Quality of Experience

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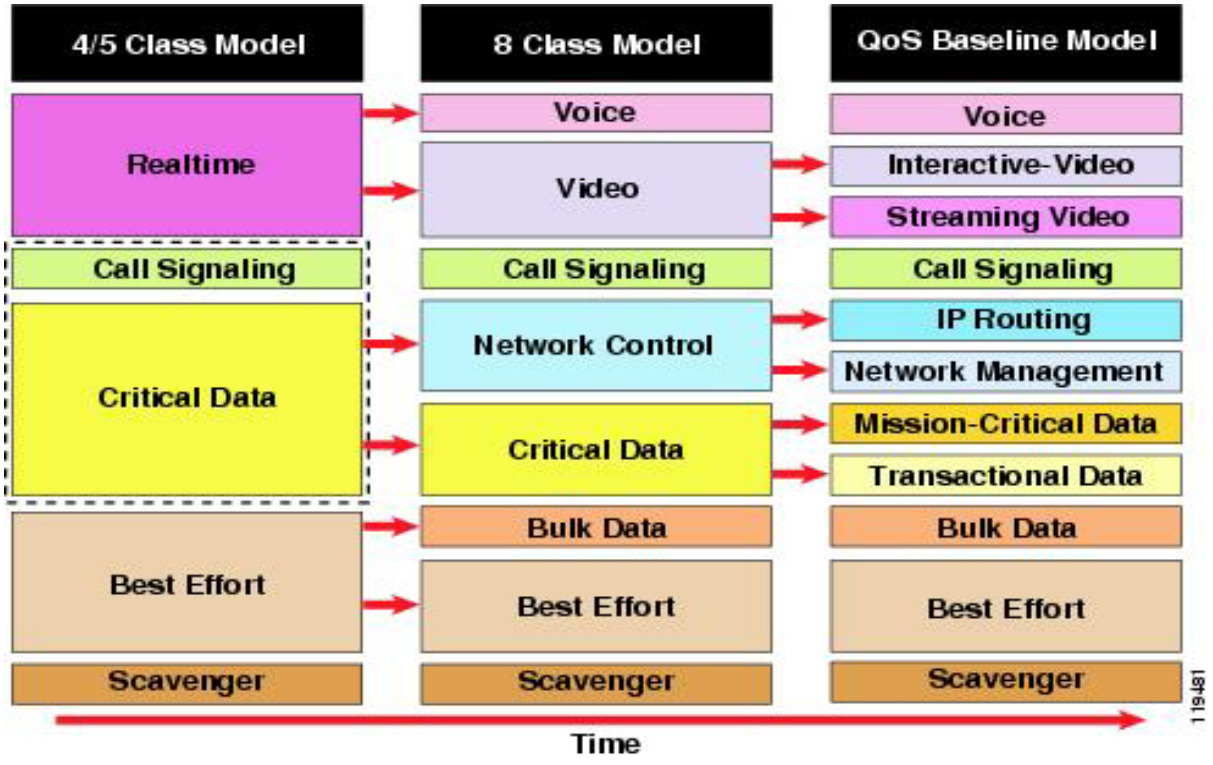
Quality of Service (QoS)

- What is QoS?
- Measures the "**quality**" of a provided service from the network's perspective
- QoS depends on network parameters, such as:
  - **Throughput**: The rate of packets which go through the network. Maximum rate is expected.
  - **Delay**: The time how long for a bit data to travel across the network from one end to another end. Minimum delay is expected.
  - **Packet loss Rate**: The rate at which the packet are lost. It should be as lower as possible.
  - **Packet Error Rate**: The errors in the packet due to corrupted bits. It should be lower as much as possible.
  - **Jitter:** is expressed as an average of the deviation from the network mean latency

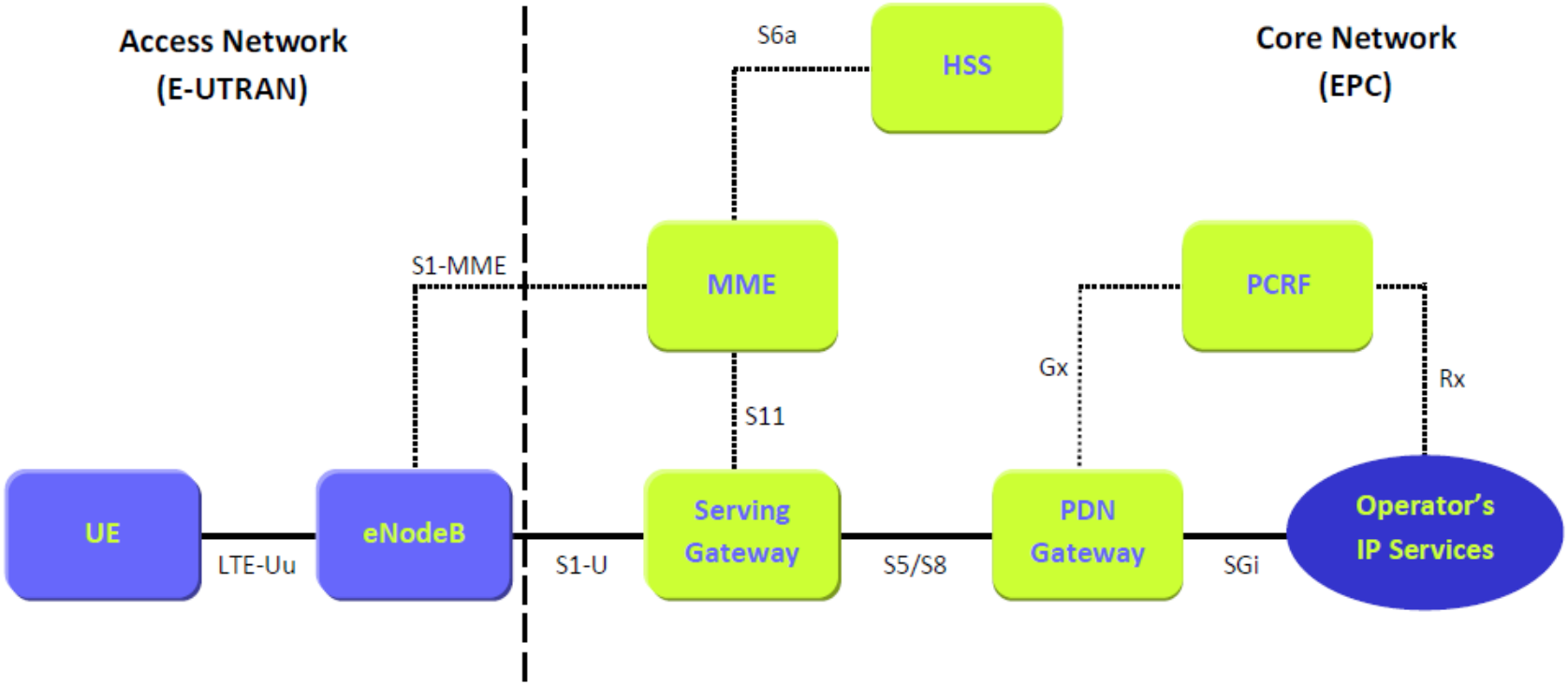
Quality of Service (QoS)

- QoS classes
  - Different services - different QoS parameters
  - Resources are not infinite! Thus, guaranteeing different QoS levels is a fundamental procedure in any system.



QoS in LTE/LTE-A

- LTE-A network Architecture

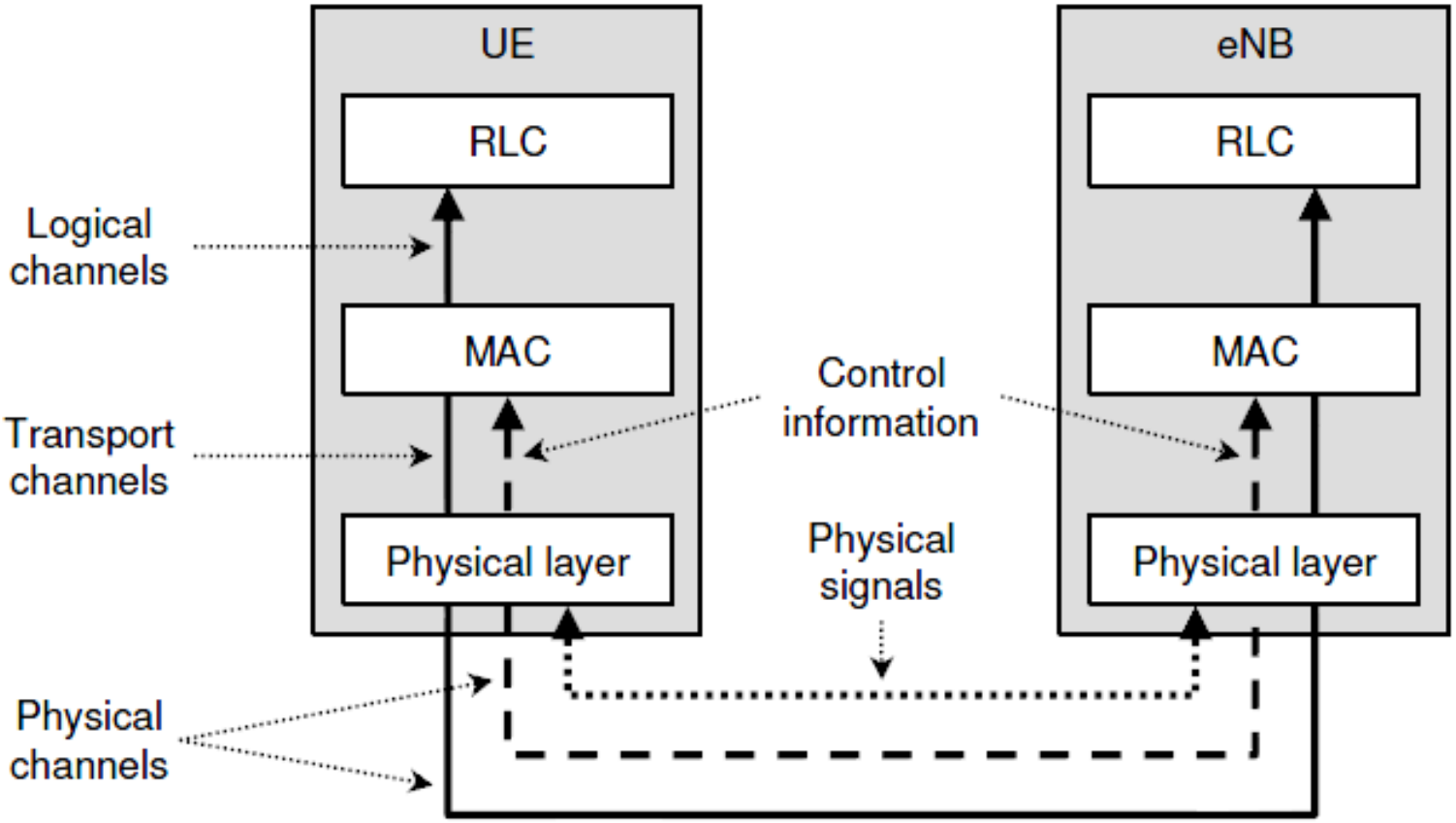


QoS in LTE/LTE-A

- Two important types of data stream are defined in the EPS
  - **Channels**, which carry information between different levels of the air interface protocol stack.
  - **Bearers**, which carry information from one part of the system to another, with a particular **quality of service.**
- The most important bearers are **EPS bearers**, which carries data between the UE and the PDN gateway (P-GW).
- When the network sets up a data stream, the data are carried by an EPS bearer, and are associated with a particular **quality of service.**

