Quality of Experience

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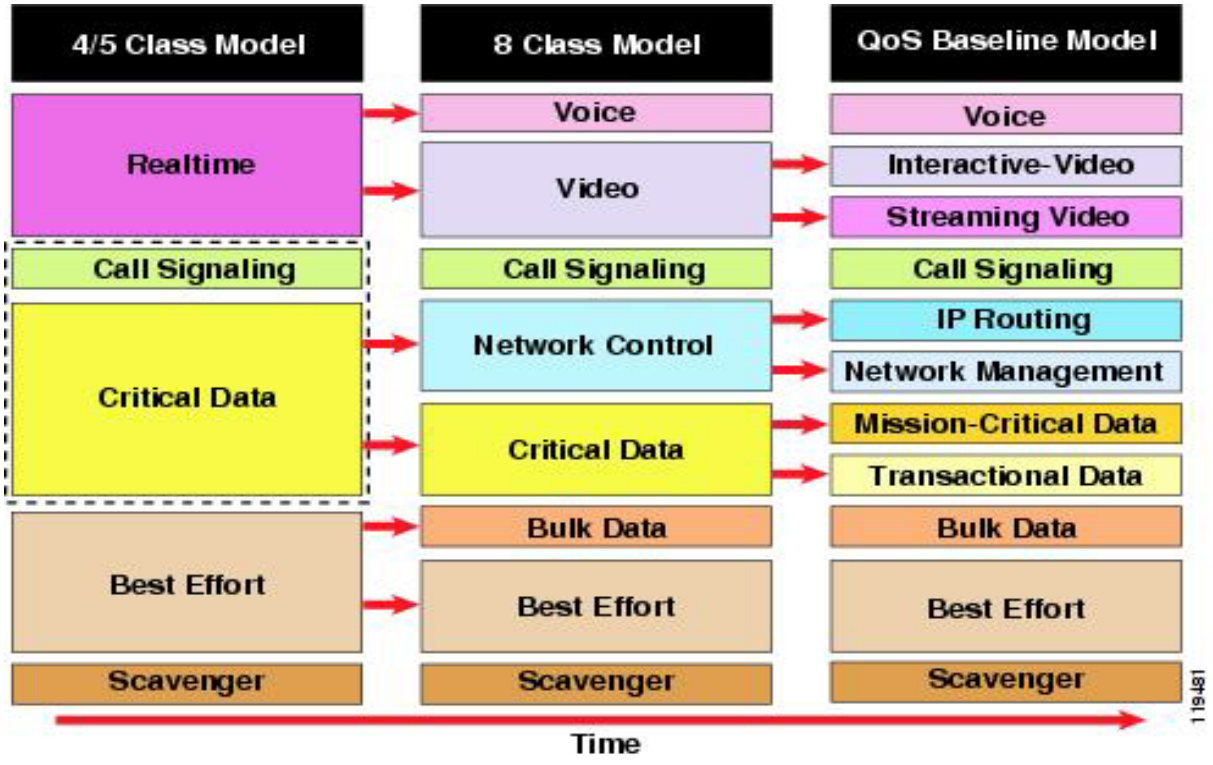
Quality of Service (QoS)

- 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

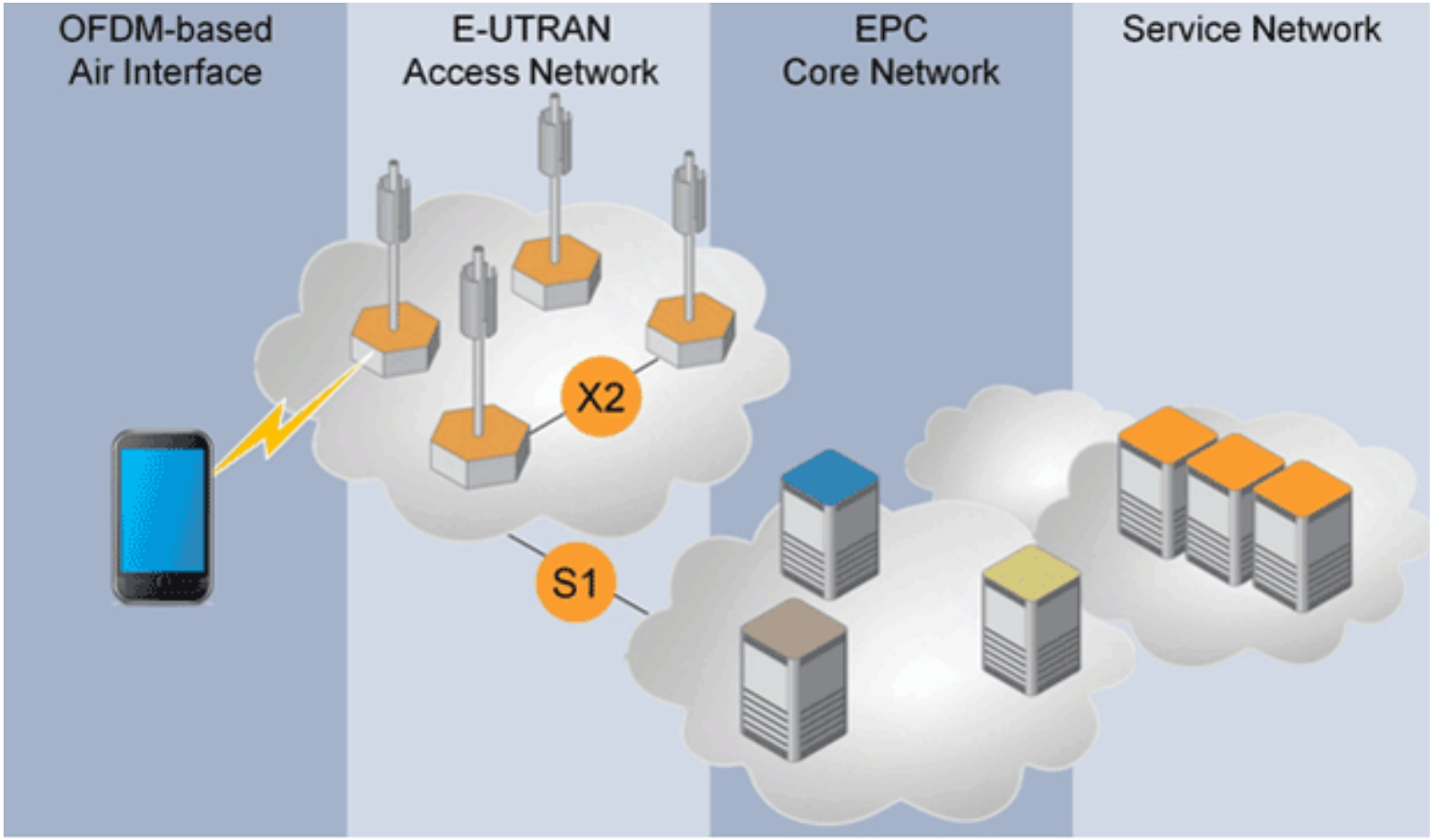
Quality of Service (QoS)

