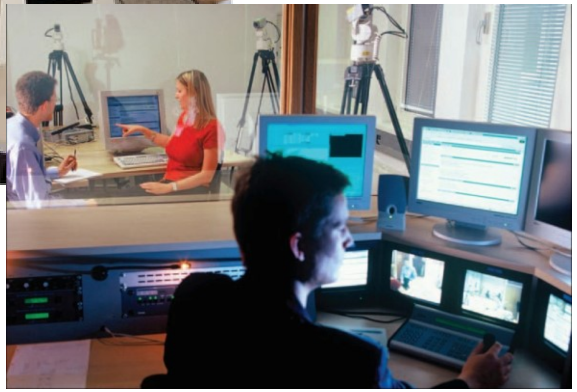
A square function of MOS → SOS hypothesis

No diversity at the edges and maximal diversity at MOS = 3

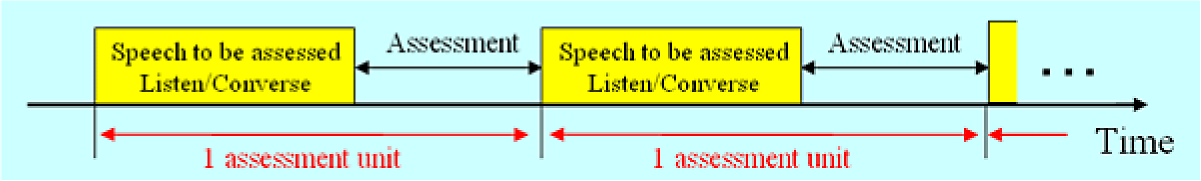



* T. Hossfeld, R. Schatz, and S. Egger, “SOS: The MOS is not enough!,” in 2011 Third International Workshop on Quality of Multimedia Experience, 2011, pp. 131–136.

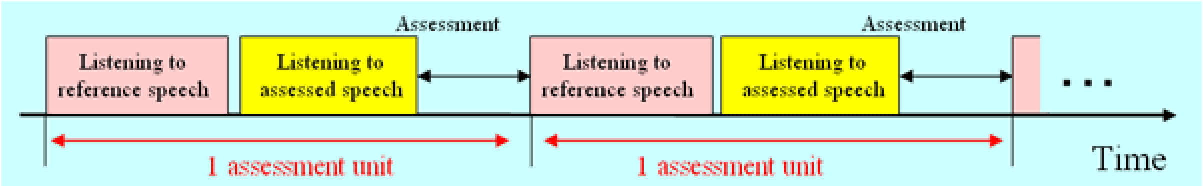
# Subjective: controlled experiments



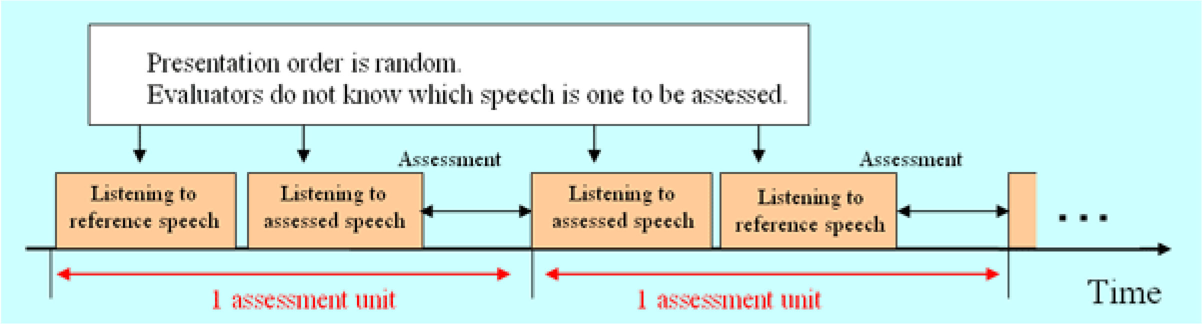
- MOS (Mean Opinion Score)



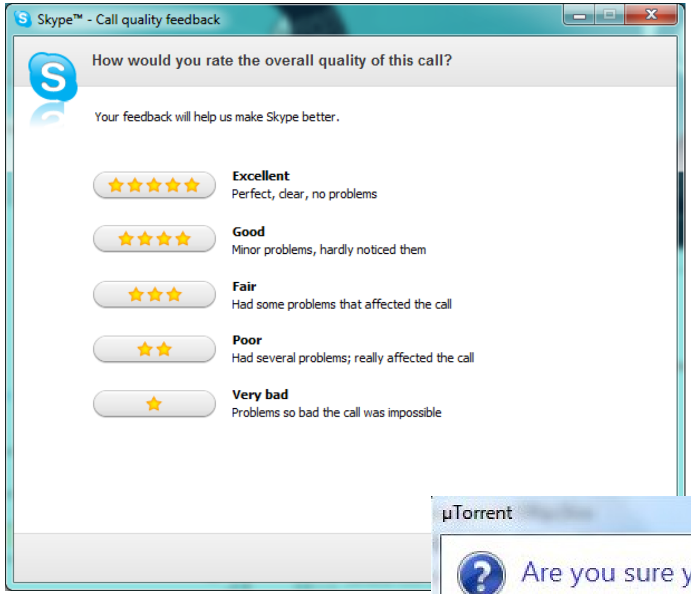

- DMOS (Degradation MOS)