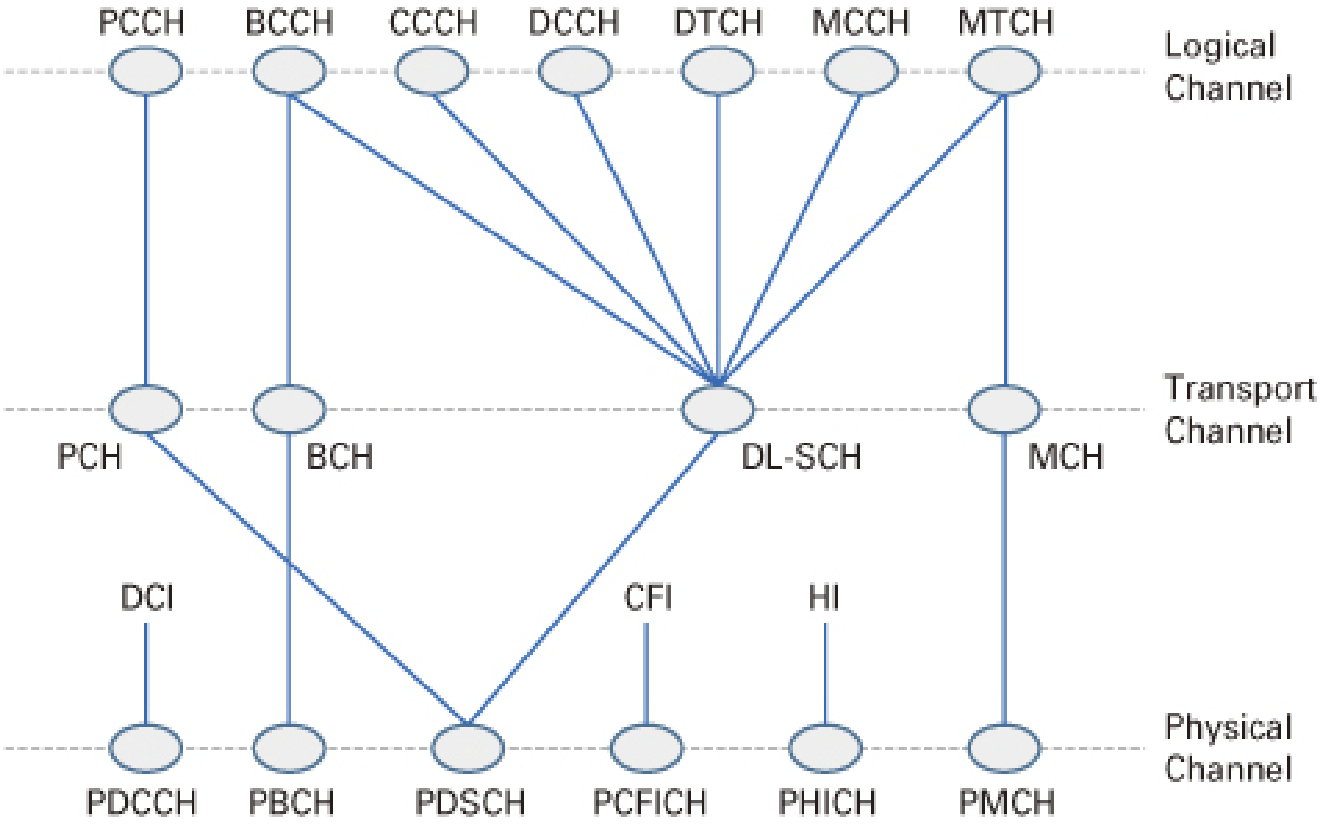
QoS in LTE/LTE-A

- Channels



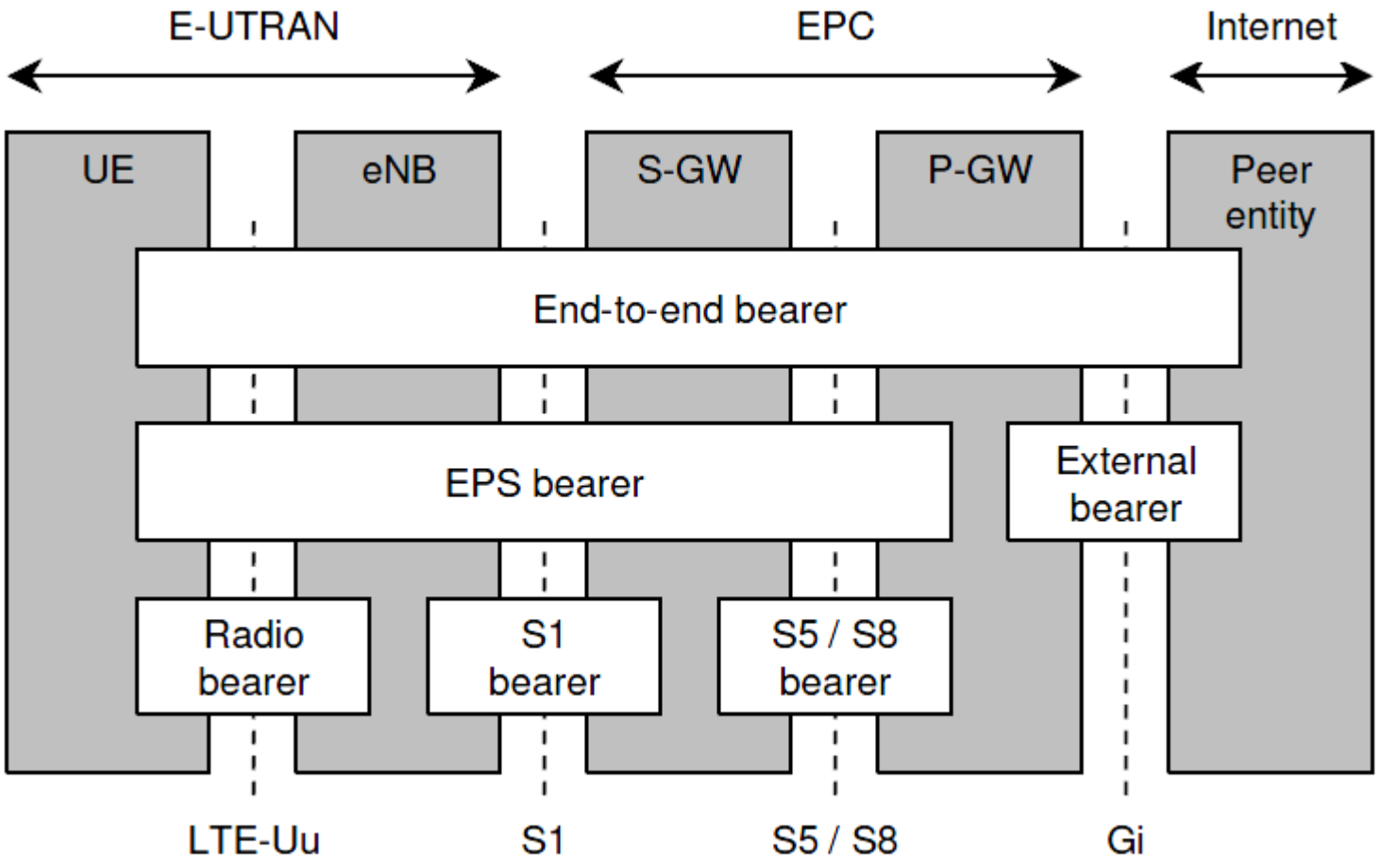
QoS in LTE/LTE-A

- Channels



QoS in LTE/LTE-A

- EPS-bearer



QoS in LTE/LTE-A

- Each EPS bearer is associated with the following QoS parameters:
  - QoS class identifier (QCI): This is a number which describes the error rate and delay that are associated with the service.
  - Allocation and retention priority (ARP): This determines whether a bearer can be dropped if the network gets congested, or whether it can cause other bearers to be dropped. Emergency calls might be associated with a high ARP, for example.

QoS in LTE/LTE-A

- There are a few different types of EPS bearer. One classification refers to quality of service:
  - A GBR bearer has a guaranteed bit rate (GBR) amongst its quality-of-service parameters. A GBR bearer would be suitable for a conversational service, such as a voice call.
  - A non-GBR bearer does not have a guaranteed bit rate. A non-GBR bearer would be suitable for a background service, such as Email.

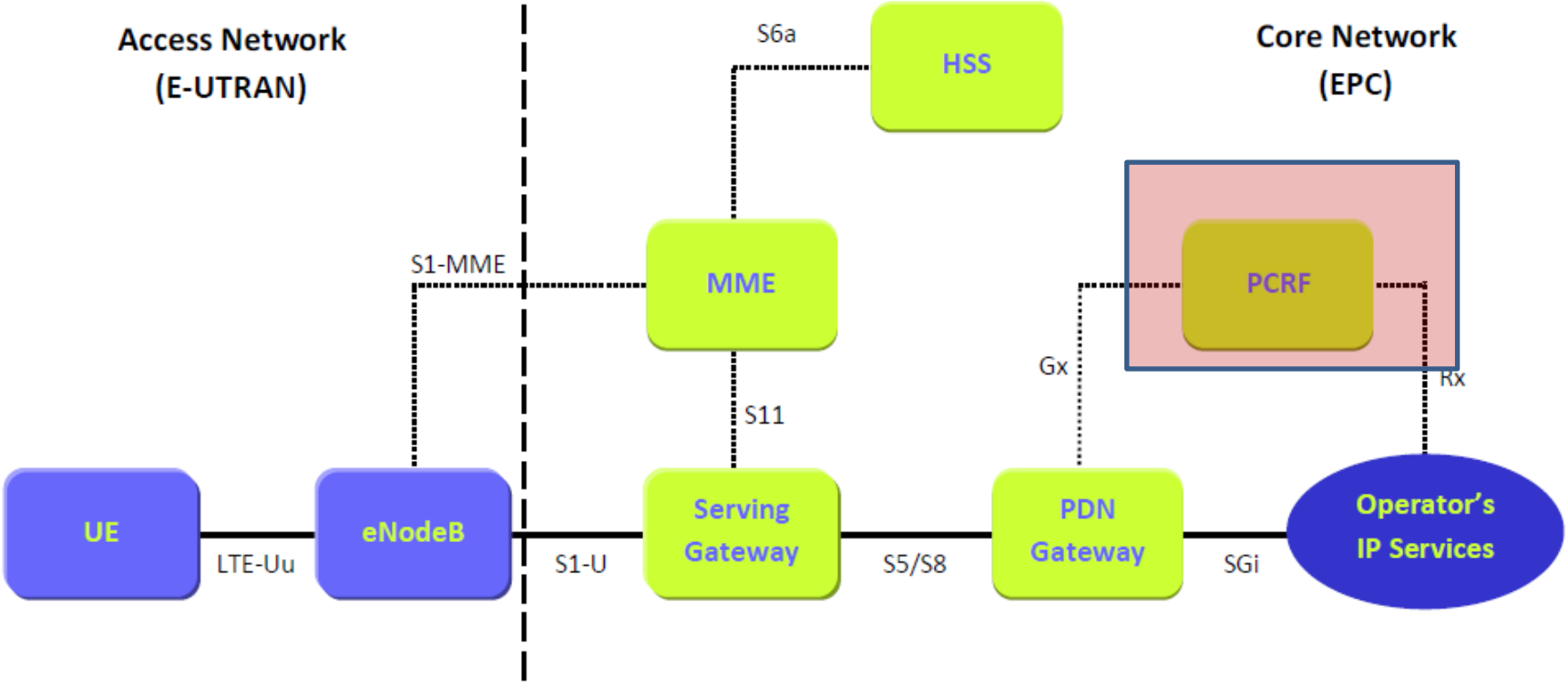
QoS in LTE/LTE-A

QCI	Resource type	Priority	Packet delay budget	Packet error loss rate	Example services
1	GBR	2	100 ms	10^{-2}	Conversational voice
2		4	150 ms	10^{-3}	Conversational video (live streaming)
3		3	50 ms	10^{-3}	Real time gaming
4		5	300 ms	10^{-6}	Non-conversational video (buffered streaming)
5	Non-GBR	1	100 ms	10^{-3}	IMS signaling
6		6	300 ms	10^{-6}	Video (buffered streaming), TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100 ms	10^{-6}	Voice, Video (live streaming), Interactive gaming
8		8	300ms	10^{-3}	Video (buffered streaming), TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		9		10^{-6}	

*IP Multimedia Subsystem (IMS)

QoS in LTE/LTE-A

- QoS main entity: PCRF



QoS in LTE/LTE-A

To summarize…

- Guaranteeing different QoS levels is a fundamental procedure in any system.
- QoS in LTE/ LTE-A system
  - LTE/LTE-A network use bearers to carry information from one part of the system to the other
  - Data are carried by EPS – bearers
  - There are different EPS – bearers for different **QoS**
  - A QoS-based classification is: GBR and non-GBR EPS – bearers

is QoS enough?

QoE definition and challenges

QoE - Definition

- What is QoE?
  - Several attempts in the literature
  - The definition in ITU-T Rec. P.10 (formerly G.100): "the overall acceptability of an application or service, as perceived subjectively by the end-user"
  - More or less refers to the perceptual quality of a provided service

QoE - importance

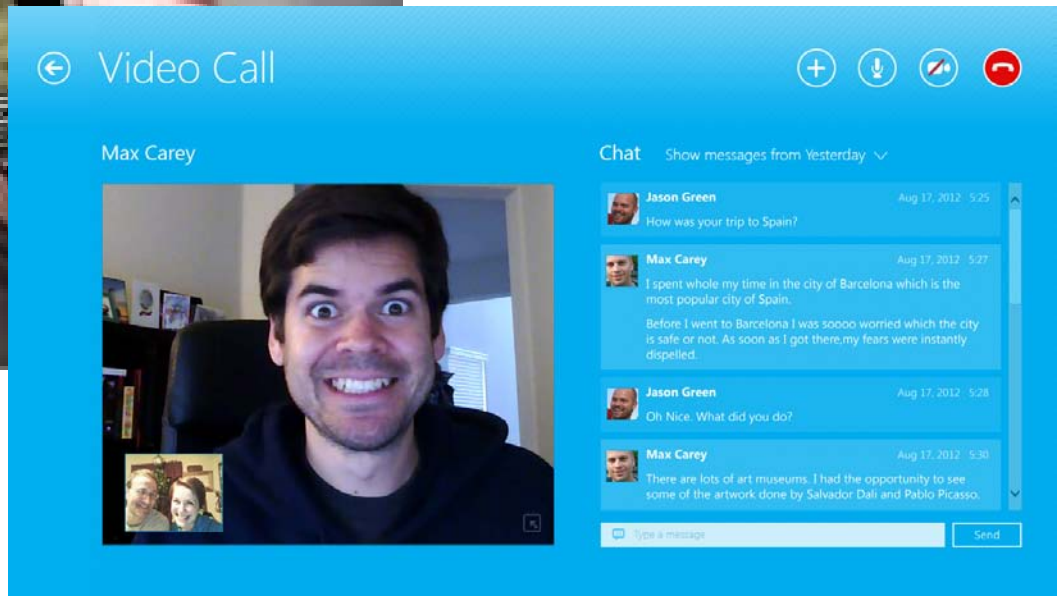
- Why the study of the QoE is important?
  - The QoE encompasses the issue of the user's decision on retaining a service (and keep paying for it) or giving it up
  - It is more efficient to focus on guaranteeing QoE than promising high QoS
    - Obviously, high QoS results in high QoE, however the quantification 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?