- 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



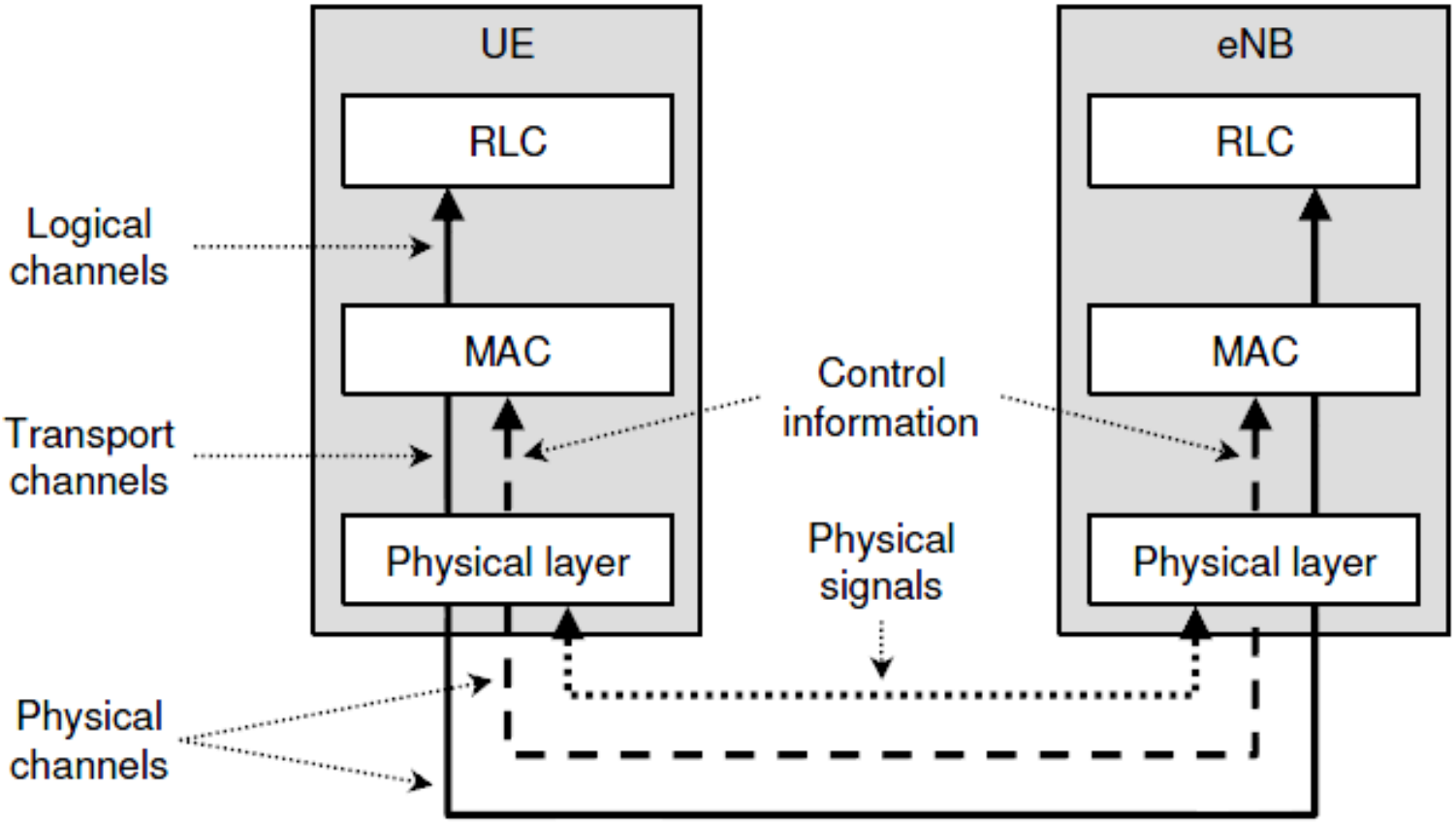
LTE Architecture

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.**

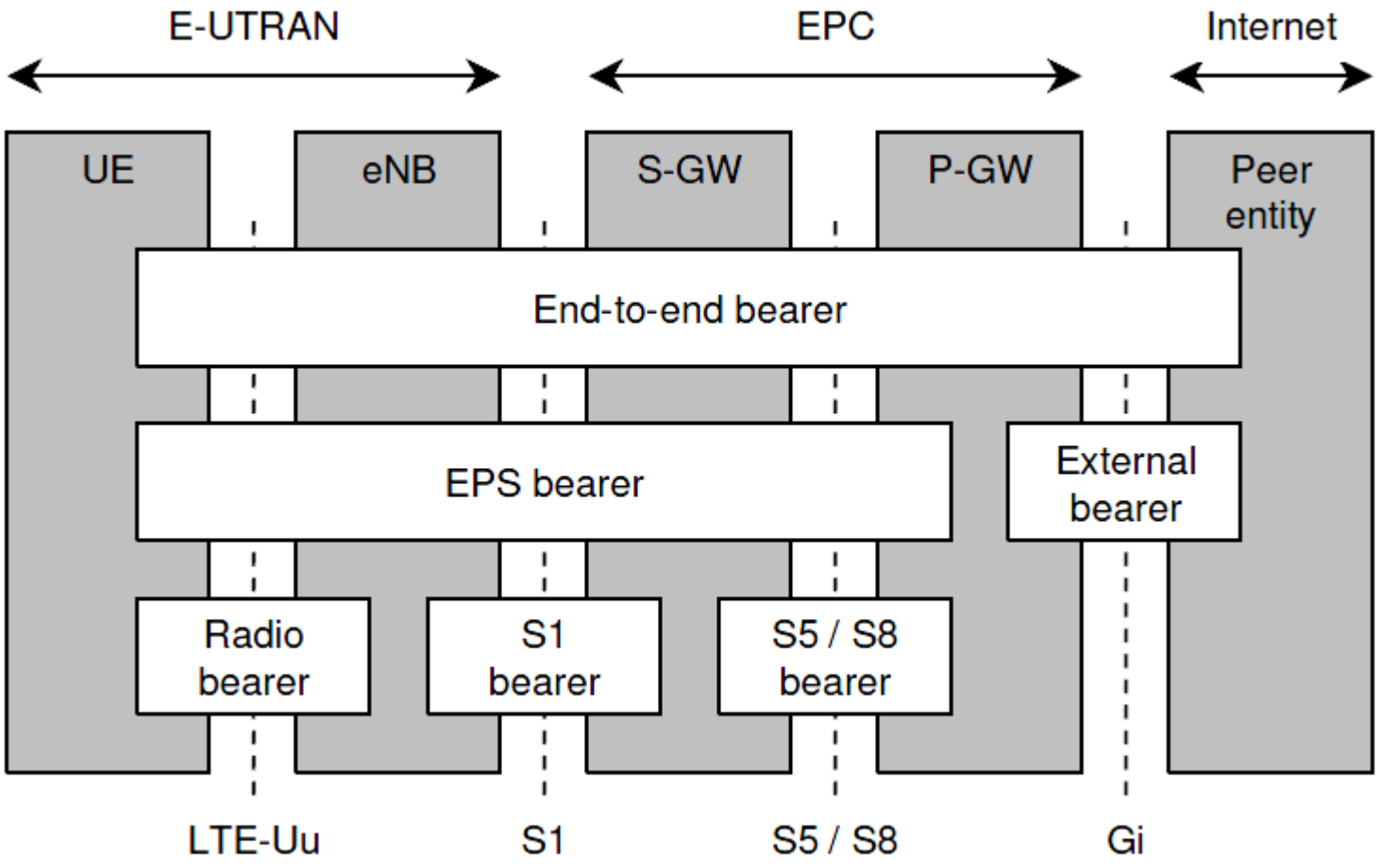
QoS in LTE/LTE-A

- Channels



QoS in LTE/LTE-A

- 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

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

The question which arises is whether guaranteeing QoS is enough?