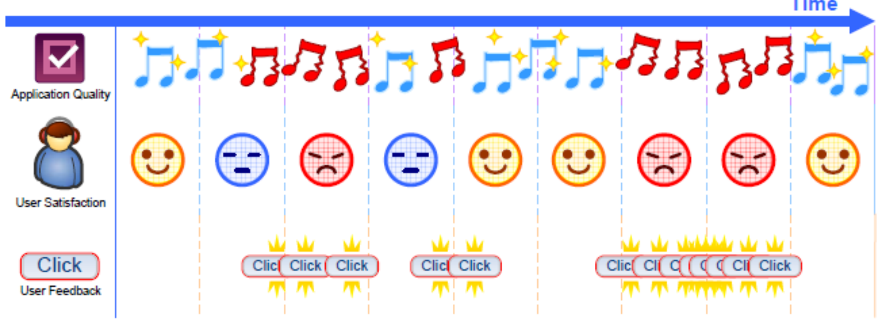

- CMOS (Comparison MOS)

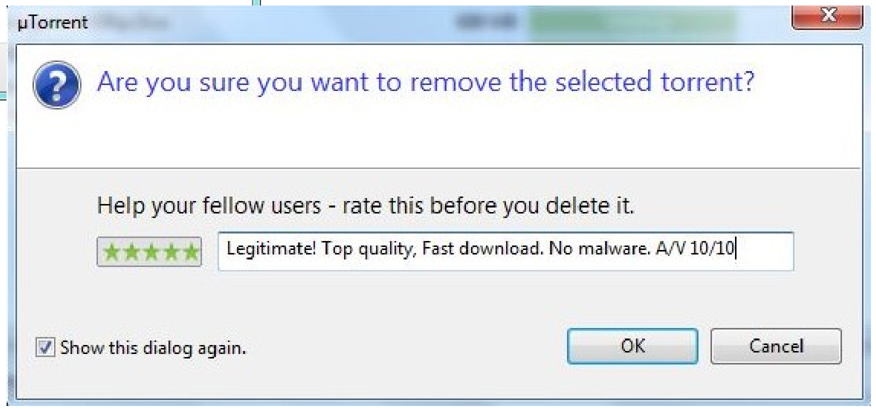


# Subjective: real service evaluation

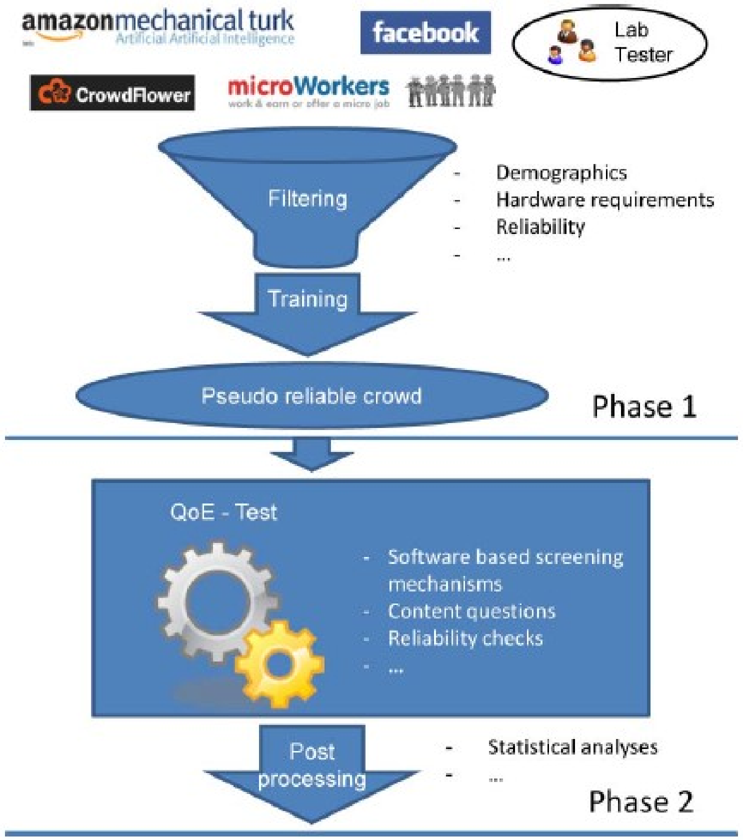



"OneClick"