QoE - Dependencies

- Application specific features



QoE - Dependencies

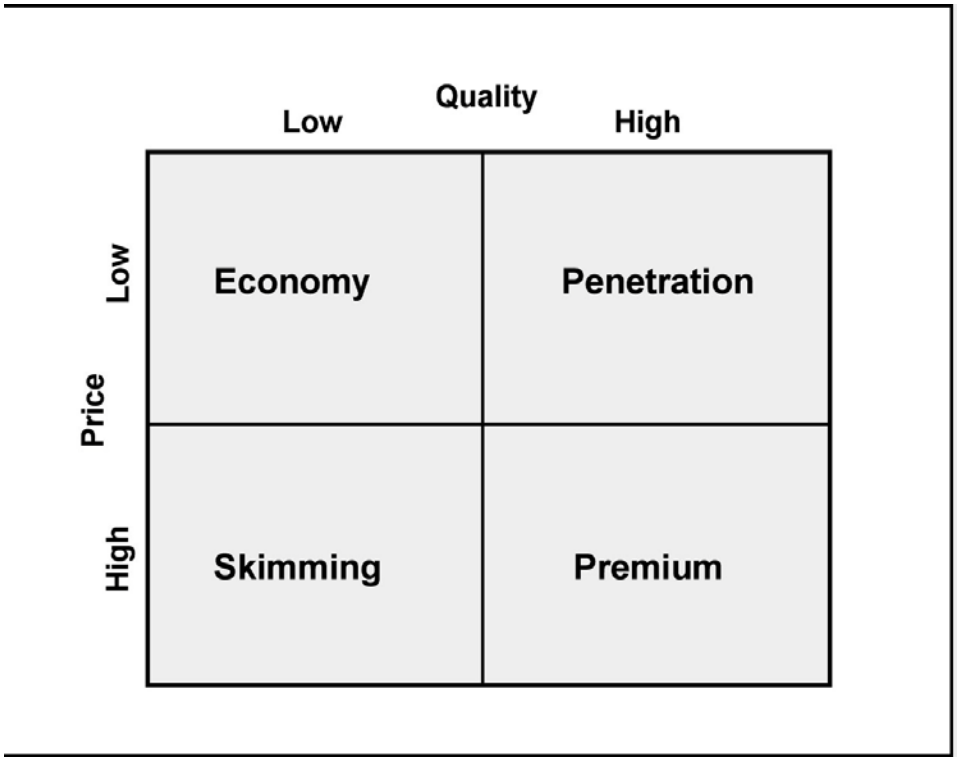
- Terminal type

QoE - Dependencies

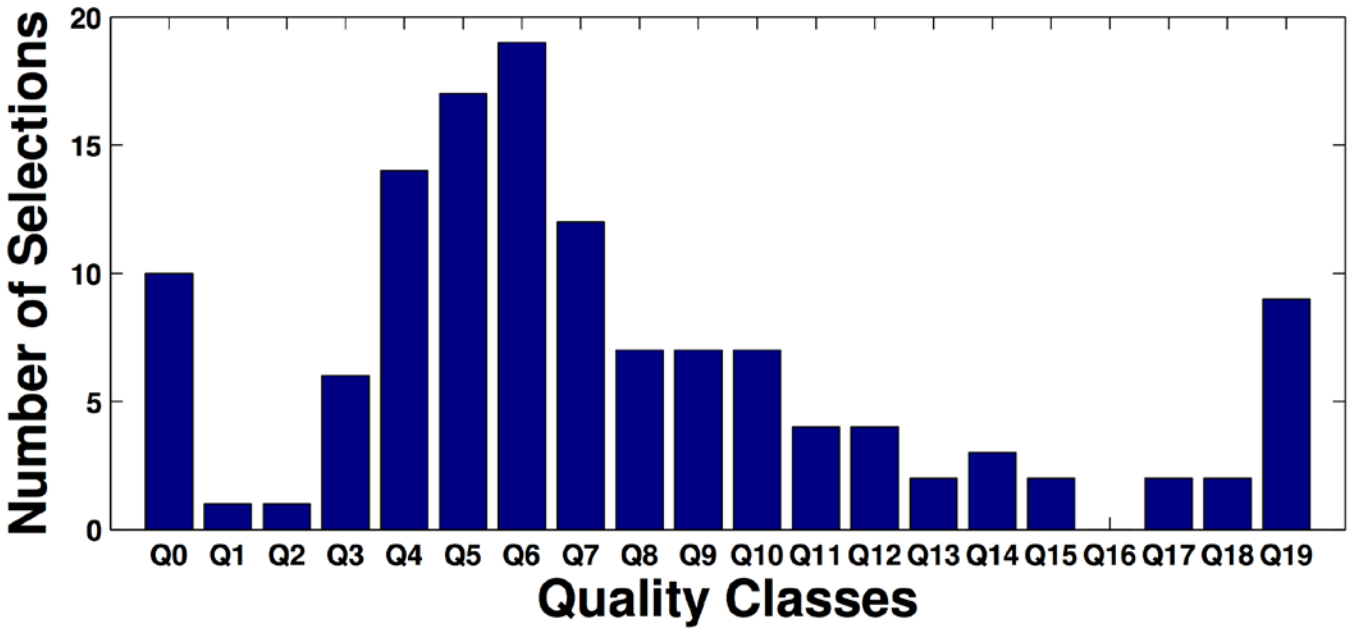
- Content

QoE - Dependencies

- Pricing policy



Willingness to pay



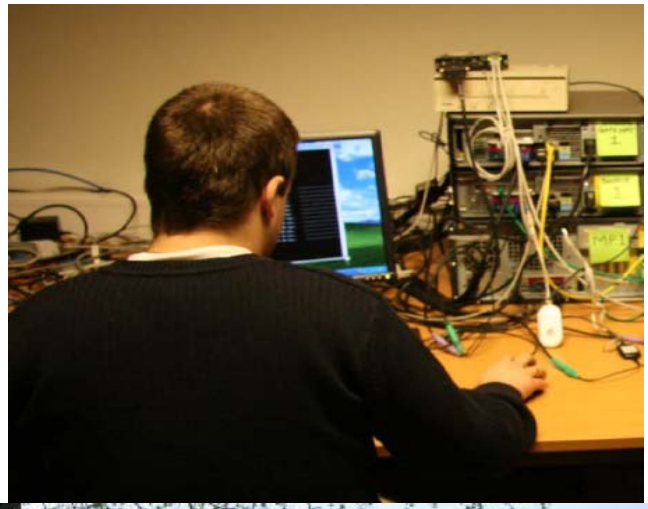
A. Sackl, P. Zwickl, and P. Reichl. “The trouble with choice: An empirical study to investigate the influence of charging strategies and content selection on QoE”. . In: *Network and Service Management (CNSM), 9th International Conference on. Oct. 2013*

QoE - Dependencies

- Sociological factors

QoE - Dependencies

- Environmental parameters

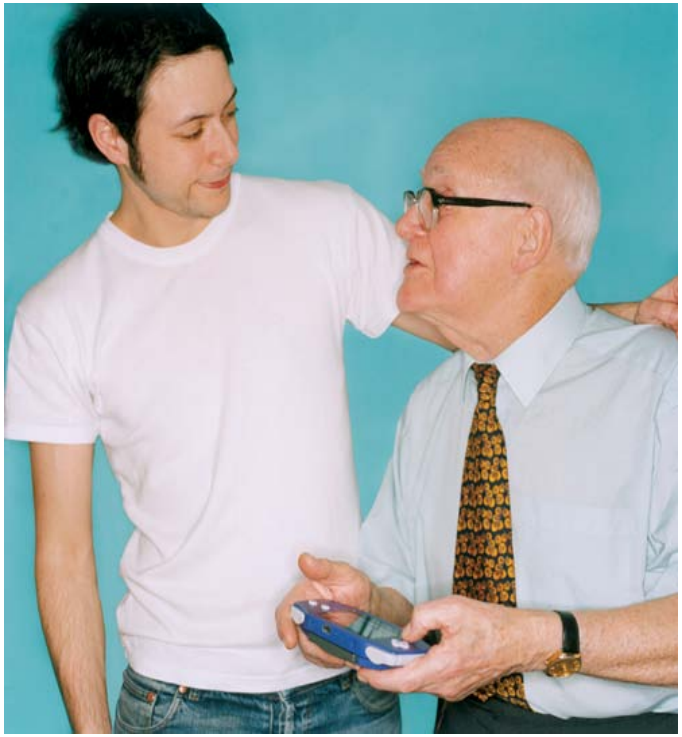


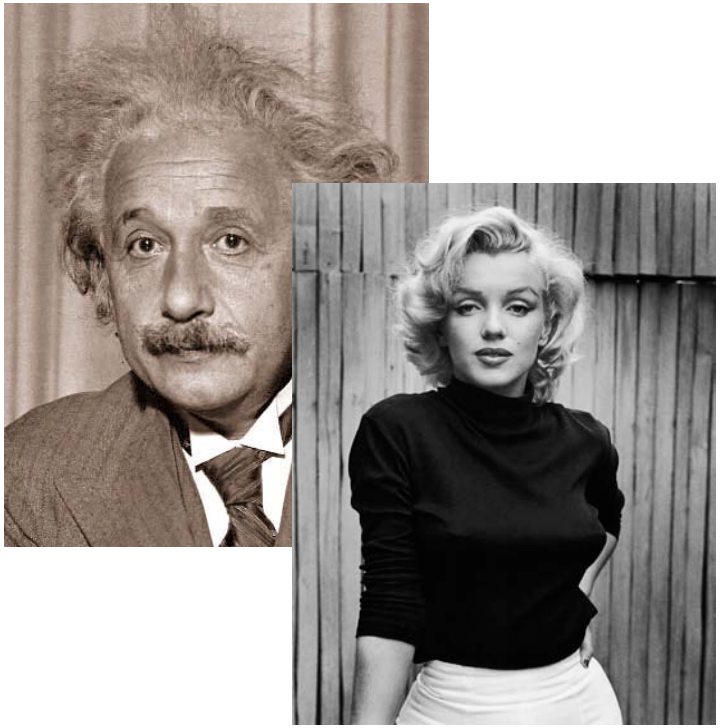
QoE - Dependencies

- Psychological factors

QoE - Dependencies

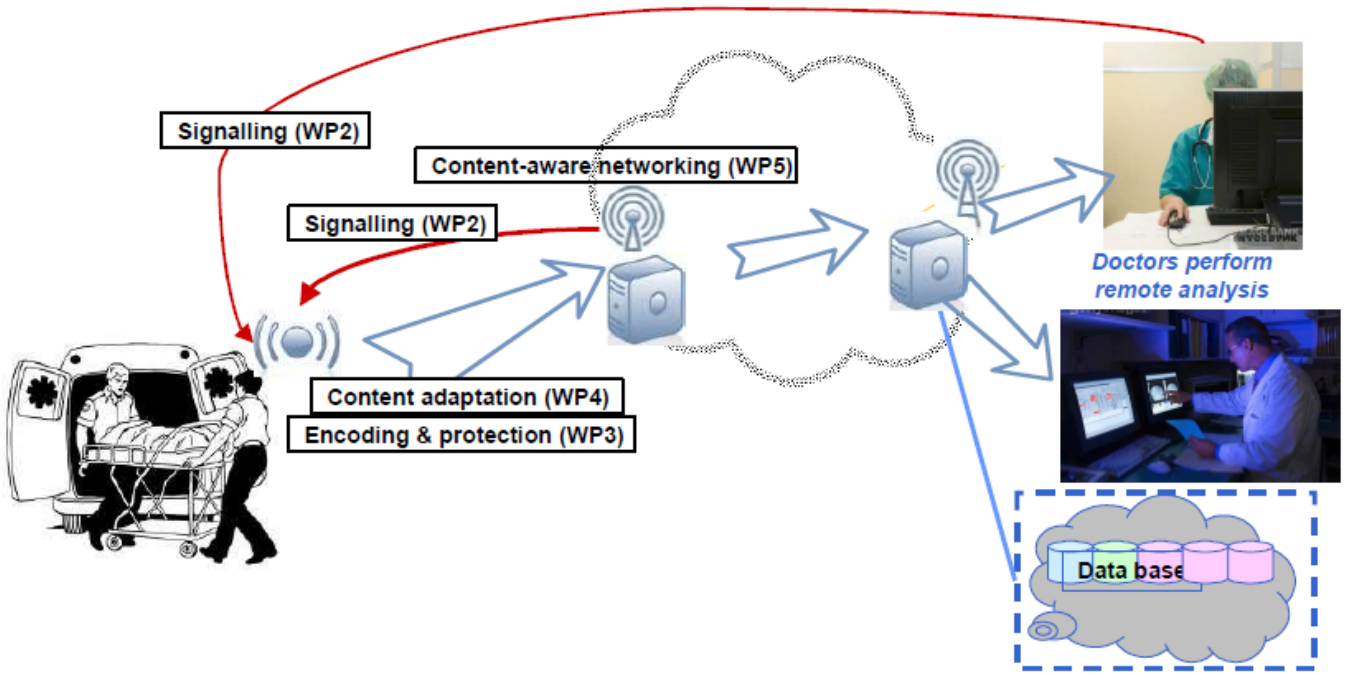
- User's profile





QoE - Dependencies

- User's experience



CONCERTO EU project

QoE - challenges

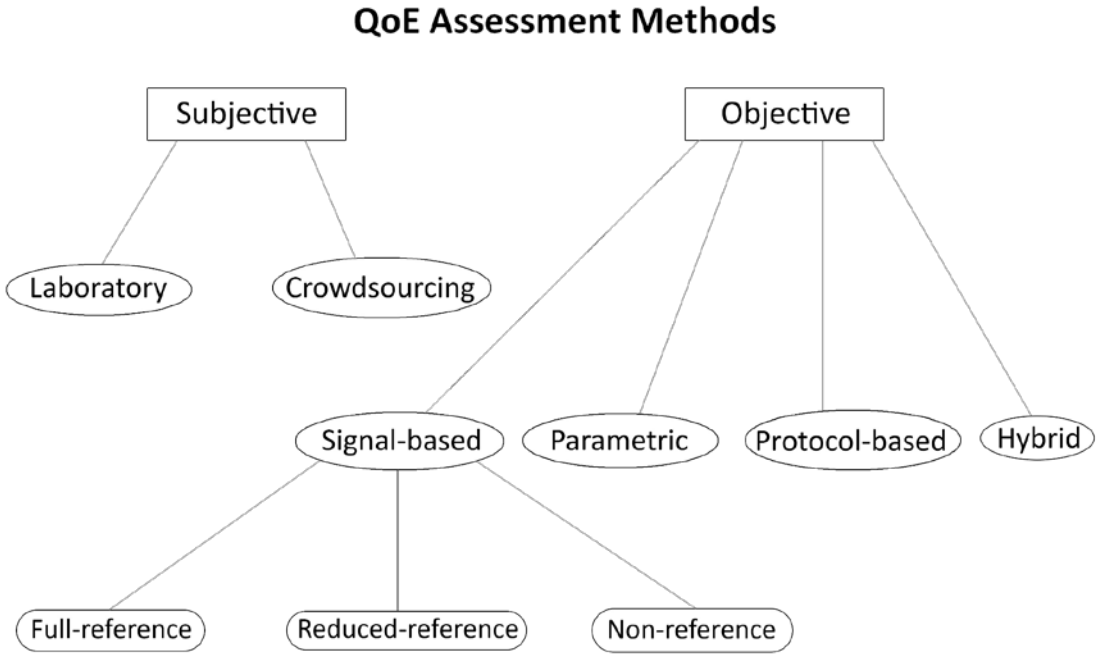
Can we measure QoE?

Highly subjective metric - there is a long list of dependences

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

QoE - estimation

- **QoE estimation**
  - Can be based on subjective or objective methods.
  - How to assure the reliability of subjective methods and how to map objective parameters to QoE?



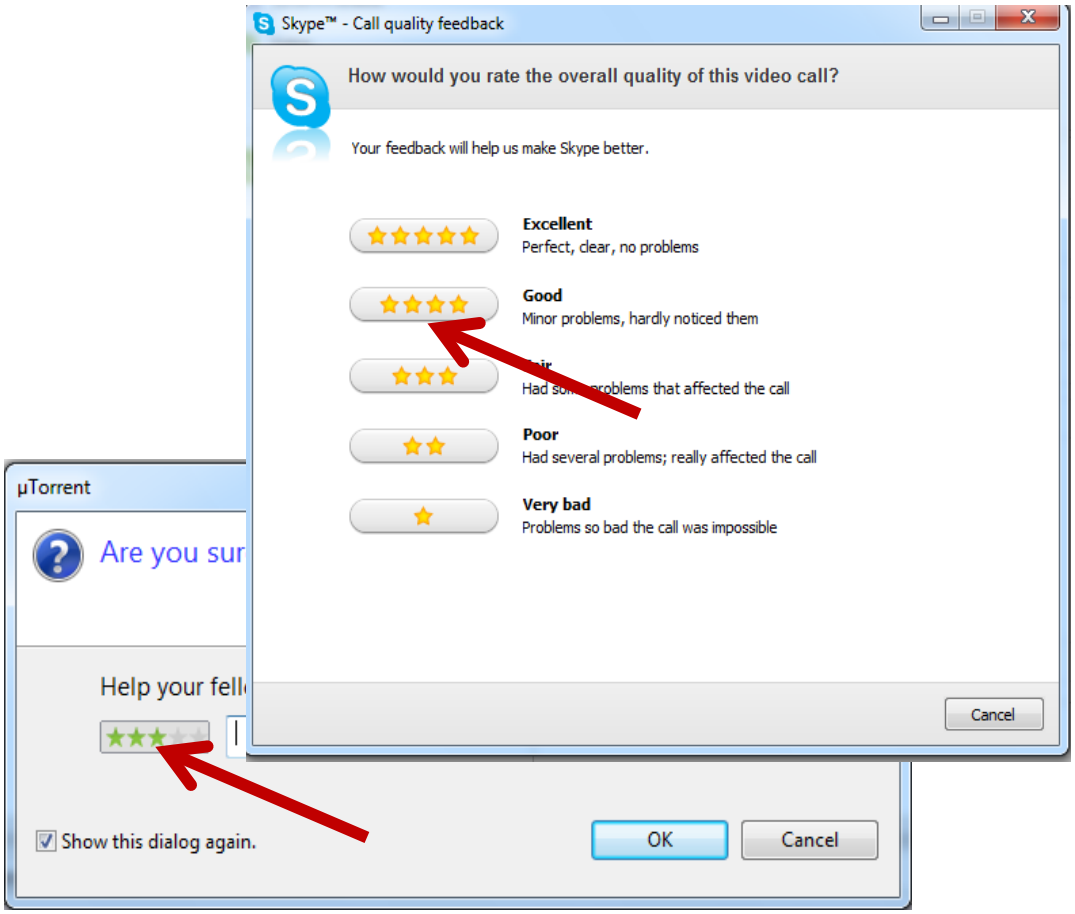
Subjective QoE Estimation

QoE

Subjective Methods:

MOS ITU P.800

MOS	Quality
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad



Subjective QoE Estimation

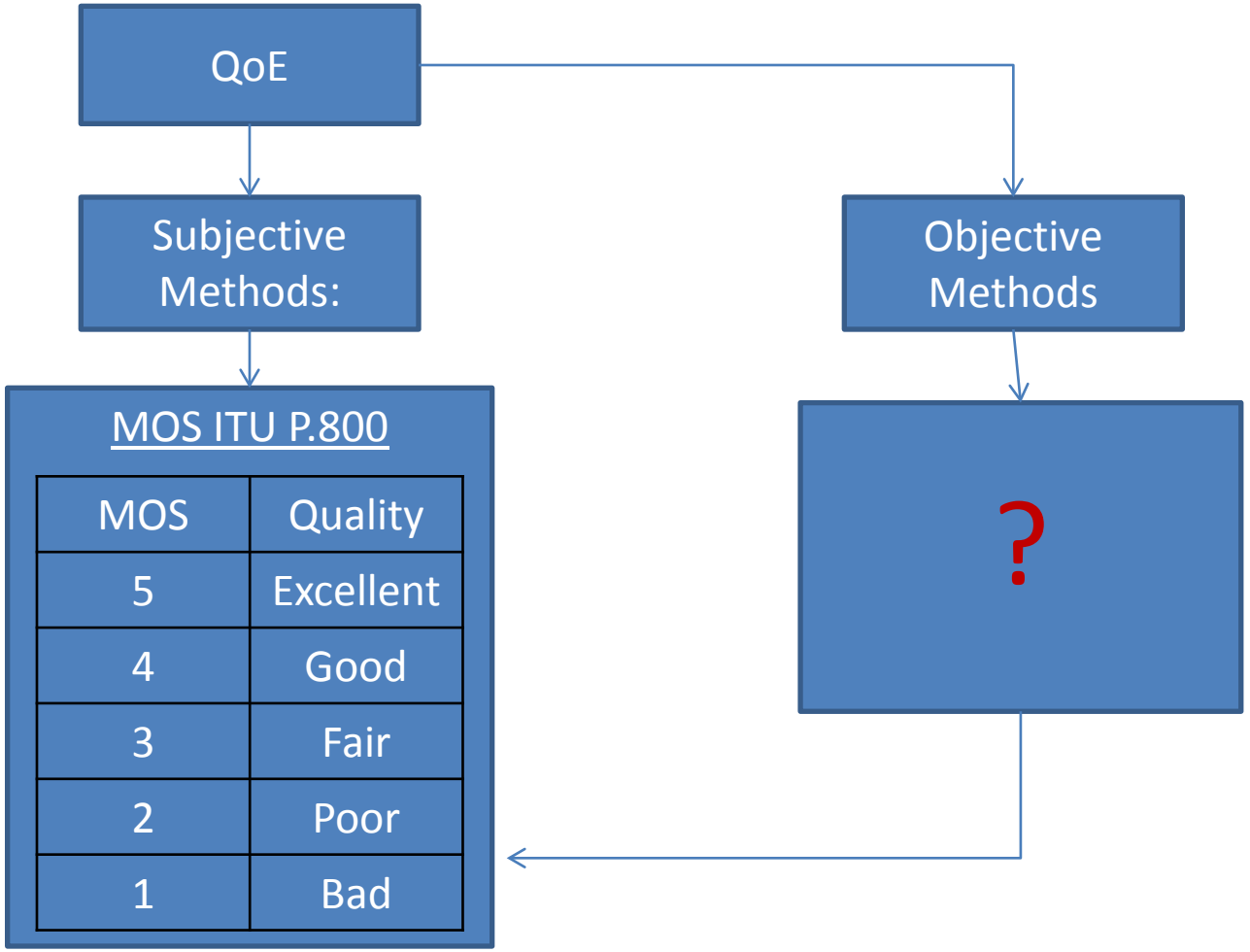
Several standardized recommendations, among which

- ITU-T P.800: fr telephony (and VoIP) applications
- ITU-R BT.500-13: for TV (and by extension video) applications
- ITU-T P.911: for audiovisual applications (P.910for the video modality)
- ITU-T P.920: interactive methods for audiovisual applications
- ITU-T P.1301: audio and audiovisual assessment for multiparty telemeetings
- ITU-T P.1501: for web browsing

Those are the most commonly used, cf

- http://www.itu.int/rec/T-REC-P/en for more.

Objective QoE Estimation

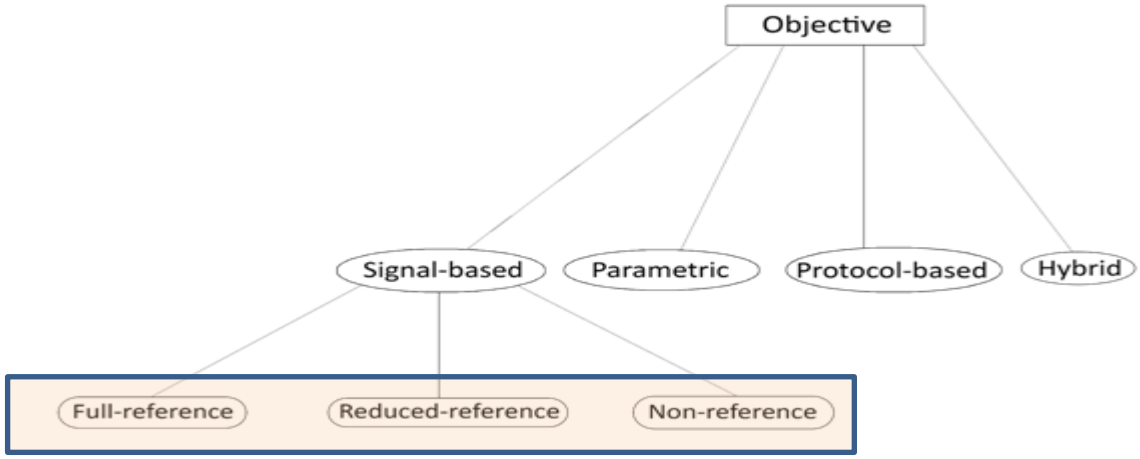


Objective QoE Estimation

A huge number of objective methods in the literature, many standardized ones, too:

- ITU-T P.863:Perceptual objective listening quality assessment, FR method for voice applications
- ITU-T G.107: E-model, NR parametric model for dimensioning in voice applications
- ITU-T P.563: NR signal based method for voice applications
- ITU-T J.247: FR method for video quality estimation, low-res, able to cope with losses during transmission
- ITU-T J.341: FR method for HD video, can cope with losses and freezes of up to 2s.
- ITU-T P.1201: NR parametric method for video streaming
- ITU-T P.1202: NR parametric method for video streaming, bitstream-based

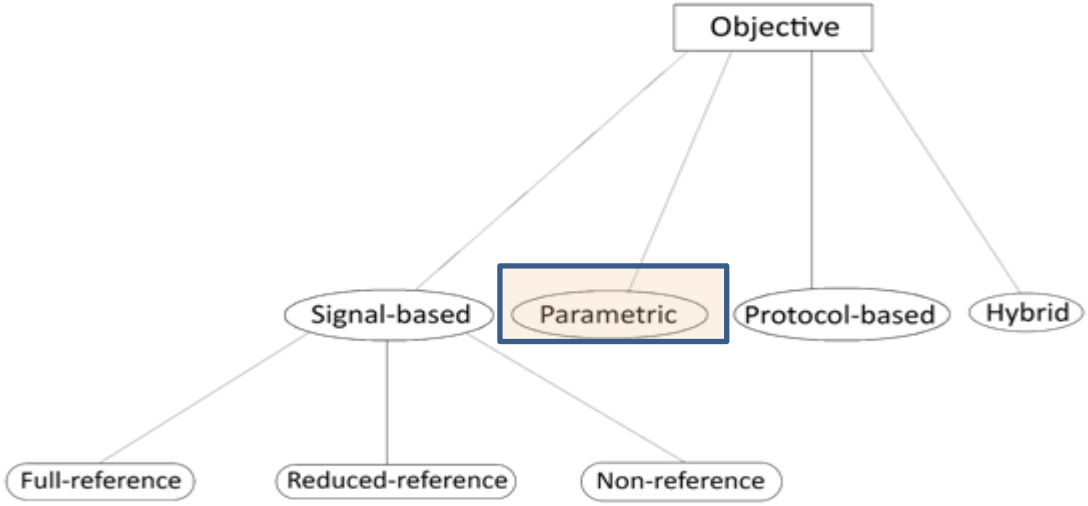
QoE Estimation – Objective methods



A first classification:

- Full-reference (FR): compare the degraded signal to the original one
- Reduced-reference (NR): use features of the original signal in the comparison
- No-reference (NR): do not rely at all on the original signal

QoE Estimation – Objective methods



Parametric models:

- Use of mathematical models to translate network parameters to QoE

QoE - other challenges

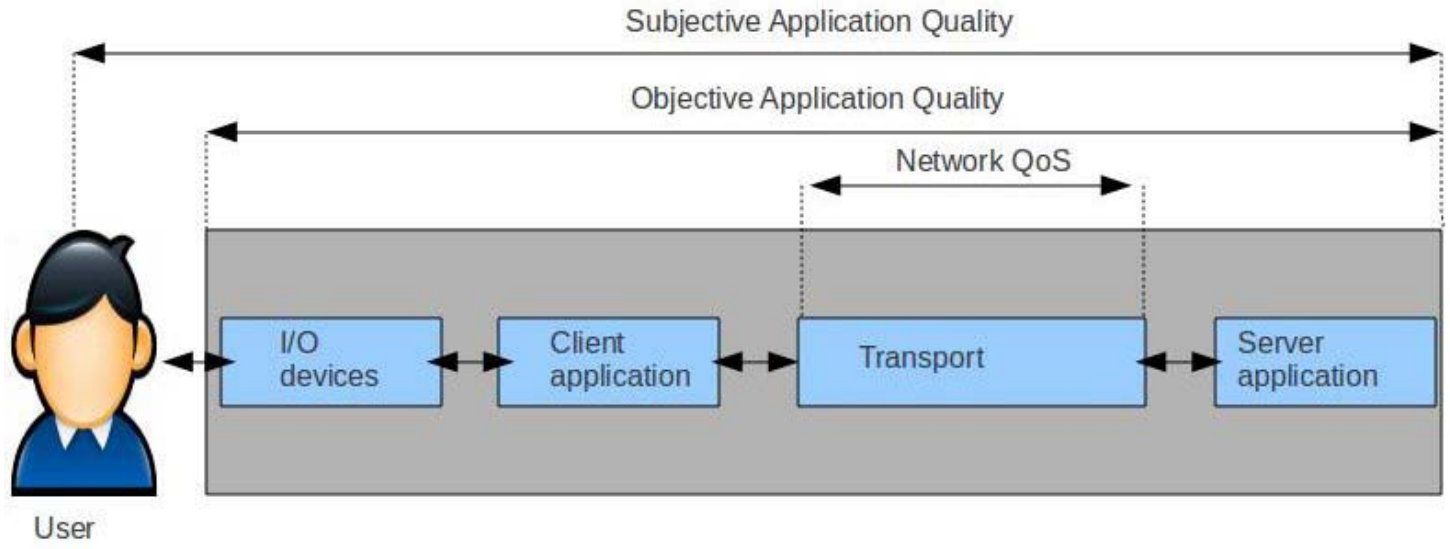
- **QoE monitoring**
  - Find user-transparent and passive ways to feed QoE measures back to the core network
- **QoE management**
  - How QoE variations can drive the resource, interference and mobility management?

QoS - QoE relation

QoS - QoE relation

- QoS
- From network perspective
  - **delay,**
  - **jitter,**
  - **packet loss,**
  - **throughput…**

- QoE
  - Objective estimation of what is provided to the end-user
  - Subjective service perception from the end-user:
    - **application specific features**
    - **Environmental etc..**



QoS - QoE relation: the IQX Hypothesis

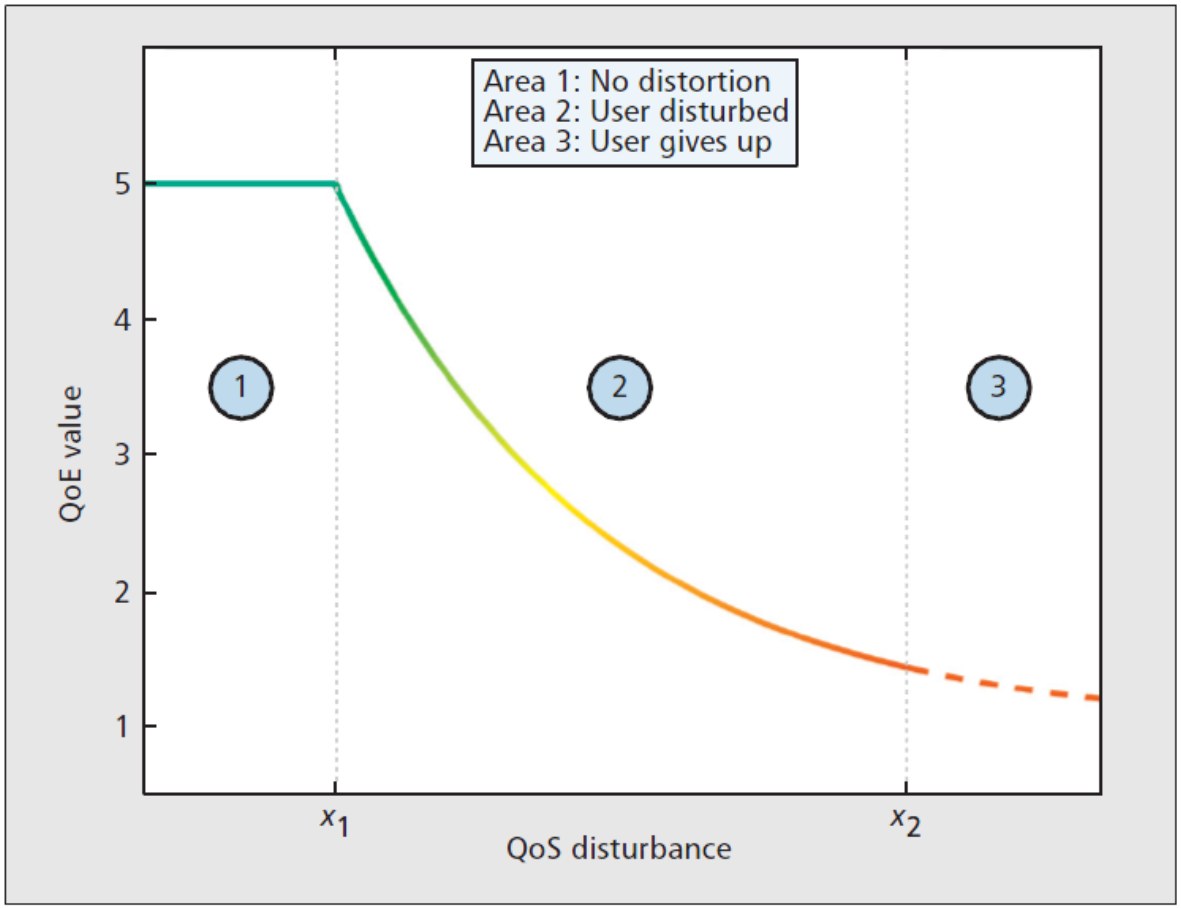
The subjective sensibility of the QoE is more pronounced the higher this experienced quality is.

- If the QoE is very high, a small disturbance will strongly decrease the QoE.
- if the QoE is already low, a further disturbance is not perceived significantly.

Example

This relationship can be motivated considering a restaurant QoE: If we dined in a five-star restaurant, a single spot on the clean white tablecloth would strongly disturb the atmosphere. The same incident would go unnoticed in a simple tavern.