QoE - Definition

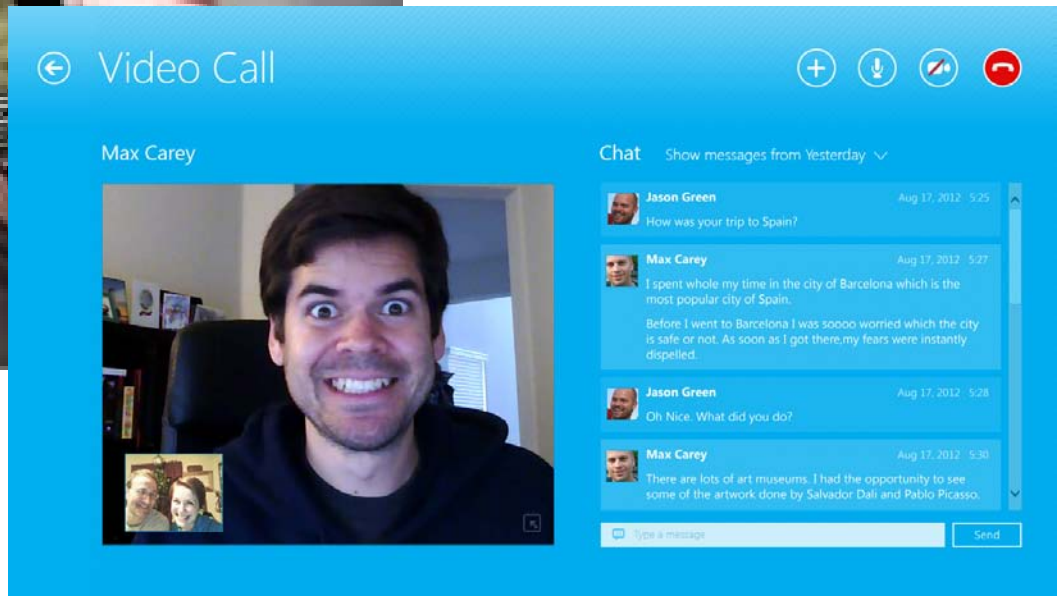
- What is QoE?
  - The definition can be found in ITU-T Rec. P.10 (formerly G.100): "the overall acceptability of an application or service, as perceived subjectively by the end-user"
  - Practically,

QoE = the level of end-user's satisfaction

- QoE is
  - the Objective estimation of what is provided to the end-user, combined with
  - the Subjective service perception from the end-user
    - application specific features
    - environmental, psychological, and sociological factors
    - user's profile
    - terminal type
    - pricing policy