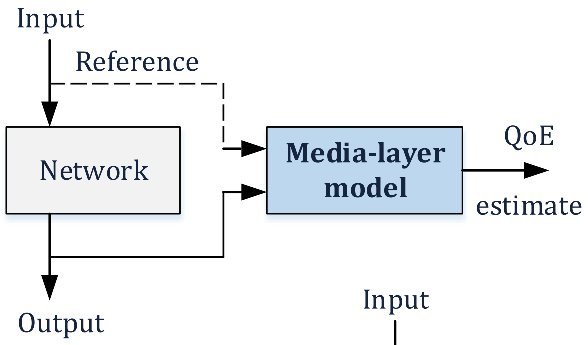

# Subjective: Crowdsourcing



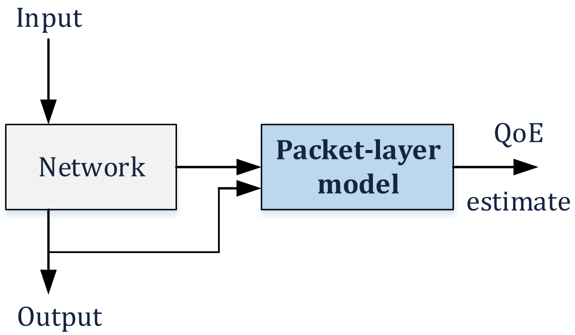

* T. Hossfeld, C. Keimel, M. Hirth, B. Gardlo, J. Habigt, K. Diepold, and P. Tran-Gia, "Best Practices for QoE Crowdtesting: QoE Assessment With Crowdsourcing," IEEE Trans. Multimed., vol. 16, no. 2, pp. 541–558, Feb. 2014.

# Objective: evaluation methods

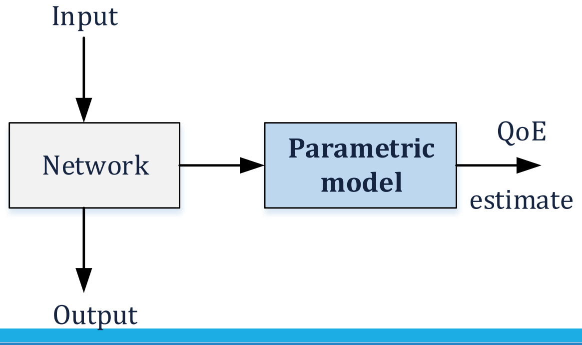
**Media-layer**




**Packet-layer / Bitstream**




**Parametric planning**



# Objective: evaluation methods

| Model | Advantages | Disadvantages |
|---|---|---|
| **Media-layer:**<br><br>**Full Reference**<br>**(e.g. PESQ)** | + Do not require any a-priori knowledge or assumptions about the underlying network<br>+ Highly accurate and robust (based on psycho-acoustics) | - Require the reference signal (intrusive)<br>- Very high computational effort<br>- Practically impossible to implement at network midpoint<br>- Do not enable insight into the internal system functionality & degradation causes (black-box) => diagnosis not possible<br>- Neglect human dimensions, pure technical |
| **Parametric planning:**<br><br>**E-model** | + Ease of use and respect of privacy<br>+ The network is characterized by the technical specifications of its constituent elements, (non-intrusive approach )<br>+ Quantifies the human factor through the “Advantage factor”, & contextual factor<br>+ Mouth-to-ear complete transmission chain => conversational<br>+ No restrictions on the network with respect to size, configuration, hierarchy, technology used, nor on the components of the network | - Intended only for the planning phase of a system (extended format)<br>- Good in theory, but difficult to include all the model parameters online<br>- Accurate only under strict application scenarios: new subjective tests and regression analysis needed for different conditions<br>- Speech independent<br>- A-priori information requirement |
| **Packet-layer:**<br><br>**ITU-T P.564** | + Enables insight into the internal system functionality (glass-box)<br>+ Light in terms of computational effort<br>+ Multiple monitoring points help identify the root of a network impairment<br>+ Used not only for speech quality predictions but also for the production of diagnostic outputs<br>+ In-service, non-intrusive (privacy)<br>+ Quality followed and pooled over time | - Not standardized, models need to be created that comply with these recommendations<br>- The model doesn’t know the characteristics of speech content to evaluate (speech level, echo, background noise etc.): assumes a generic voice payload<br>- Only concerns impairments on the IP network (no end-to-end evaluation)<br>- Large volume of QoE data<br>- Models deployed require strict conformance testing |