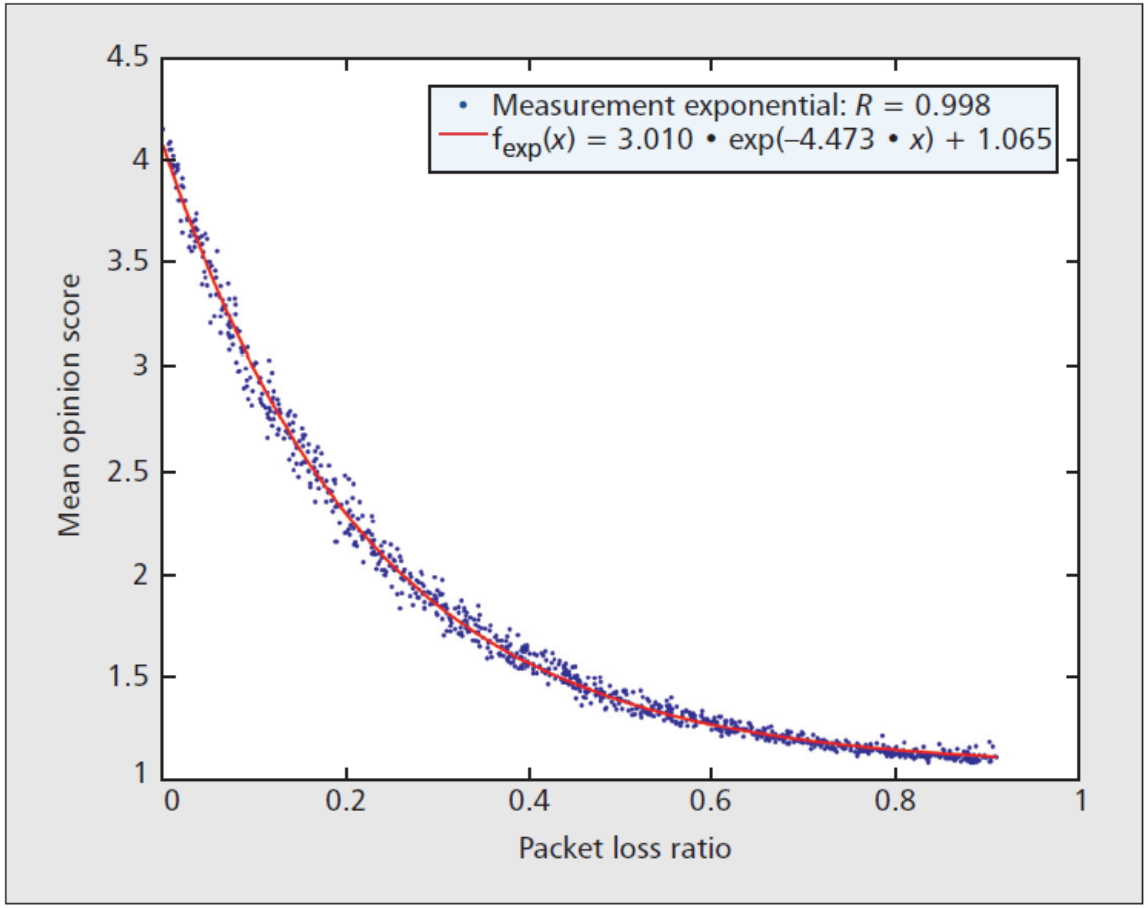
QoS - QoE relation: the IQX Hypothesis



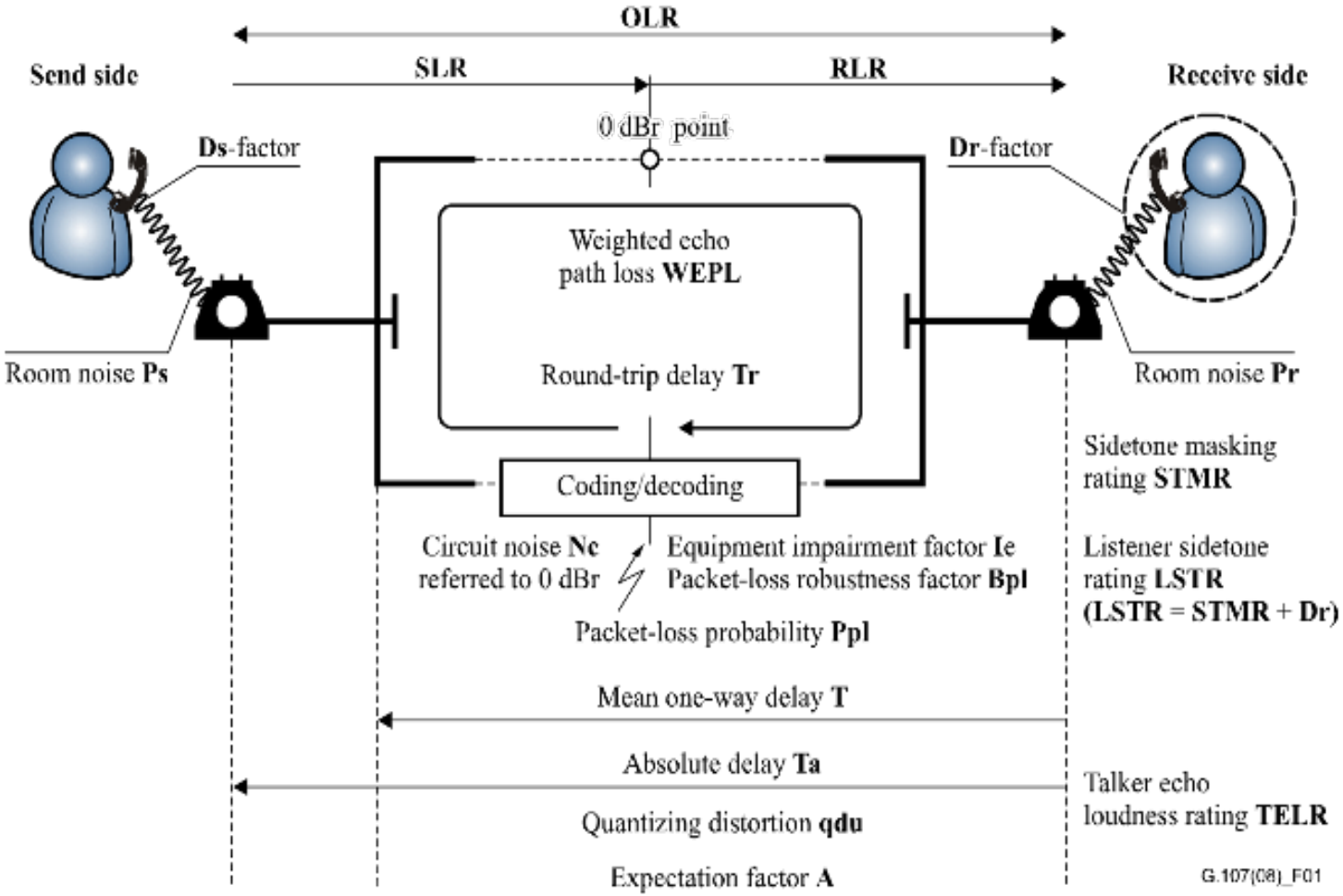
$$\frac{\partial QoE}{\partial QoS} \sim -\left(QoE - \gamma\right).$$

$$QoE = \alpha \cdot e^{-\beta \cdot QoS} + \gamma$$

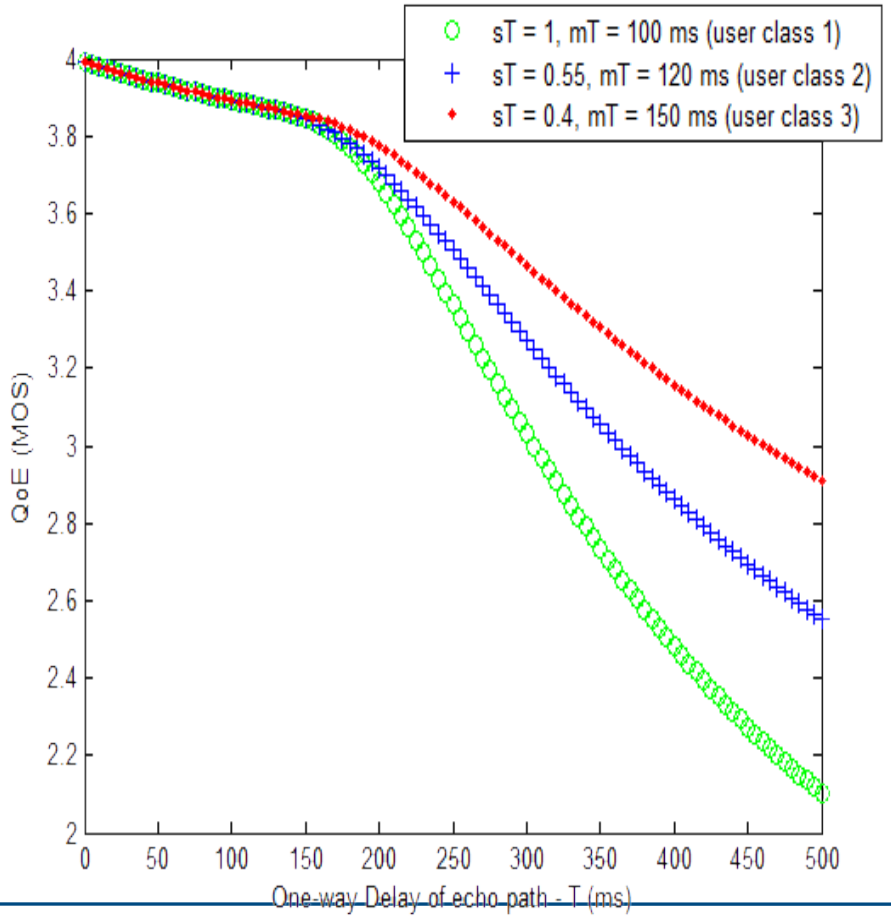
QoS - QoE relation: the IQX Hypothesis
MOS vs Packet loss



QoE estimation for VoIP

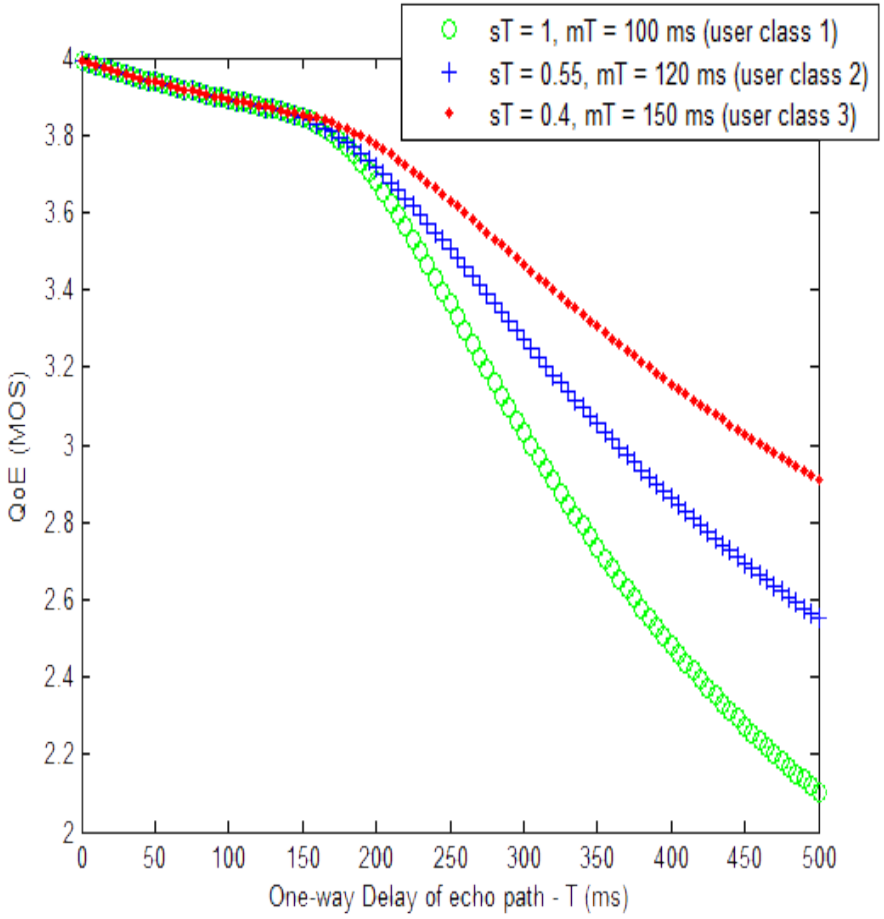

OLR
Send side
SLR
RLR
Receive side
0 dBr point
Ds-factor
Dr-factor
Weighted echo
path loss WEPL
Round-trip delay Tr
Room noise Ps
Room noise Pr
Coding/decoding
Sidetone masking
rating STMR
Circuit noise Ne
referred to 0 dBr
Equipment impairment factor Ie
Packet-loss robustness factor Bpl
Listener sidetone
rating LSTR
(LSTR = STMR + Dr)
Packet-loss probability Ppl
Mean one-way delay T
Absolute delay Ta
Talker echo
loudness rating TELR
Quantizing distortion qdu
Expectation factor A
G.107(08)_F01

Χρήση E-model για τη μελέτη της σχέσης QoE-χρόνος μέσης καθυστέρησης σύνδεσης T



Τάξη ευαισθησίας καθυστέρησης	sT	mT	Περίπτωση χρήσης
Τυχαία	1	100	Εφαρμόσιμο σε όλους τους τύπους τηλεφωνικής συνομιλίας Άγνωστες ομάδες χρηστών και απαιτήσεις καθυστερήσεων
Χαμηλή	0.55	120	Περιπτώσεις χρηστών με χαμηλή ευαισθησία στις καθυστερήσεις
Πολύ χαμηλή	0.4	150	Περιπτώσεις χρηστών με πολύ χαμηλή ευαισθησία στις καθυστερήσεις

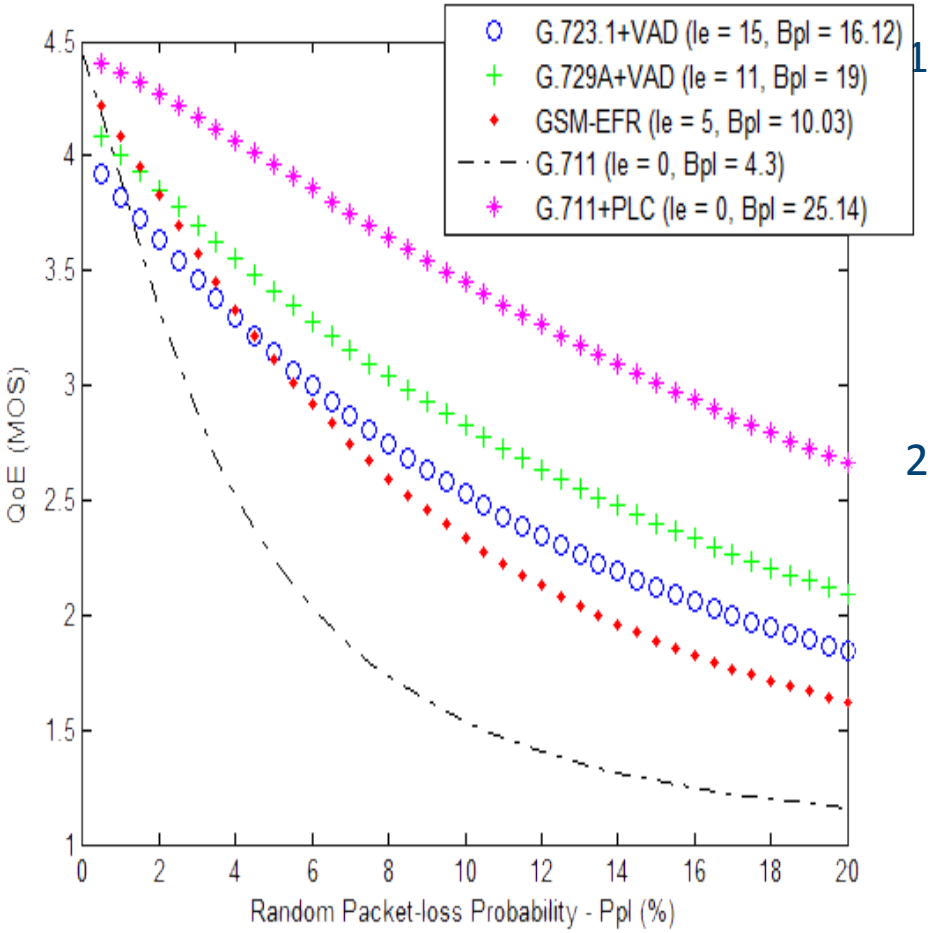
Χρήση E-model για τη μελέτη της σχέσης QoE-χρόνος μέσης καθυστέρησης σύνδεσης T



1. Ο τύπος του χρήστη διαδραματίζει ενεργό ρόλο όταν οι καθυστερήσεις υπερβαίνουν τα 150 ms

2. Ο τύπος του χρήστη διαφοροποιεί το ρυθμό πτώσης της QoE καθώς αυξάνουν οι καθυστερήσεις, αναδεικνύοντας την σημασία της ένταξης υποκειμενικών παραμέτρων στην εκτίμηση του QoE.