QoE - Dependencies

- Application specific features



QoE - Dependencies

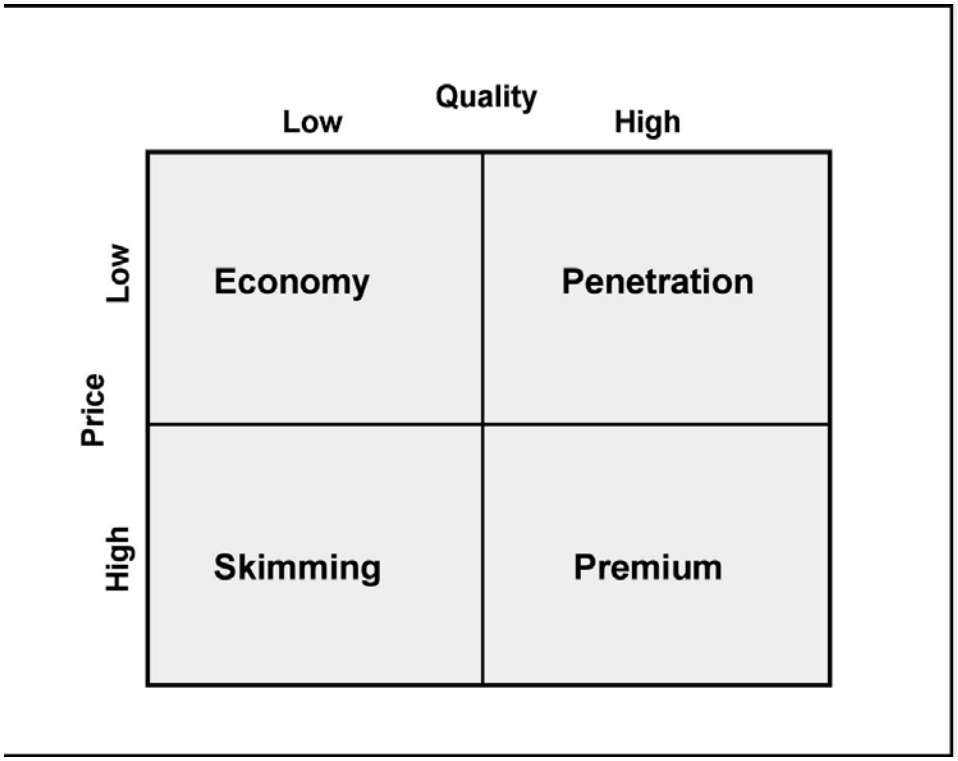
- Terminal type

QoE - Dependencies

- Content

QoE - Dependencies

- Pricing policy

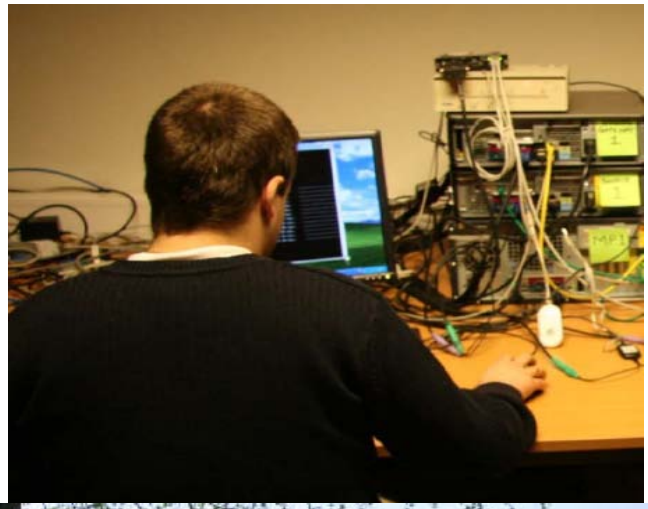


QoE - Dependencies

- Sociological factors

QoE - Dependencies

- Environmental parameters

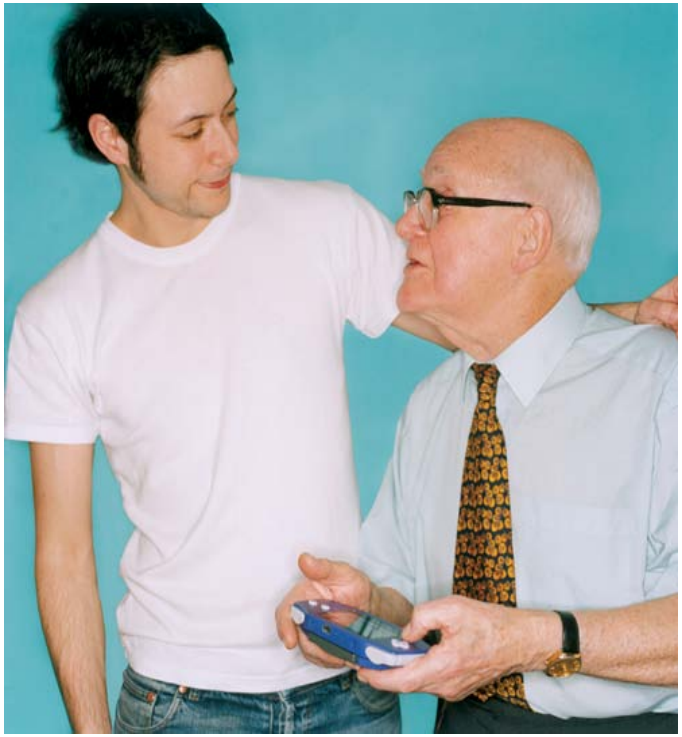


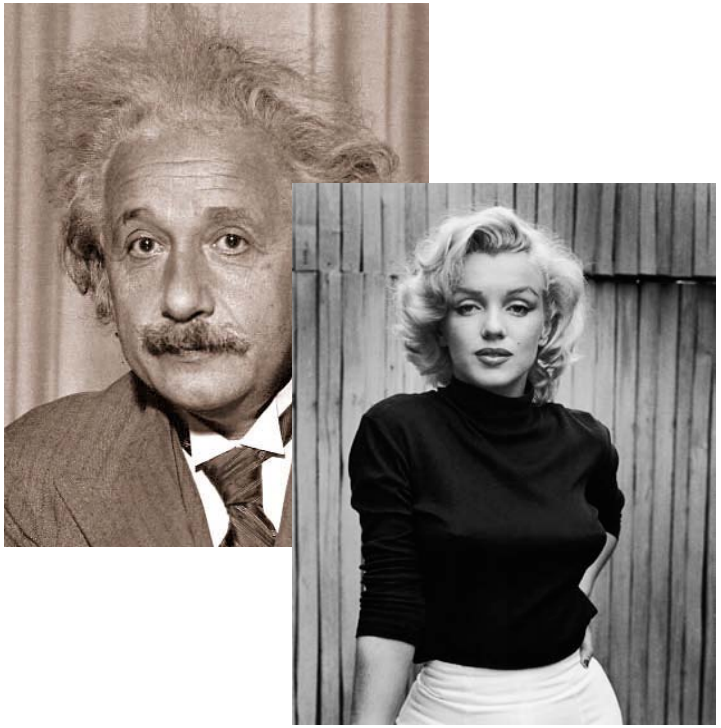
QoE - Dependencies

- Psychological factors

QoE - Dependencies

- User's profile





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

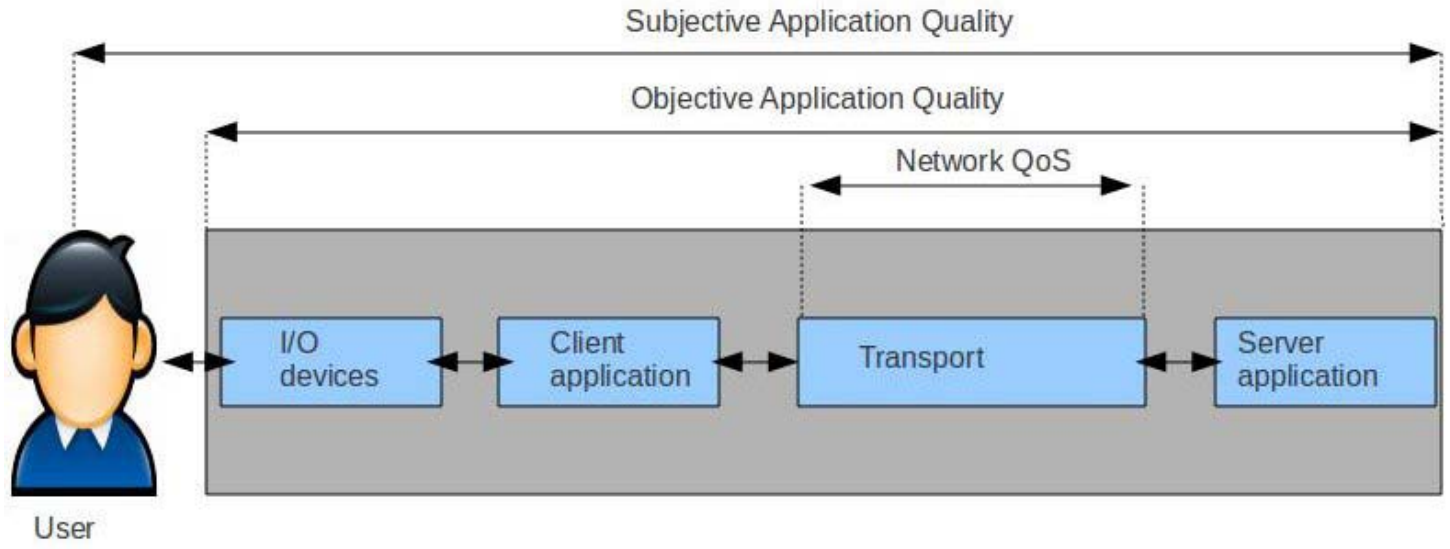
- What are the main challenges in studying QoE?
  - **QoE estimation**
    - Can be based on subjective or objective methods. How to assure the reliability of subjective methods and how to map objective parameters to QoE?
  - **QoE monitoring**
    - Find user-transparent and passive ways to feed QoE measures back to the core network
  - **QoE management**
    - How QoE variations can drive the resource, interference and mobility management?