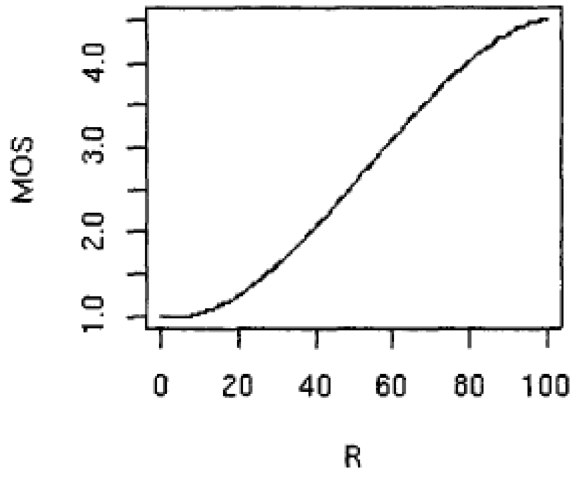
# Examples of parametric models

- [E-model] voip: $= \mathbf{94.2 - [0.024d + 0.11(d - 177.3)H(d - 177.3)] - [11 + 40\,ln(1 + 10p)]}$
  - delay
  - packet loss rate
- [E-model] Real-time video: $\mathbf{V_q = 1 + I_{coding} * I_{transmission}}$
  - FR, BR, PLR
- YouTube (TCP): $\mathbf{QoE = 3.5 * e^{-(0.15L+0.19)*N} + 1.5}$
  - #of stalling event
  - duration of stalls
- HTTP Adaptive Streaming (TCP): $\mathbf{QoE = 0.003 * e^{0.064*t} + 2.498}$
  - time on highest quality level
- FTP: $QoE = \alpha\, \mathbf{log_{10}(\beta R)}$, $\mathbf{10kbps < R < 300kbps}$
  - data rate

# ITU-T G.107 "E-model" for voice

A parametric model that produces the so-called Rating factor $R$:

$$R = R_0 - I_s - I_d - I_{e-eff} + A$$




**$R_o$** → basic signal-to-noise ratio, **$R_o$ = 100**

**$I_s$** → impairments due to the **voice signal travelling** in the network

**$I_d$** → impairments caused by **delay from end-to-end travelling** signal

**$I_{e\text{-}eff}$** → equipment impairment factor & impairments due to **packet loss**

**A** → advantage/expectation factor, in exchange for some user benefits or other factors difficult to quantify

# ITU-T G.107 “E-model” for voice (simplified)

$$R = R_0 - I_s - I_d - I_{e-eff} + A$$

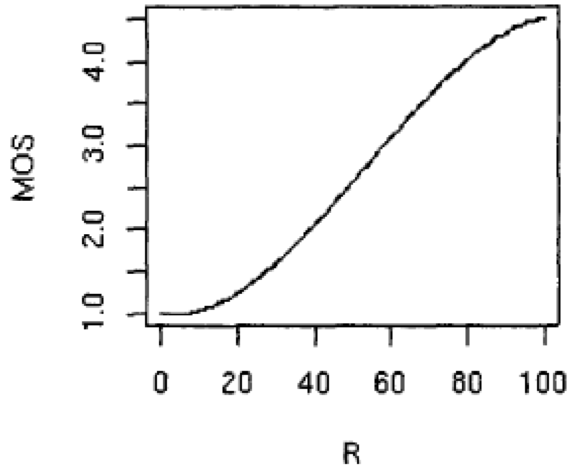
Under specific assumptions, the model may be simplified:

- $I_s$ → default values, A → neglected ⇒ $R = 94.2 - I_d - I_{e-eff}$
- $I_d = 0.024\mathbf{d} + 0.11(\mathbf{d} - 177.3)H(\mathbf{d} - 177.3)$ → G.107
- $I_{e-eff} = 11 + 40\ln(1 + 10\boldsymbol{e})$ → G.113
- G.729a codec
- more…

**delay** = $d_{network} + d_{codec} + d_{de\text{-}jitter\_buffer}$

**packet loss** = $e_{network} + e_{de\text{-}jitter\_buffer}$

Then, R [0..100] is mapped to MOS [0..5]




- Purpose: monitoring the conversational voice quality
- Delay & Packet loss are isolated

* R. G. Cole, J. H. Rosenbluth, “Voice over IP performance monitoring,” ACM SIGCOMM Comput. Commun. Rev., vol. 31, no. 2, p. 9, 2001.

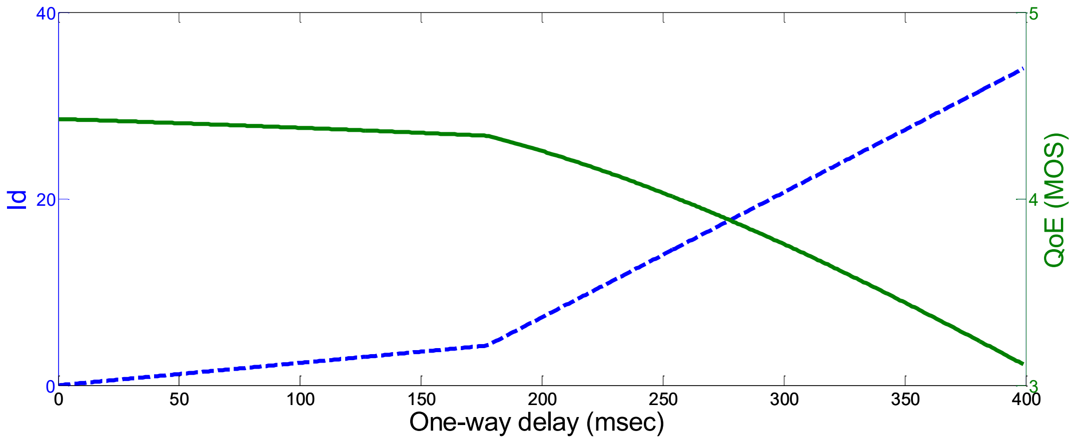
# ITU-T G.107 “E-model” for voice (simplified)