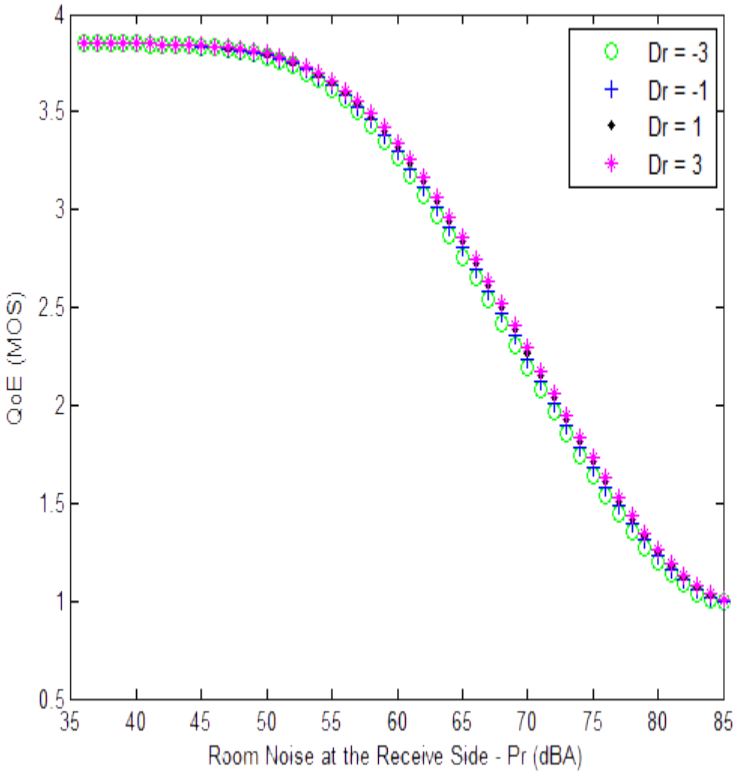
Χρήση E-model για τη μελέτη της σχέσης QoE-ποσοστό χαμένων πακέτων

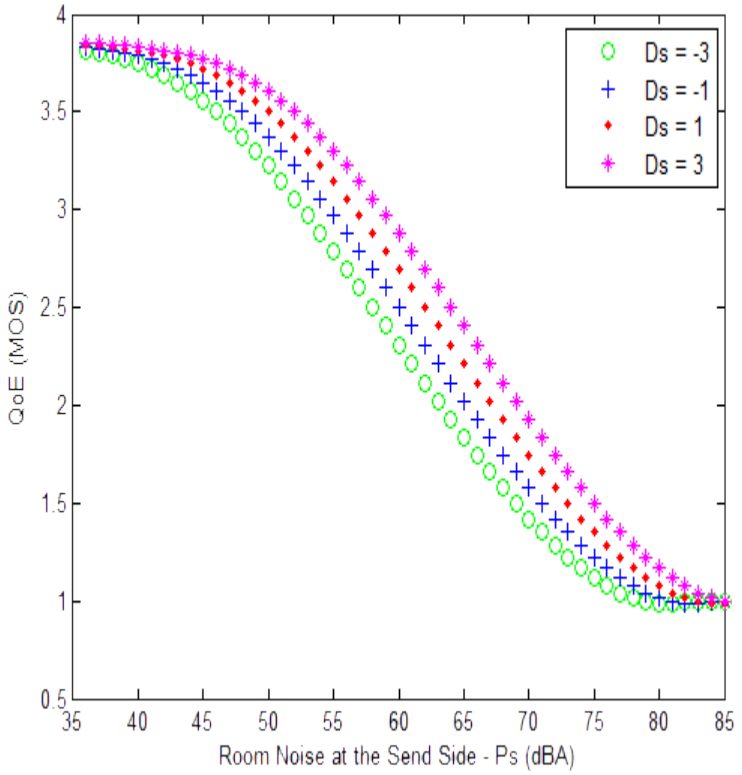


1. Η καλή ποιότητα του εξοπλισμού του κωδικοποιητή/αποκωδικοποιητή (Ie) ομιλίας έχει ως αποτέλεσμα την επίτευξη μεγαλύτερων τιμών QoE ανεξάρτητα από το ρυθμό απώλειας πακέτων.

2. Η ευρωστία του κωδικοποιητή/ αποκωδικοποιητή ομιλίας (Bpl) επιδρά σημαντικά στον ρυθμό με τον οποίο μειώνεται η ποιότητα εμπειρίας καθώς αυξάνεται το ποσοστό χαμένων πακέτων.

Χρήση E-model για τη μελέτη της σχέσης του QoE με τα περιβάλλοντα θορύβου παραλήπτη (P_r) και αποστολέα (P_s)



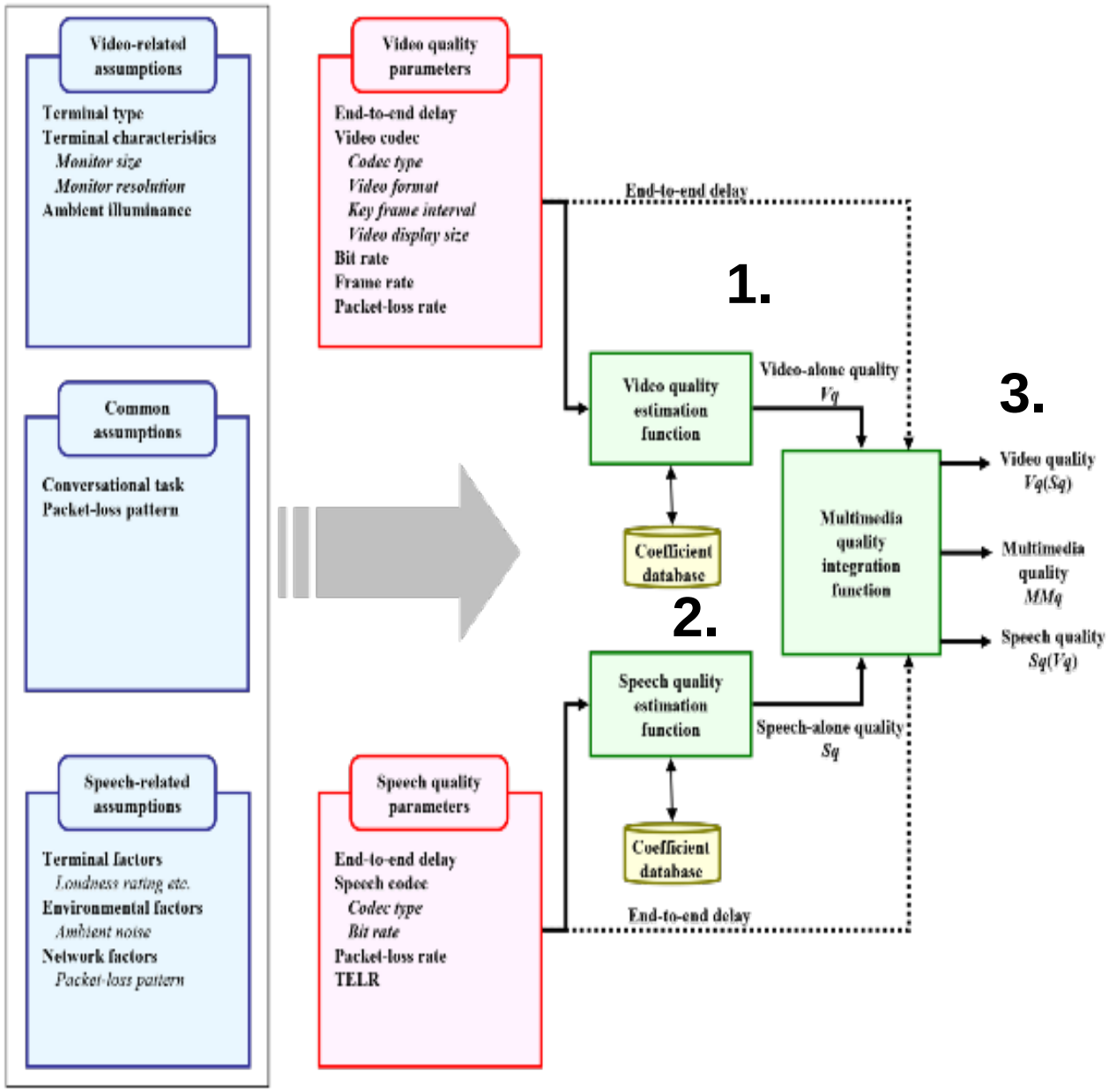


Η συσκευή ομιλίας του αποστολέα διαδραματίζει σημαντικότερο ρόλο σε σχέση με την συσκευή του παραλήπτη στην διαμόρφωση του QoE, αφού τυχόν αστοχίες/υποβαθμίσεις πολλαπλασιάζονται διαδιδόμενες μέσα στο δίκτυο.

QoE estimation for Video

ITU-T G.1070

- Three functions:
  - Video assessment
  - Audio assessment
  - Multimedia assessment.


Video-related assumptions
Terminal type
Terminal characteristics
Monitor size
Monitor resolution
Ambient illuminance
Common assumptions
Conversational task
Packet-loss pattern
Speech-related assumptions
Terminal factors
Loudness rating etc.
Environmental factors
Ambient noise
Network factors
Packet-loss pattern
Video quality parameters
End-to-end delay
Video codec
Codec type
Video format
Key frame interval
Video display size
Bit rate
Frame rate
Packet-loss rate
Speech quality parameters
End-to-end delay
Speech codec
Codec type
Bit rate
Packet-loss rate
TELR
End-to-end delay
1.
Video quality estimation function
Video-alone quality
Vq
Coefficient database
2.
Speech quality estimation function
Speech-alone quality
Sq
Coefficient database
End-to-end delay
3.
Multimedia quality integration function
Video quality
Vq(Sq)
Multimedia quality
MMq
Speech quality
Sq(Vq)

ITU-T G.1070

- **1. Video assessment**

$$V_q = 1 + I_{coding} \cdot e^{-\frac{P_{plV}}{D_{P_{plV}}}}$$

$$I_{coding} = I_{Ofr} \cdot e^{-\frac{\left(\ln(F_{rV}) - \ln(O_{fr})\right)^2}{2D_{frV}{}^2}}$$

Υποβαθμίσεις λόγω κωδικοποίησης

$$D_{P_{plV}} = \nu_{10} + \nu_{11} \cdot e^{-\frac{F_{rV}}{\nu_8}} + \nu_{12} \cdot e^{-\frac{B_{rV}}{\nu_9}}$$

Βαθμός ευρωστίας βίντεο ως προς την απώλεια πακέτων

ITU-T G.1070

- **2. Audio assessment**

$$S_q = \begin{cases} 1, & \alpha\nu\ Q < 0 \\ 1 + 0.035Q + Q(Q-60)(100-Q)\cdot 7\cdot 10^{-6}, & \alpha\nu\ 0 < Q < 100 \\ 4.5, & \alpha\nu\ Q > 100 \end{cases}$$

$$Q = 93.193 - I_{dte} - I_{e-eff}$$

$$I_{dte} = \left[\frac{94.769 - R_e}{2} + \sqrt{\frac{(94.769 - R_e)^2}{4} + 100} - 1\right](1 - e^{-T_s})$$

Υποβαθμίσεις λόγω «ηχούς» του ομιλητή

$$I_{e-eff} = I_{es} + (95 - I_{es})\cdot\frac{P_{pls}}{P_{pls} + B_{pls}}$$

Υποβαθμίσεις λόγω εξοπλισμού

ITU-T G.1070

- **3. Multimedia assessment**

$$MM_q = m_1 \cdot MM_{SV} + m_2 \cdot MM_T + m_3 \cdot MM_{SV} \cdot MM_T + m_4$$

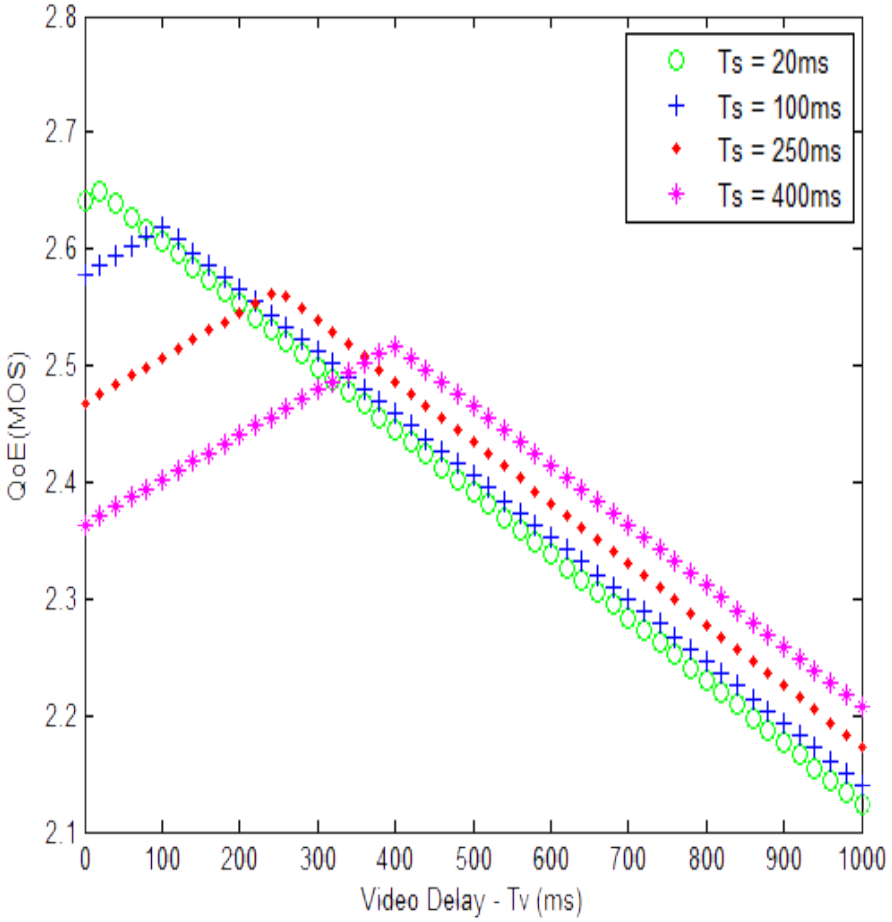
$$MM_{SV} = m_5 \cdot S_q + m_6 \cdot V_q + m_7 \cdot S_q \cdot V_q + m_8$$

$$MM_T = max\{AD + MS, 1\}$$

$$AD = m_9 \cdot (T_S + T_V) + m_{10}$$

$$MS = \begin{cases} min\{m_{11} \cdot (T_S - T_V) + m_{12}, 0\}, & \alpha\nu\ T_S > T_V \\ min\{m_{13} \cdot (T_V - T_S) + m_{14}, 0\}, & \alpha\nu\ T_V > T_S \end{cases}$$