QoS - QoE relation

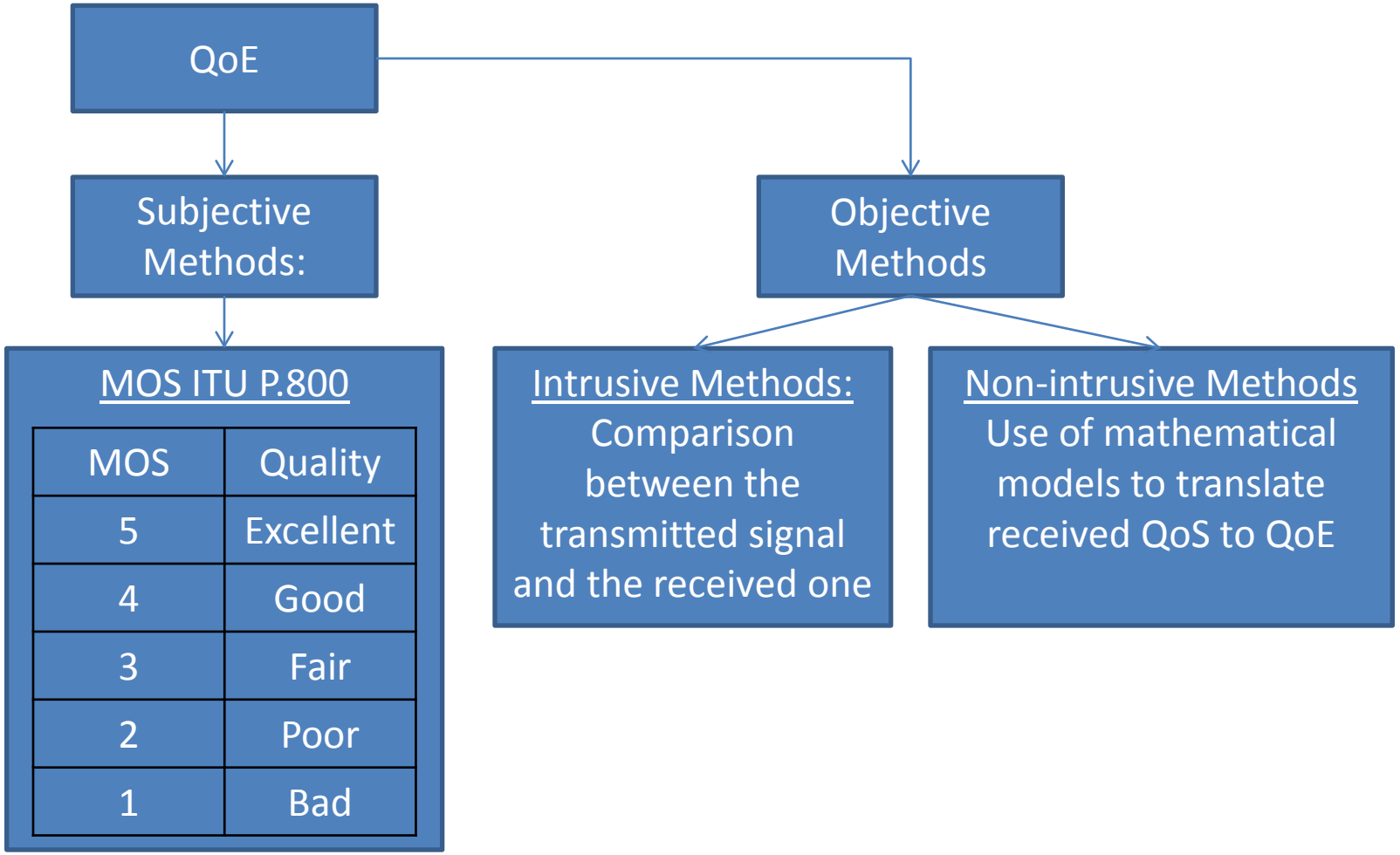
QoS - QoE relation

- 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..**



QoE Estimation



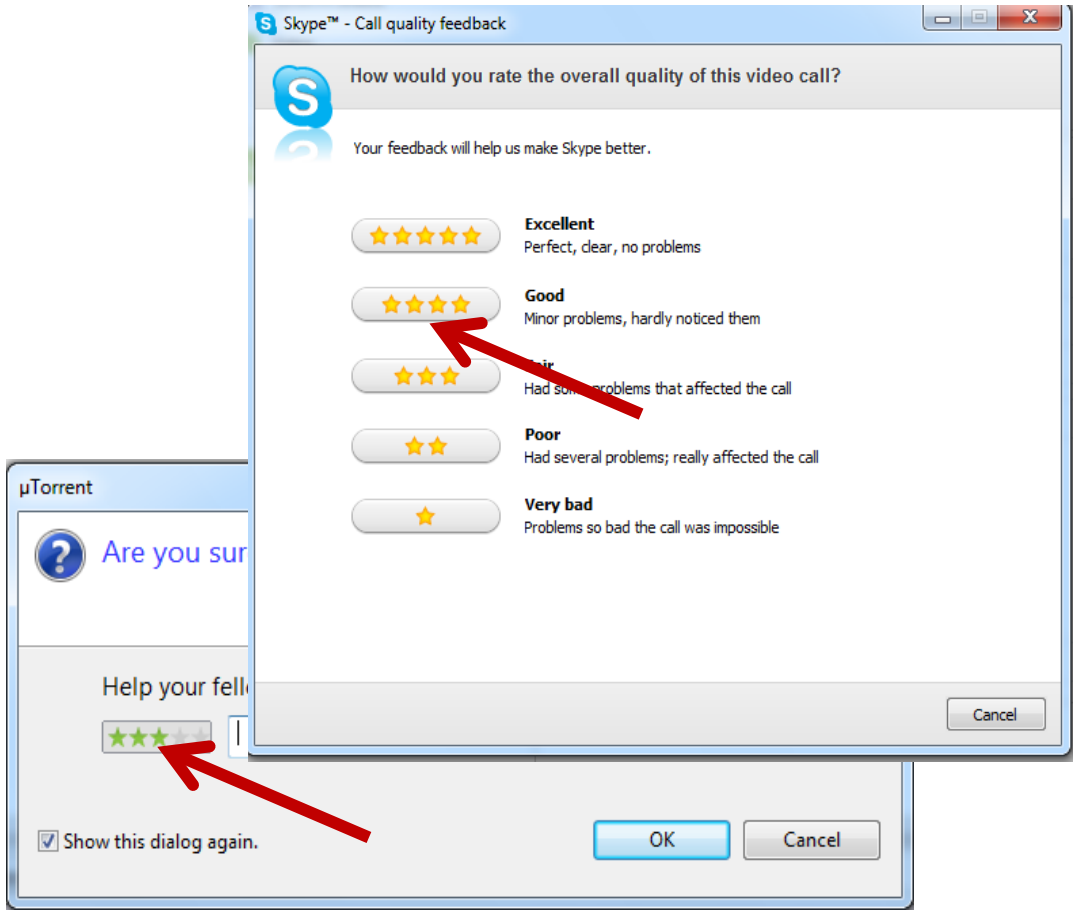
QoE Estimation - subjective methods

QoE

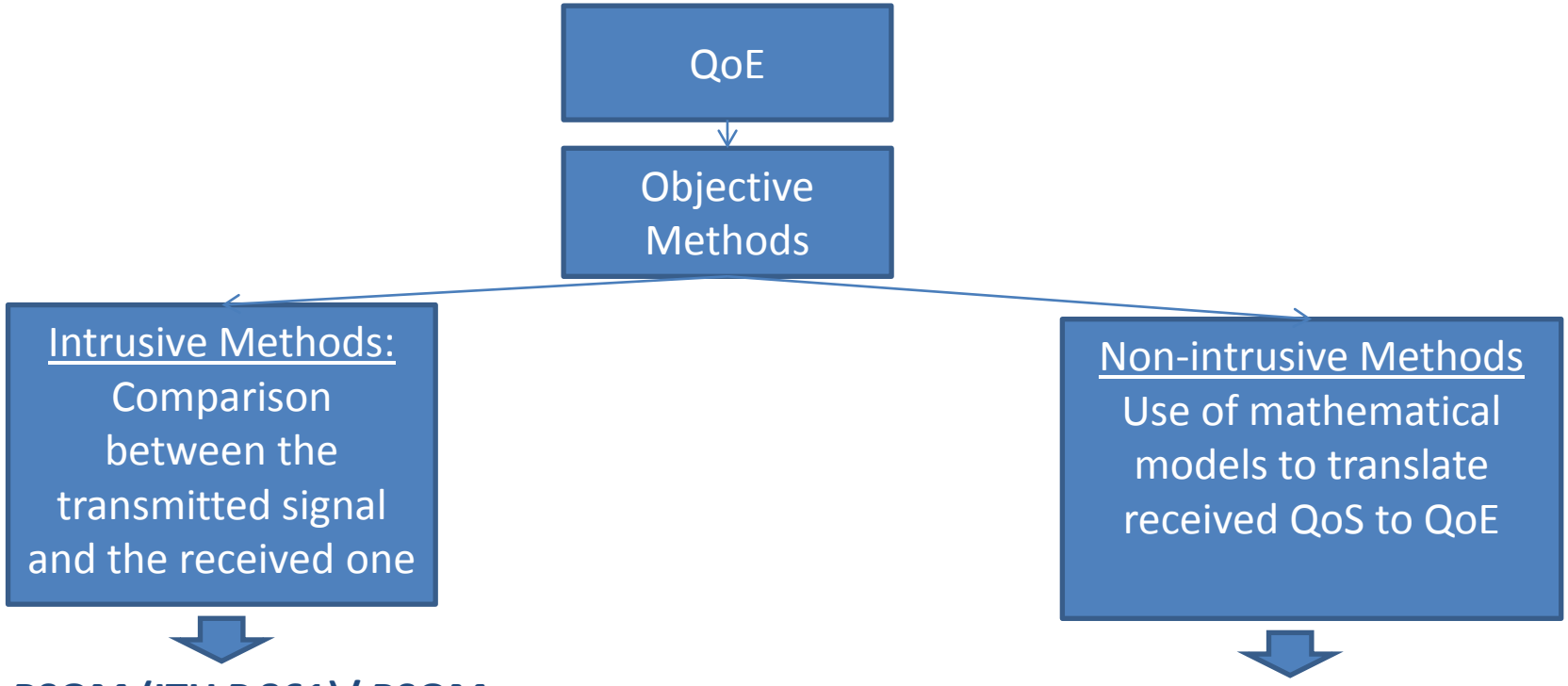
Subjective Methods:

MOS ITU P.800

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



QoE Estimation – Objective methods Voice Services



- **PSQM (ITU P.861)/ PSQM+**