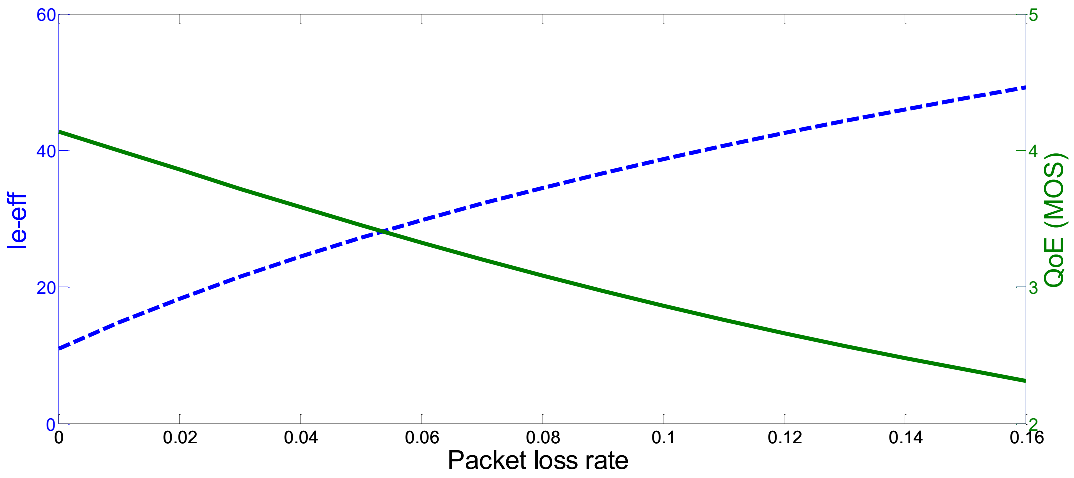
$$R = R_0 - I_s - I_d - I_{e-eff} + A$$

$$R = 94.2 - 0.024d - 0.11(d - 177.3)H(d - 177.3) - 11 - 40\,ln(1 + 10p)$$

delay

packet loss rate



# ITU-T G.1070 “E-model” for video

A computational model for point-to-point interactive videophone applications over IP networks (UDP-based - lossy video)

Network, Application & Terminal parameters incorporated

Video quality =

$$V_q = 1 + I_{coding} * I_{transmission}$$

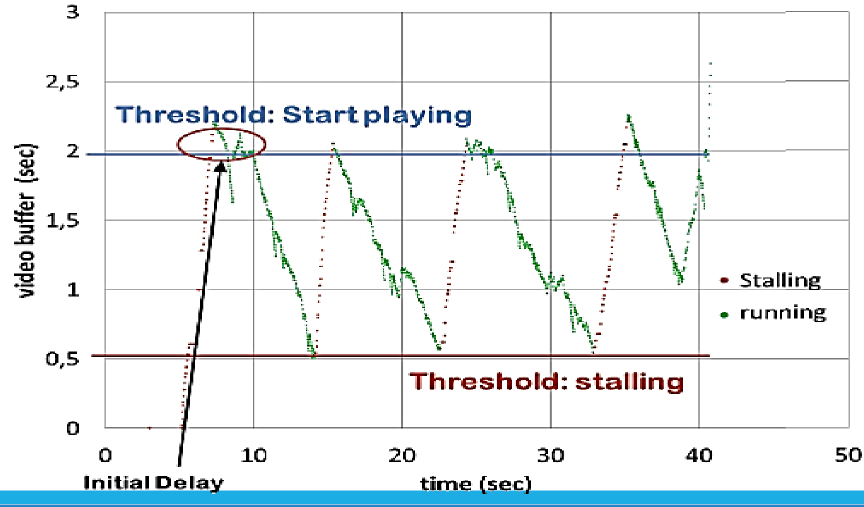
- $I_{coding}$ = the video quality affected by the coding distortion
- $I_{transmission}$ = the video quality affected by the transmission process
- Ultimately everything is a function of:
  - the **video frame rate** (fps) - FR
  - the **video bit rate** (kbps) - BR
  - the **video packet loss rate** - PLR
  - 12 coefficients

# QoE model for YouTube

Video on Demand (VoD), TCP-based connection (no losses)

Quality influence factors (by crowdsourcing & lab tests):

- Number of stalling events, ***N***
- Duration of stalling events, ***L***
- Total video duration, ***T*** (total stalling duration over video duration)
- Initial delay (video start-up delay) → cache redirections' impact



# QoE model for YouTube

Some conclusions:

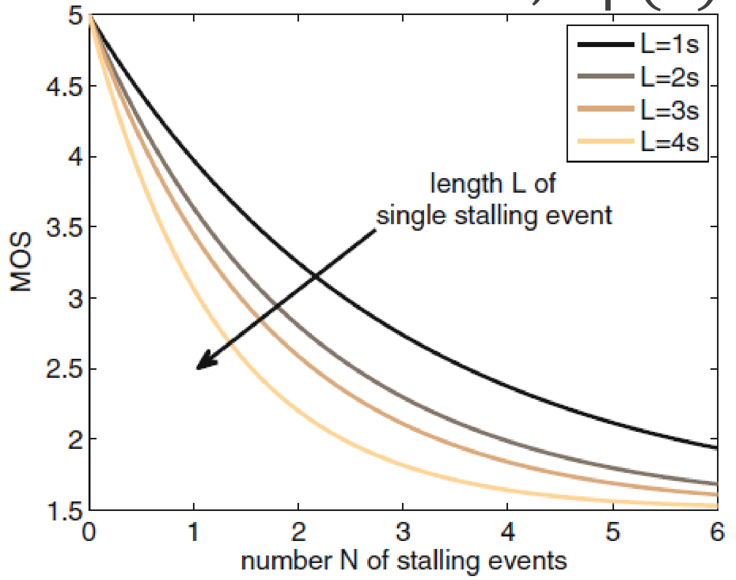
- The user demographics have no significant influence (!)
- Initial delays have almost no influence on MOS for videos of duration 60s and 30s compared to the influence of stalling length
- The user ratings are statistically independent from video motion, type of content, the usage pattern of the user, access speed, etc.
- The number of stalling events together with the stalling length are clearly dominating the user perceived quality
- The video duration only plays a role if there are only a very few stalling events

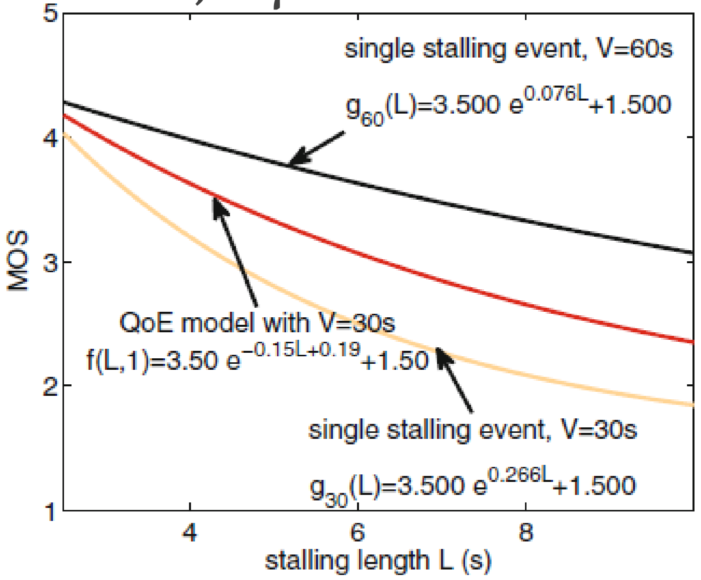
# QoE for YouTube

IQX hypothesis validation:

$$QoE(L, N) = \alpha * e^{-\beta(L)*N} + \gamma,$$

$$\alpha = 3.5, \quad \beta(L) = 0.15L + 0.19, \quad \gamma = 1.5$$

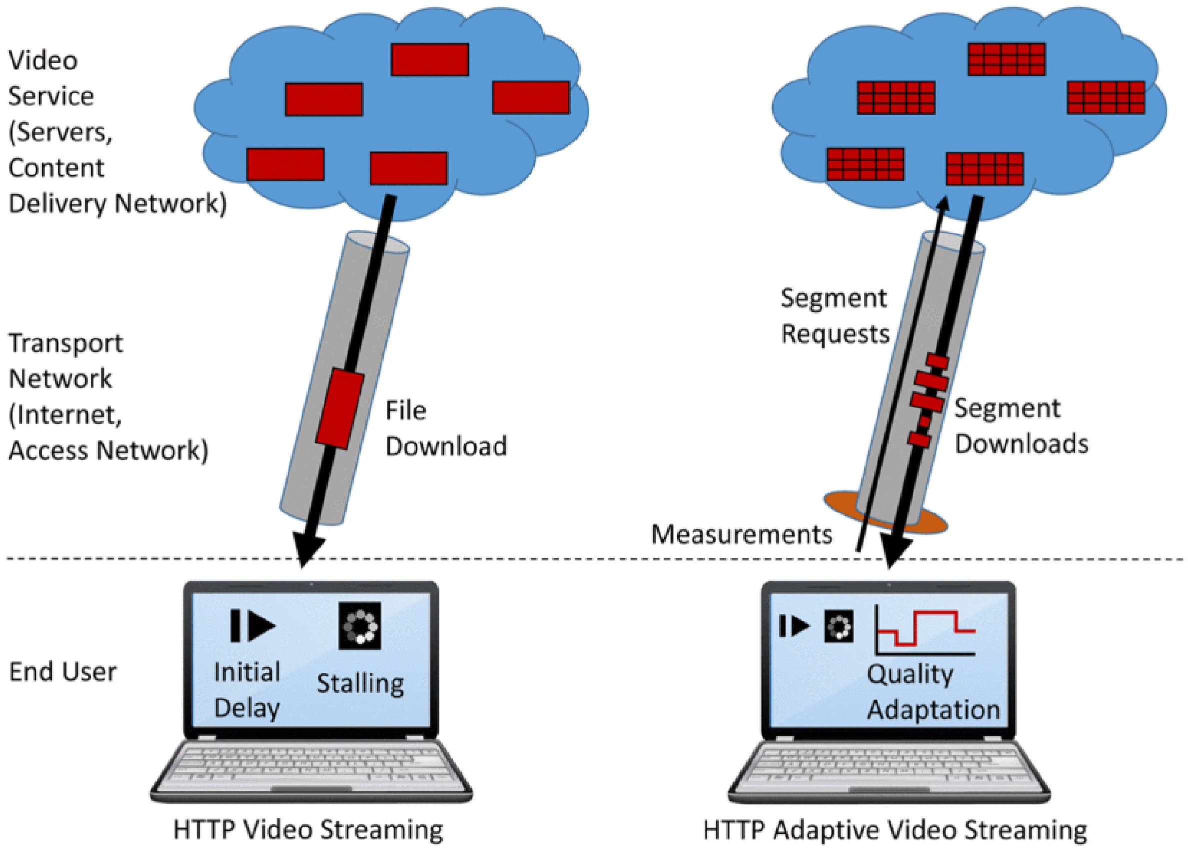


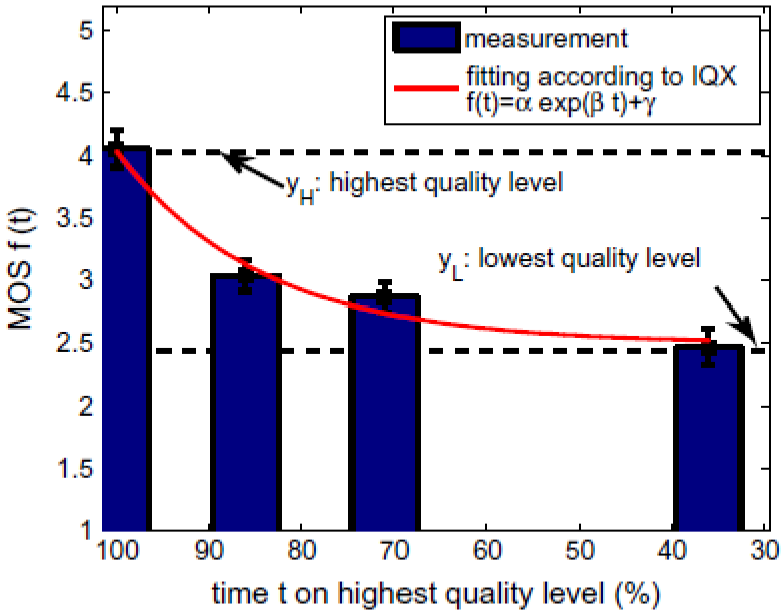

* T. Hossfeld, R. Schatz, E. W. Biersack, and L. Plissonneau, "Internet Video Delivery in YouTube: From Traffic Measurements to Quality of Experience," in Data Traffic Monitoring and Analysis, Eds. Springer Berlin Heidelberg, pp. 264–301, 2013.

# QoE model for HTTP Adaptive Streaming (HAS)

Comparison of HTTP video streaming and HTTP adaptive video streaming



# QoE model for HTTP Adaptive Streaming (HAS)




$$QoE = 0.003 * e^{0.064 * t} + 2.498$$

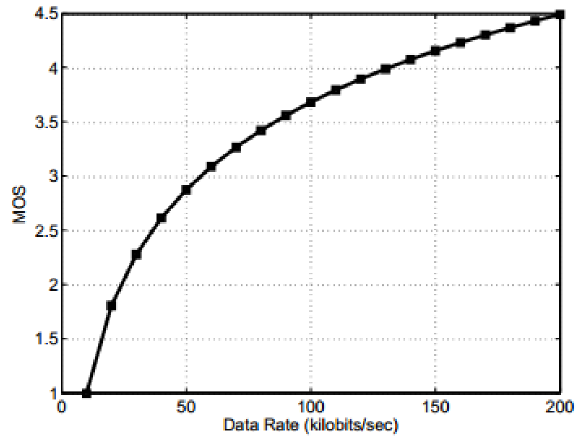
$t$ = time on highest layer

**Other influence factors:** Adaptation frequency (number of switches), adaptation amplitude, adaptation direction, segment length, buffer size, etc.