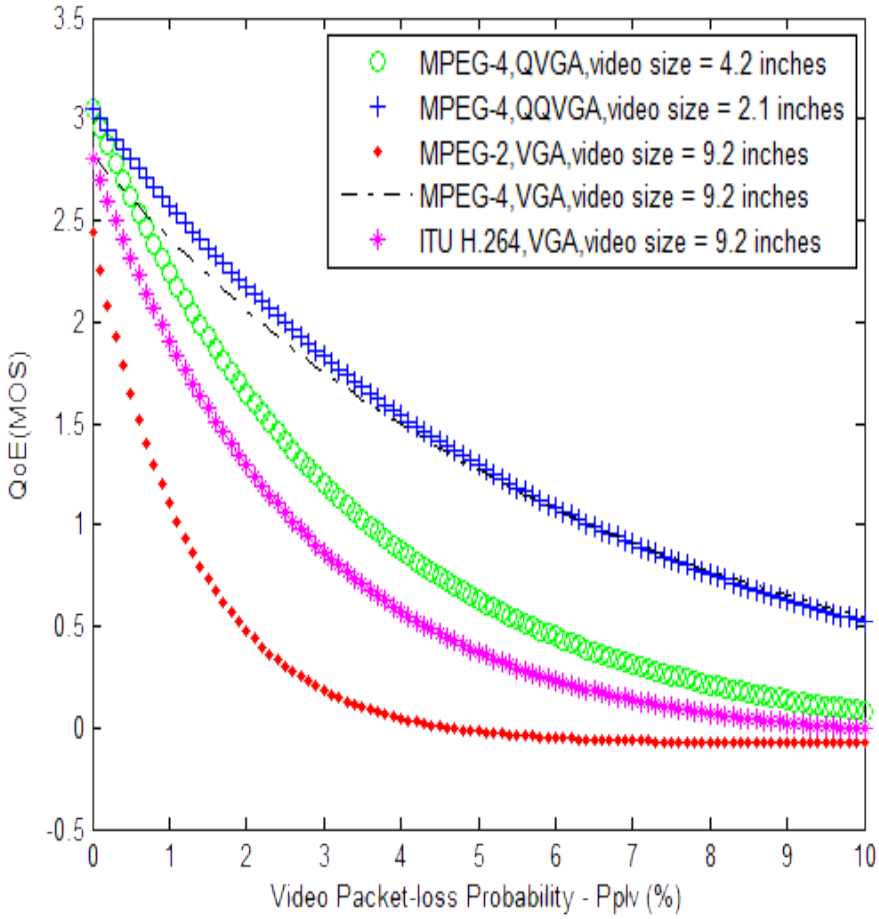
Χρήση G.1070 για τη μελέτη της σχέσης QoE-καθυστέρηση του σήματος βίντεο T_v



1. Οι παραπλήσιες τιμές καθυστερήσεων ομιλίας και βίντεο προσδίδουν τη βέλτιστη ποιότητα εμπειρίας, για κάθε μία περίπτωση συνθηκών δικτύου.

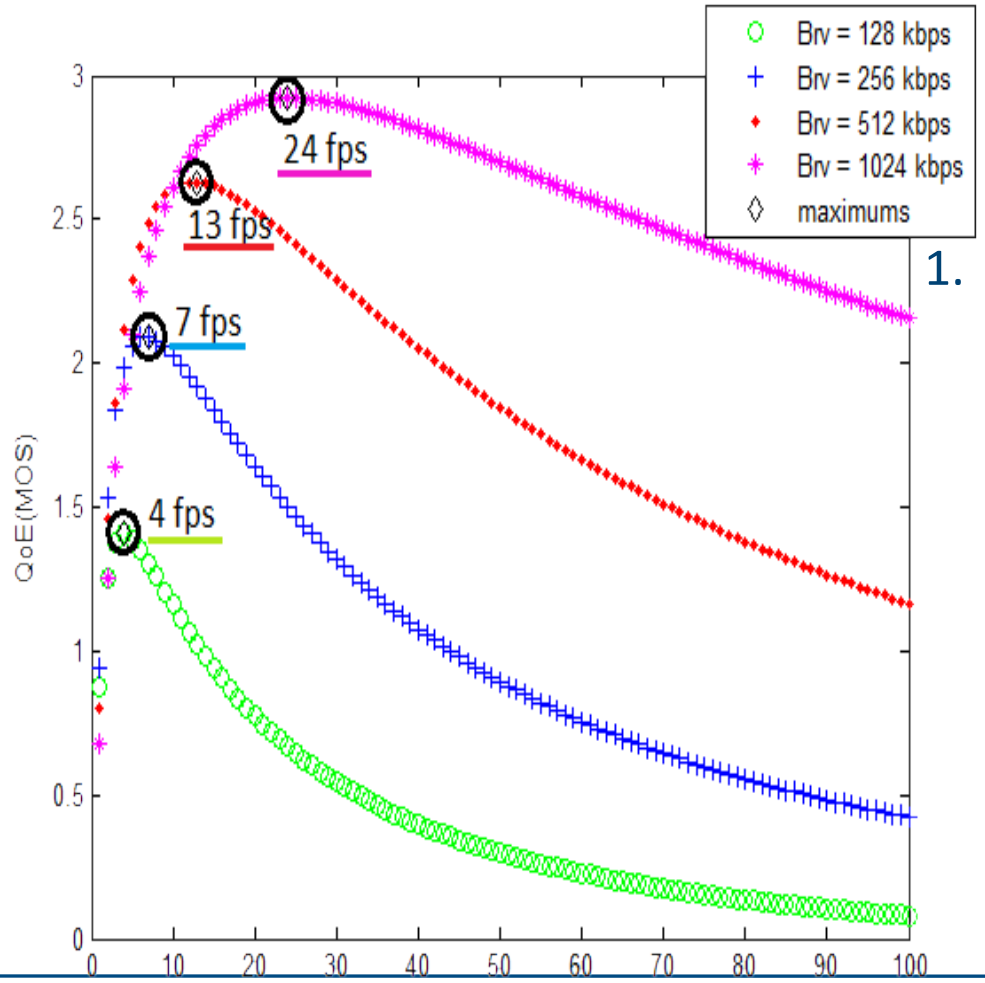
2. Απαιτείται συγχρονισμός εικόνας και ήχου

Χρήση G.1070 για τη μελέτη της σχέσης QoE-ποσοστό των χαμένων πακέτων βίντεο P_{plv}



1. Η ποιότητα εμπειρίας παρουσιάζει φθίνουσα εκθετική συμπεριφορά ως προς την απώλεια πακέτων, καθώς η δεύτερη αυξάνεται.
2. Ο τρόπος όμως με τον οποίο φθίνει η συνάρτηση εξαρτάται από τα χαρακτηριστικά του προβαλλόμενου βίντεο, όπως η κωδικοποίηση, η ανάλυση και η οθόνη προβολής.
3. Μεγάλο μέγεθος της οθόνης σπρώχνει όλη τη καμπύλη προς τα κάτω
4. Χειρότερη κωδικοποίηση δημιουργεί μεγαλύτερη κυρτότητα

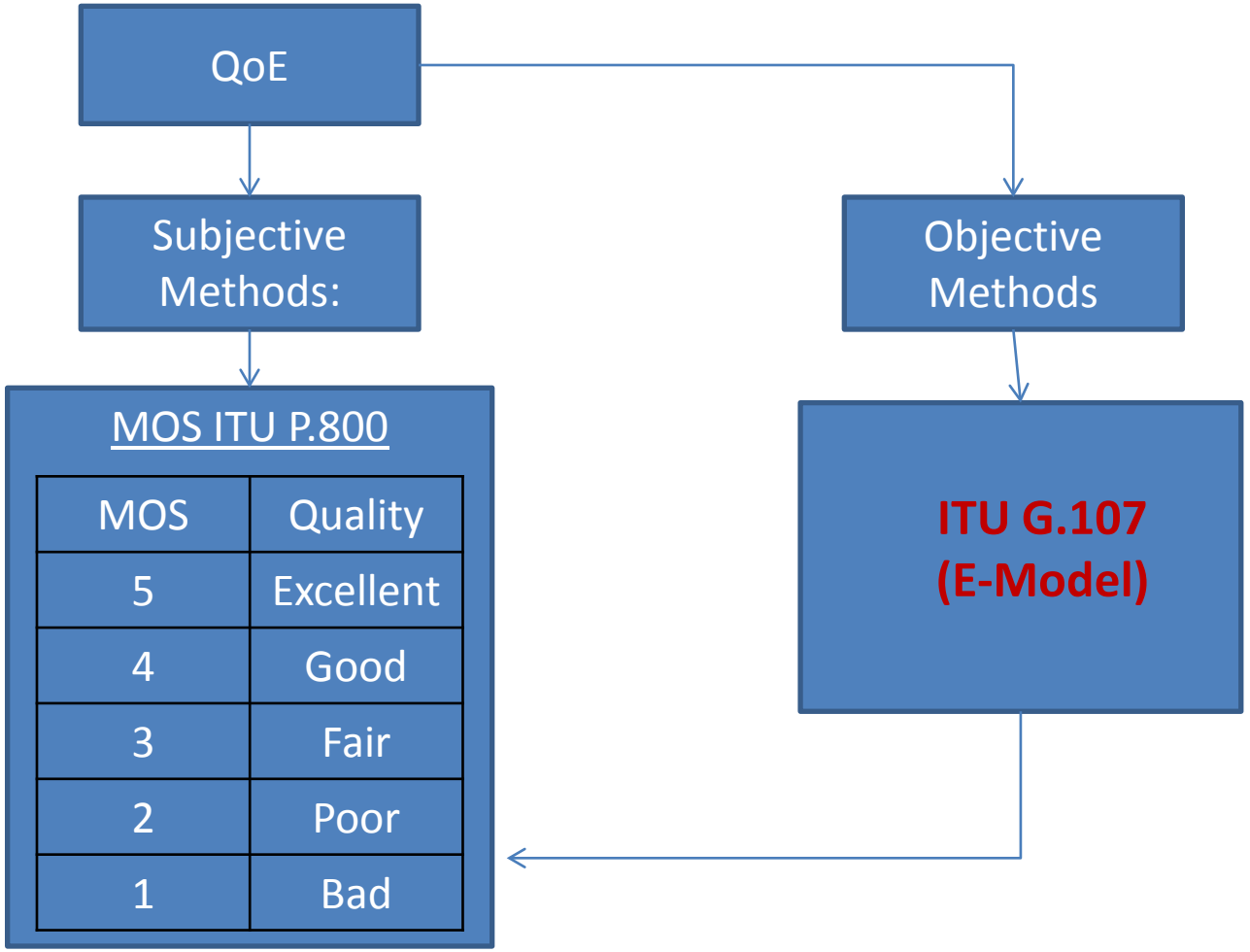
Χρήση G.1070 για τη μελέτη της σχέσης QoE-ρυθμό μετάδοσης πλαισίων F_{rv}



1. Υψηλή ποιότητα εμπειρίας απαιτεί σωστό συνδυασμό, μεγέθους πλαισίου και ρυθμού μετάδοσης πλαισίων για δεδομένη χωρητικότητα γραμμής μετάδοσής.

Example -1
Evaluating the impact of femtocell proliferation on VoIP QoE

QoE Estimation – Objective methods Voice Services



The E-model

- E-Model has been proposed by the ITU-T for measuring objectively the MOS of voice communications.
- E-model takes into account a variety of transmission impairments producing the so-called R factor (scales from 0 to 100) and then uses a mathematic formula to translate this factor to MOS values

$$R = R_0 = 94.2$$

$$R = R_0 - I_s - I_d - I_{ef}$$

The E-model

$$R = R_0 - I_s - I_d - I_{ef}$$

I_s : are impairments that are generated during the voice traveling into the network

I_d : are the delays introduced from end-to-end signal traveling

I_{ef} : are impairments introduced by the equipment

$$MOS = \begin{cases} 1 & if \quad R < 0, \\ 1 + 0.035R + R(R-60)(100-R)7 \cdot 10^{-6} & if \quad 0 \le R \le 100, \\ 4.5 & if \quad R > 100 \end{cases}$$

The E-model

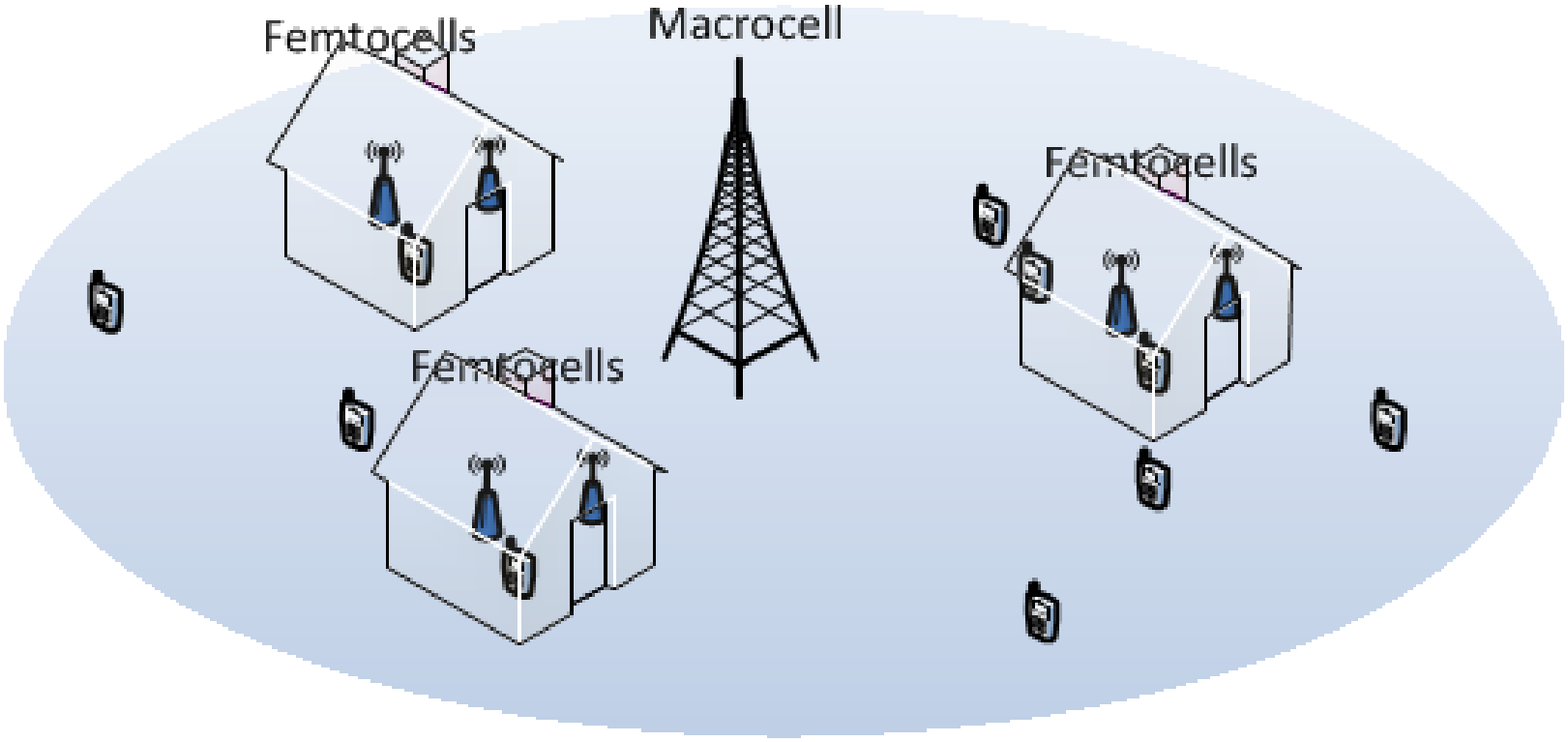
Focus on the impairments introduced by the wireless part of the network – (1) Packet loss and (2) Delay