  Perceptual Speech Quality Measure
- **PESQ (ITU P.862)**
  Perceptual Evaluation of Speech Quality
- **PAMS (British Telecom)**
  Perceptual Analysis Measurement System

- **ITU P.563**
- **ITU G.107 (E-Model)**
- **ITU P.CQO**

QoS - QoE relation: the IQX Hypothesis

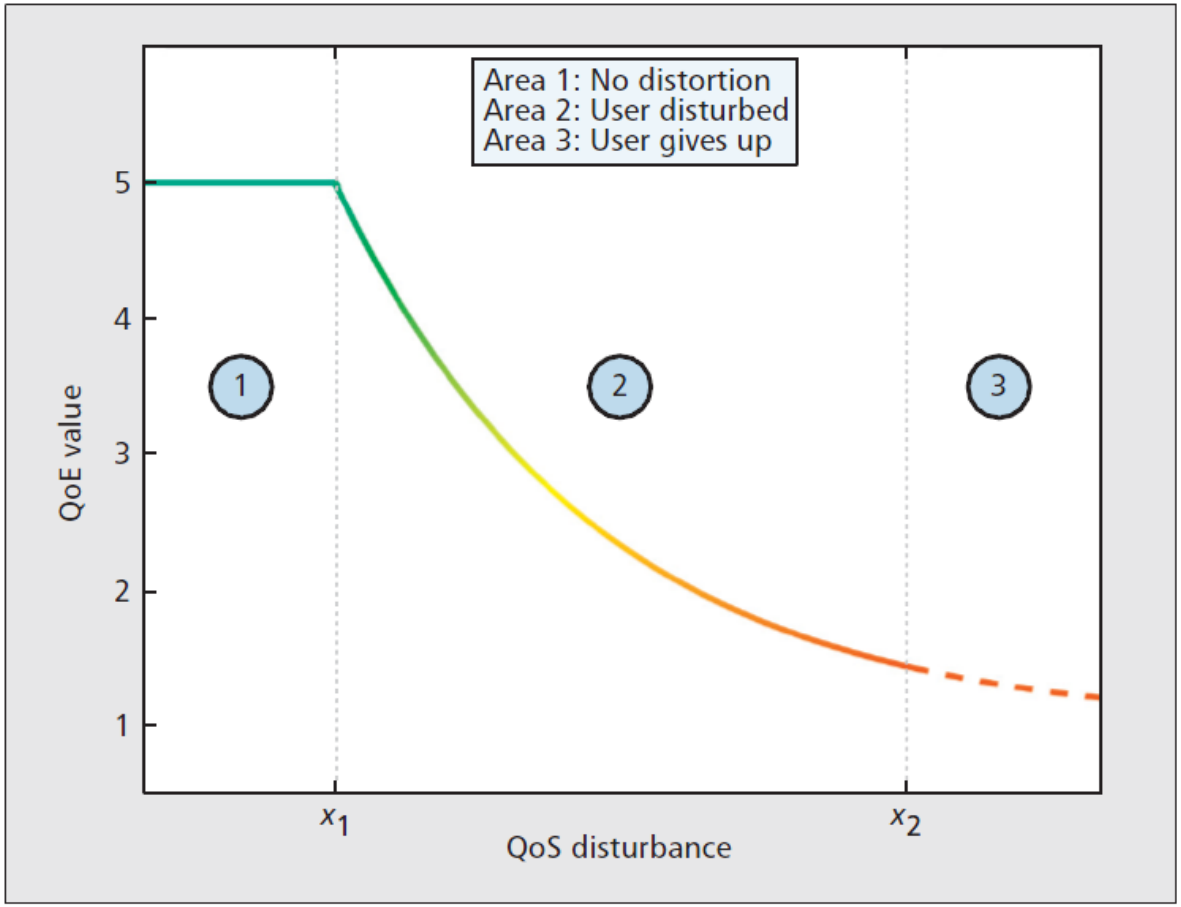
The subjective sensibility of the QoE is more pronounced the higher this experienced quality is.

- 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.