# QoE model for file download services

Elastic service, for which the utility function is an increasing, strictly concave, and continuously differentiable function of throughput

The user satisfaction of a file transfer service is solely dependent on the provided data rate




Logarithmic relationship between MOS and throughput:

$$MOS = \begin{cases} 1, & R < 10kbps \\ \alpha \log_{10}(\beta R), & 10kbps < R < 300kbps \\ 4.5, & 300kbps < R \end{cases}$$

- ***R*** is the data rate of the service
- ***α*** and ***β*** obtained from the upper and lower user perceived quality expectations

* S. Thakolsri, S. Khan, E. Steinbach, and W. Kellerer, "QoE-Driven Cross-Layer Optimization for High Speed Downlink Packet Access," J. Commun., vol. 4, no. 9, 2009

# Research areas

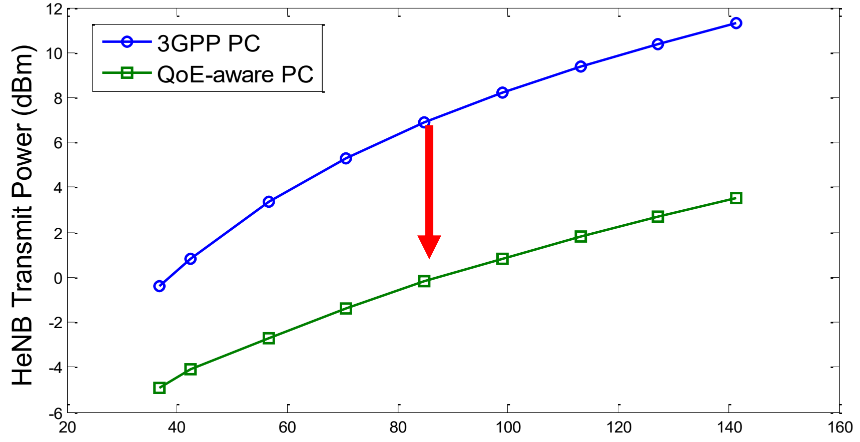
| | | | | |
|---|---|---|---|---|
| QoE Management procedure | QoE impairment prediction, diagnosis | Incorporate QoE in LTE-A mechanisms | Network dimensioning & planning for QoE | Organise subjective experiments, combine |
| QoE-driven procedures (QoE-aware routing, resource control) | Interworking problem, HetNets | Identify KPIs (Influence Factors) | Quantify user perception (impact of stimulus) | Study quality-affecting phenomena |
| Map QoS to QoE, QoE to acceptance | Network-based vs. agent-based, initialisation | QoE business models, Charge for QoE | Diversification & Fairness among users | Optimise for user + provider perspective |
| Delivery of QoE reports, expression | Security Privacy Legal issues | SLAs Certification Labelling | QoE target, Granularity, Rating scale used | Consensus in QoE practices |

# QoE Research Work

Some Examples

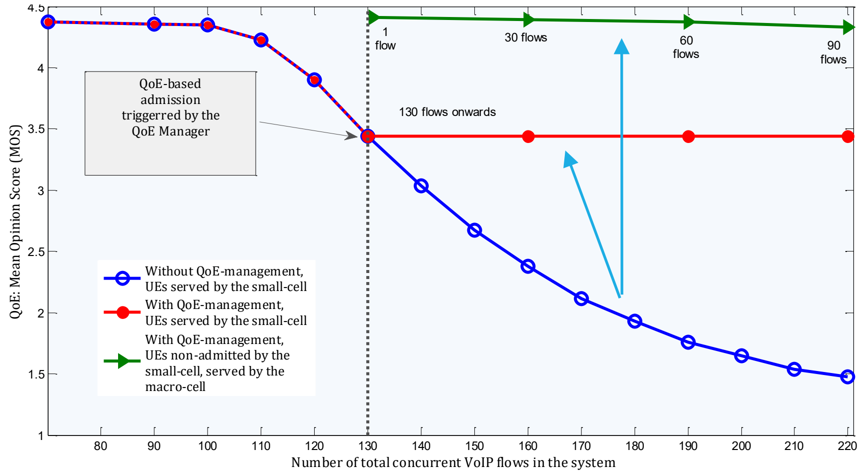
**Power Control**

D. Tsolkas, E. Liotou, N. Passas, and L. Merakos, “The Need for QoE-driven Interference Management in Femtocell-Overlaid Cellular Networks ”, in 10th International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (Mobiquitous), Tokyo, December 2013.




**Admission Control**

E. Liotou, D. Tsolkas, N. Passas and L. Merakos, “Quality of Experience management in mobile cellular networks: Key issues and design challenges,” IEEE Communications Magazine, Network & Service Management Series, July 2015.




**Radio Resource Scheduling**

E. Liotou, R. Schatz, A. Sackl, P. Casas, D. Tsolkas, N. Passas, and L. Merakos, “The beauty of consistency in radio-scheduling decisions,” 59th Global Communications Conference (IEEE Globecom Wkshps) - International Workshop on Quality of Experience for Multimedia Communications (QoEMC), Washington, DC, USA, December 2016.