$$I_{ef} = 11 + 40\ln(1 + 10p)$$

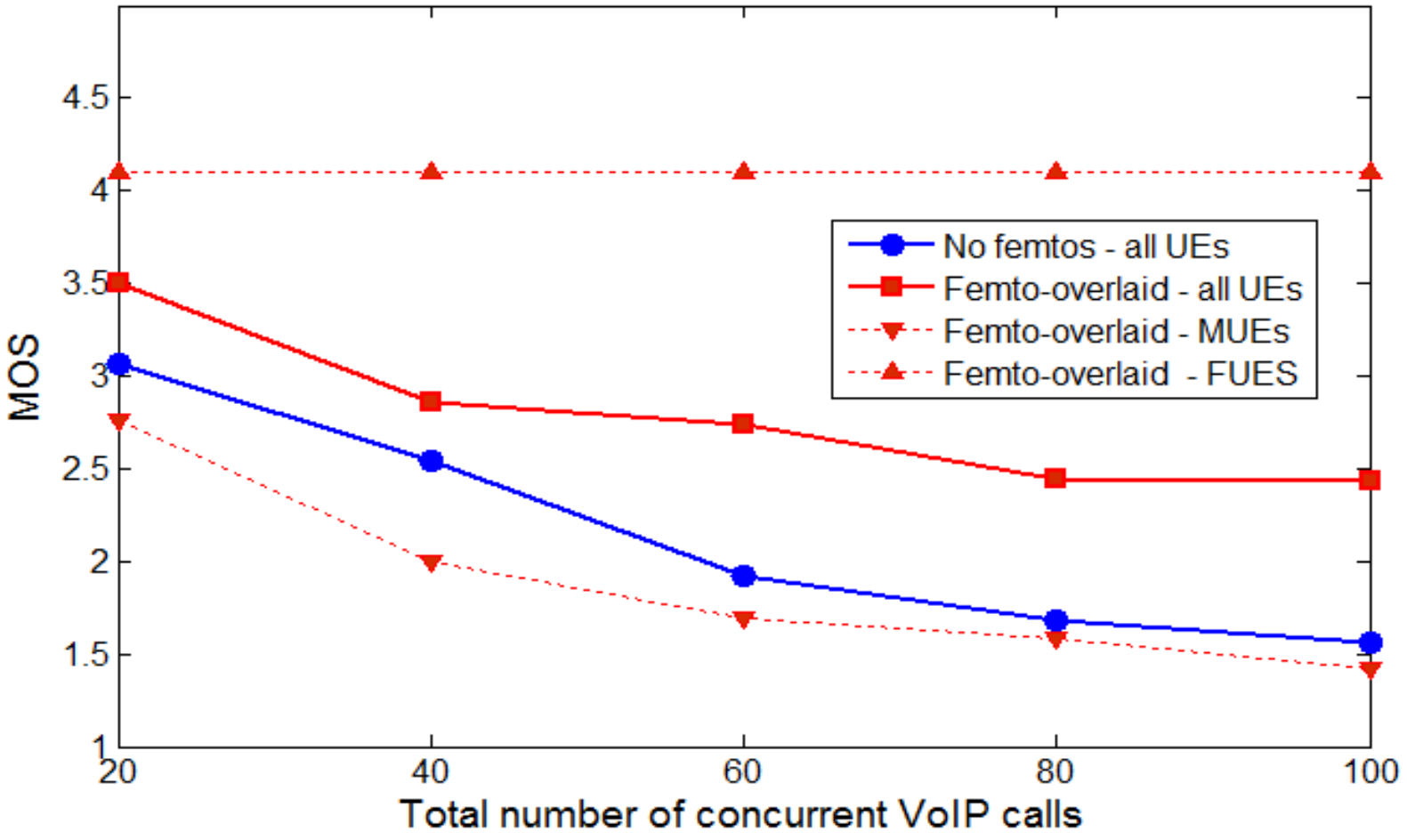
$$I_d = 0.024d + 0.11(d - 177.3)H(d - 177.3)$$

$$H(x) = \begin{cases} 0 & for\ x < 0 \\ 1 & for\ x \geq 0 \end{cases}$$

Femto-overlaid LTE-A network



Results


MOS
4.5
4
3.5
3
2.5
2
1.5
1
20
40
60
80
100
Total number of concurrent VoIP calls
No femtos - all UEs
Femto-overlaid - all UEs
Femto-overlaid - MUEs
Femto-overlaid - FUES

Example -2

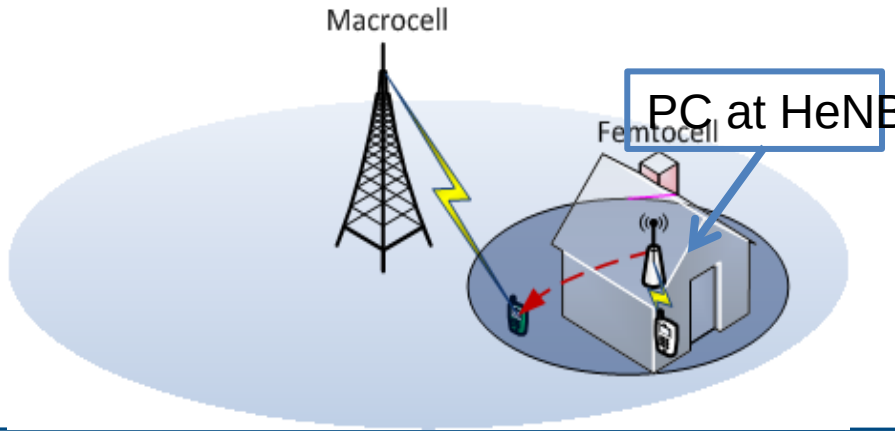
QoE-aware Power Control

QoE-aware Power Control

- **3GPP Altruistic Power Control (PC)**
- Extension of the 3GPP approach

$$P_{Tx} = median(P_{eNB-HeNB} + PL_{HeNB-MUE}, P_{max}, P_{min})$$

- P_{Tx} : transmit power of the interference aggressor
- $P_{eNB-HeNB}$: received power from the eNB (serves the victim MUE),
- $PL_{HeNB-MUE}$: pathloss between the HeNB and the victim MUE.



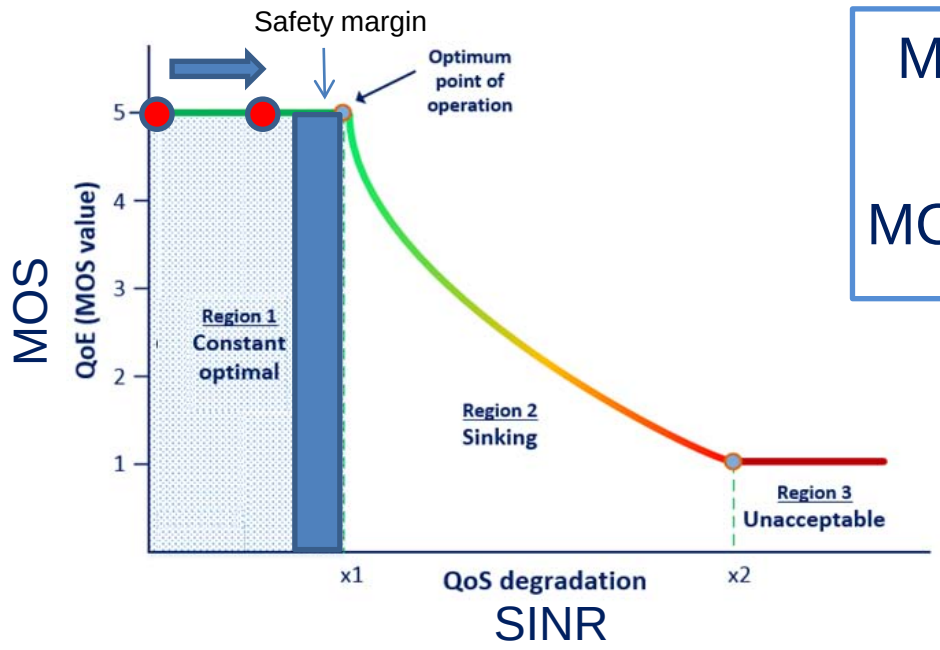
QoE-aware Power Control

Proposed Scheme (be more altruistic!)

- Enhance the 3GPP Power Control IM scheme

$$P_{Tx} = median(P_{eNB-HeNB} + PL_{HeNB-MUE}, P_{max}, P_{min})$$

$$P'_{Tx} = max(P_{min}, P_{Tx(3GPP)} - \Delta P_{COR,opt}), \quad if\ \Delta P_{COR,opt} > 0$$



Monitoring

⇩ (Through E-Model)

MOS *Vs* SINR

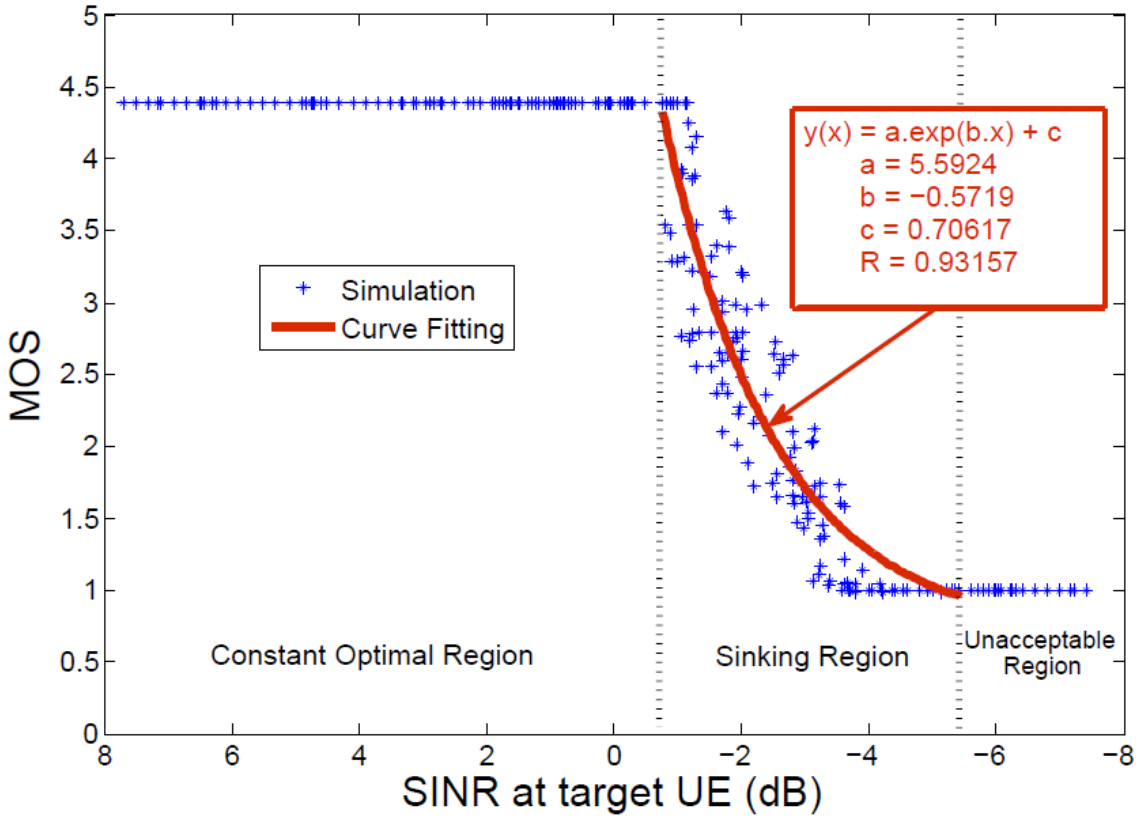
SINR in COR

⇩

$\Delta P_{COR,opt}$

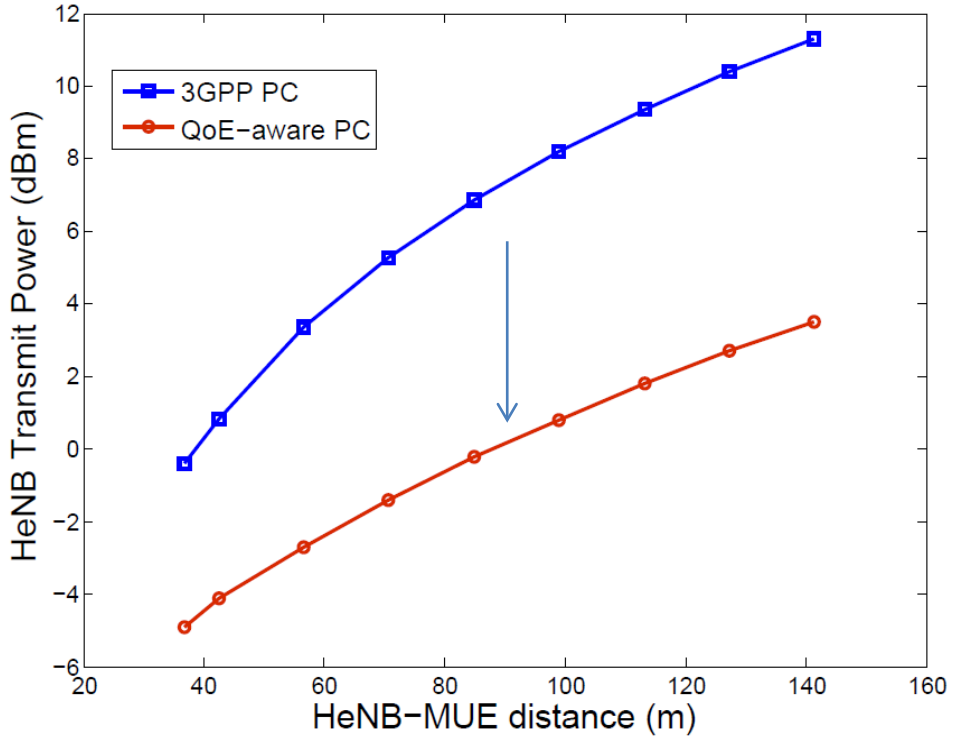
QoE-aware Power Control

Result : Monitoring phase



QoE-aware Power Control

Result: HeNB Transmit power



Indirect interference mitigation and energy saving

Thank you!