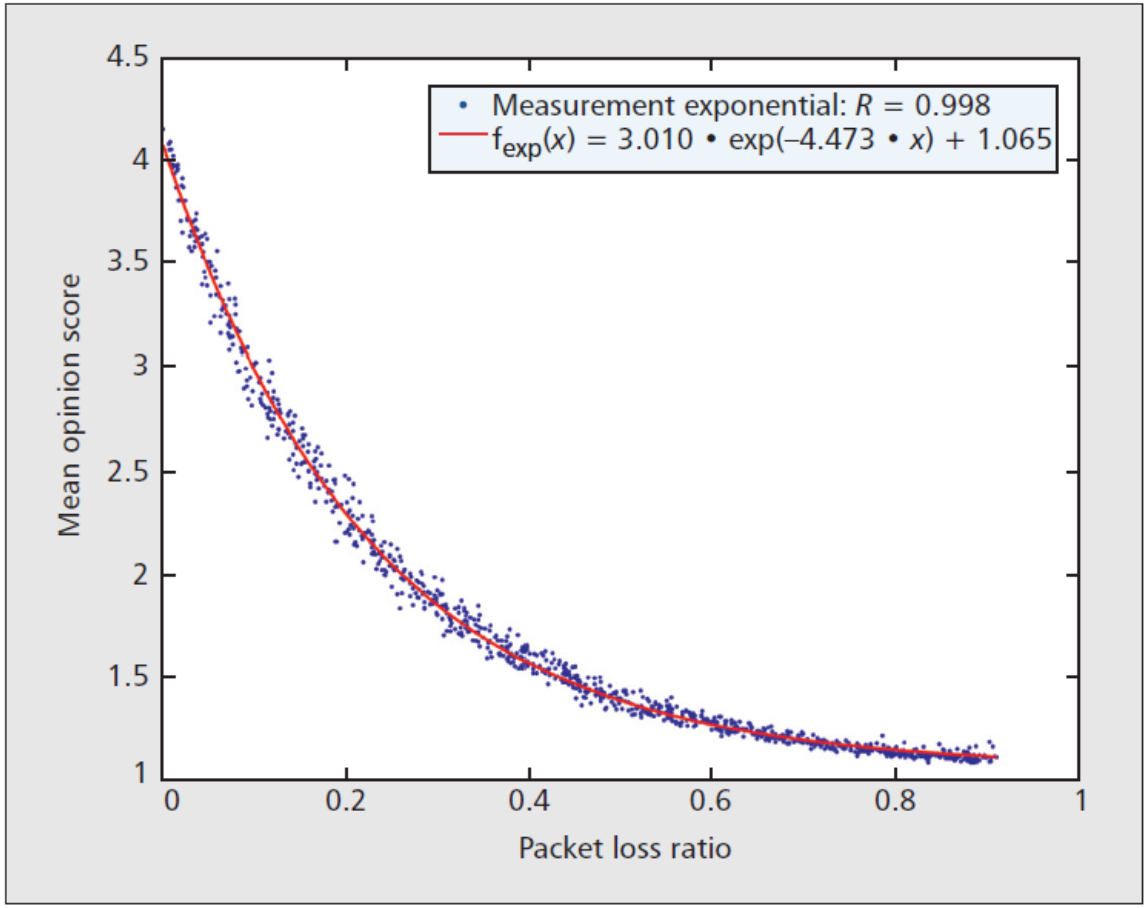
QoS - QoE relation: the IQX Hypothesis



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

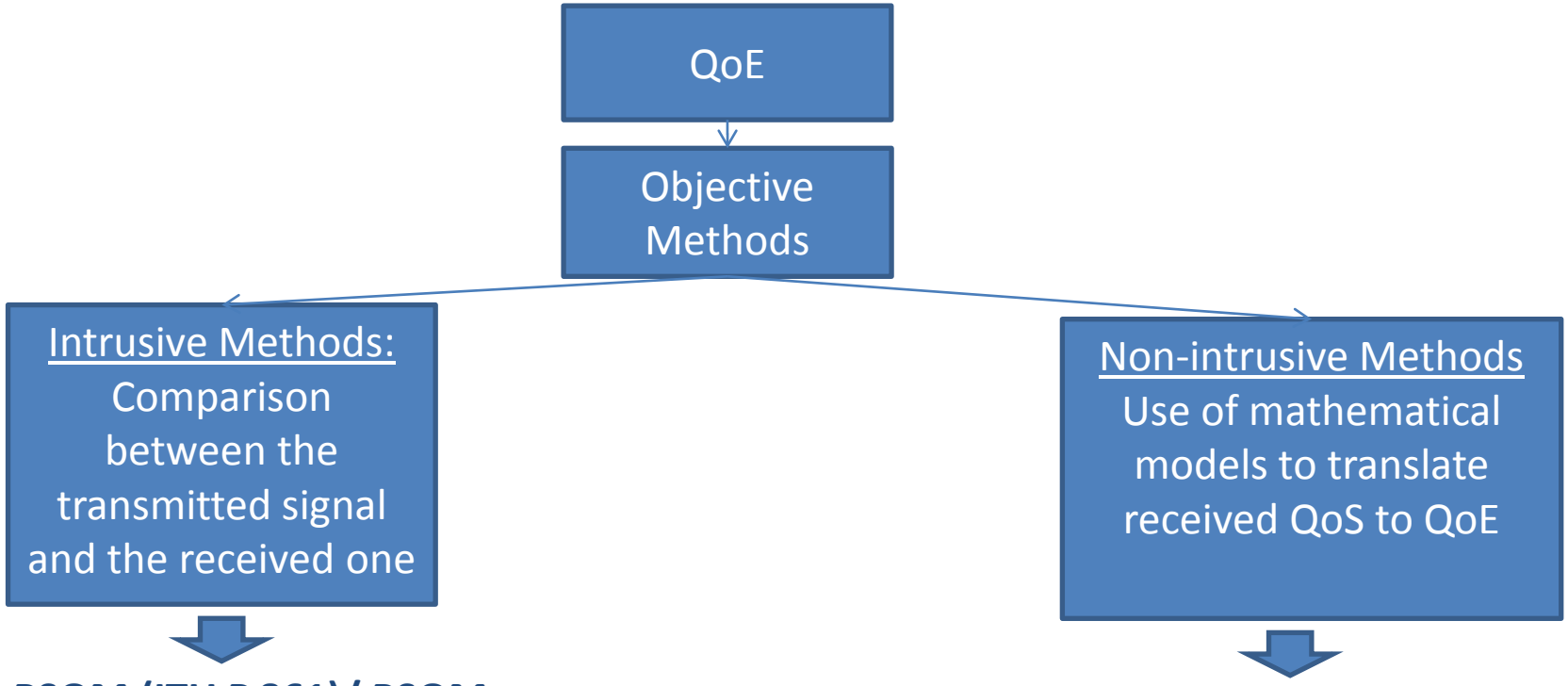
$$QoE = \alpha \cdot e^{-\beta \cdot QoS} + \gamma$$

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



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

QoE Estimation – Objective methods Voice Services



- **PSQM (ITU P.861)/ PSQM+**
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- **ITU P.563**
- **ITU G.107 (E-Model)**
- **ITU P.CQO**

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

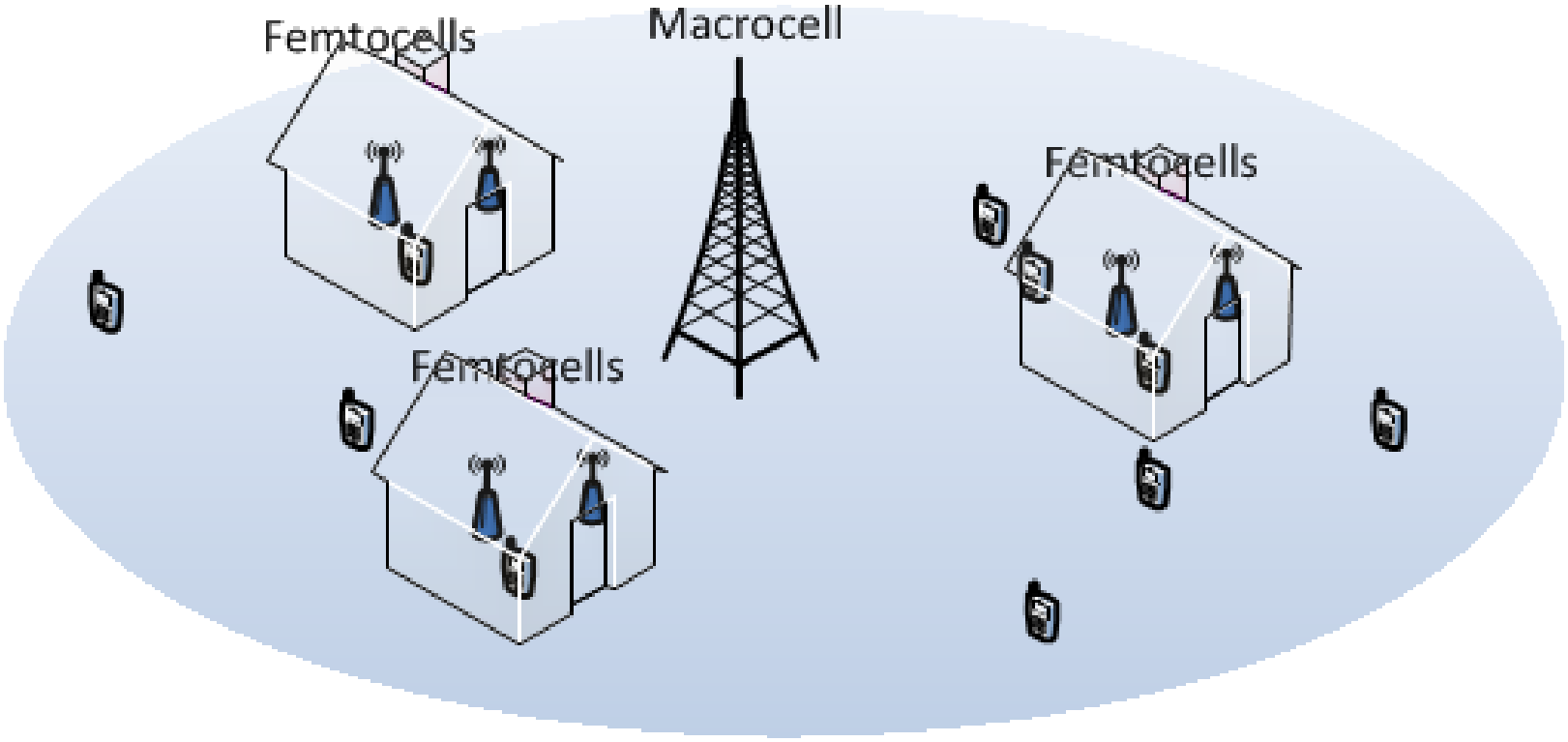
Focus on the impairments introduced by the wireless part of the network – (1) Packet loss and (2) Delay

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

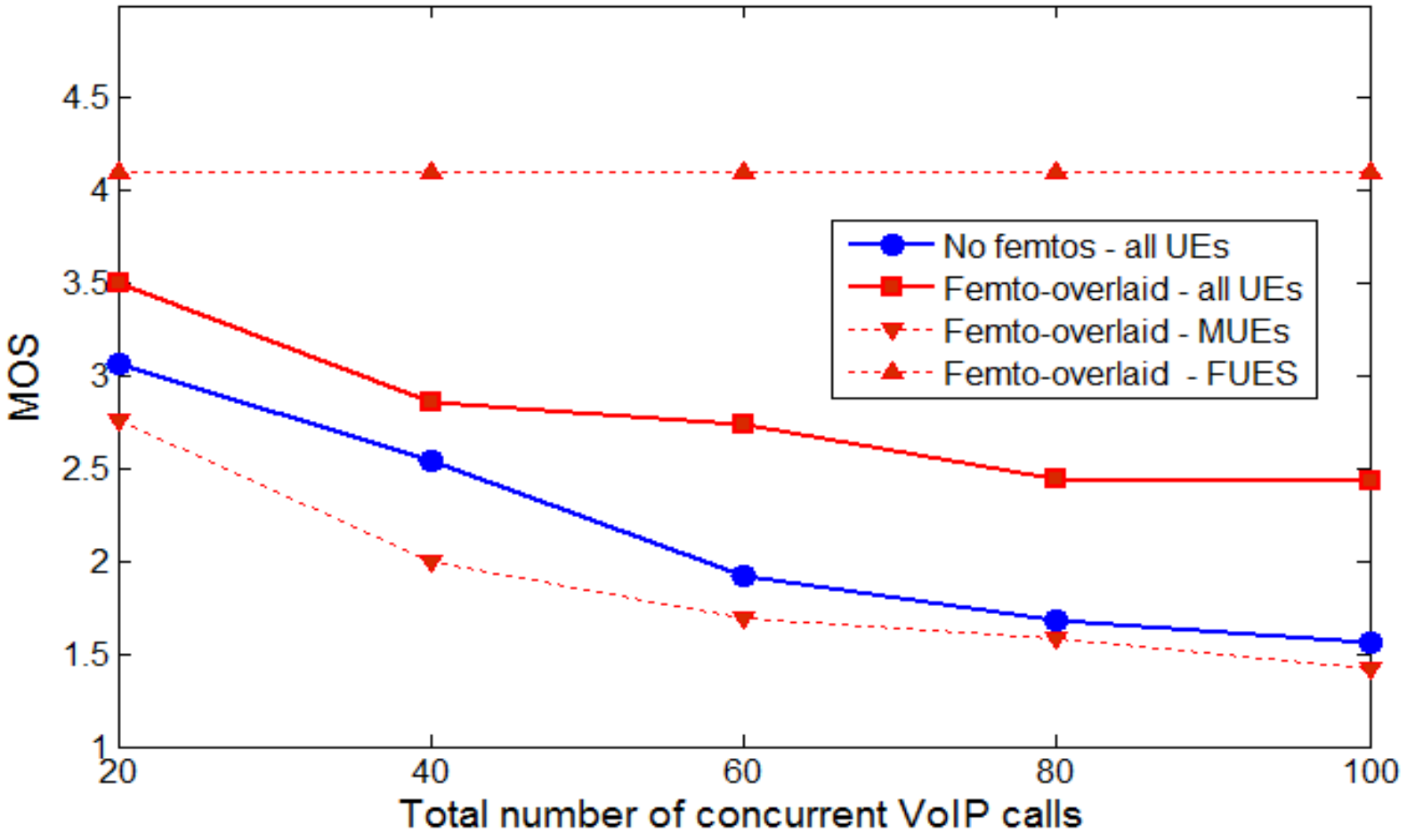
$$I_d = 0.024d + 0.11(d - 177.3)H(d - 177.3)$$

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

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

MOS-based Handover

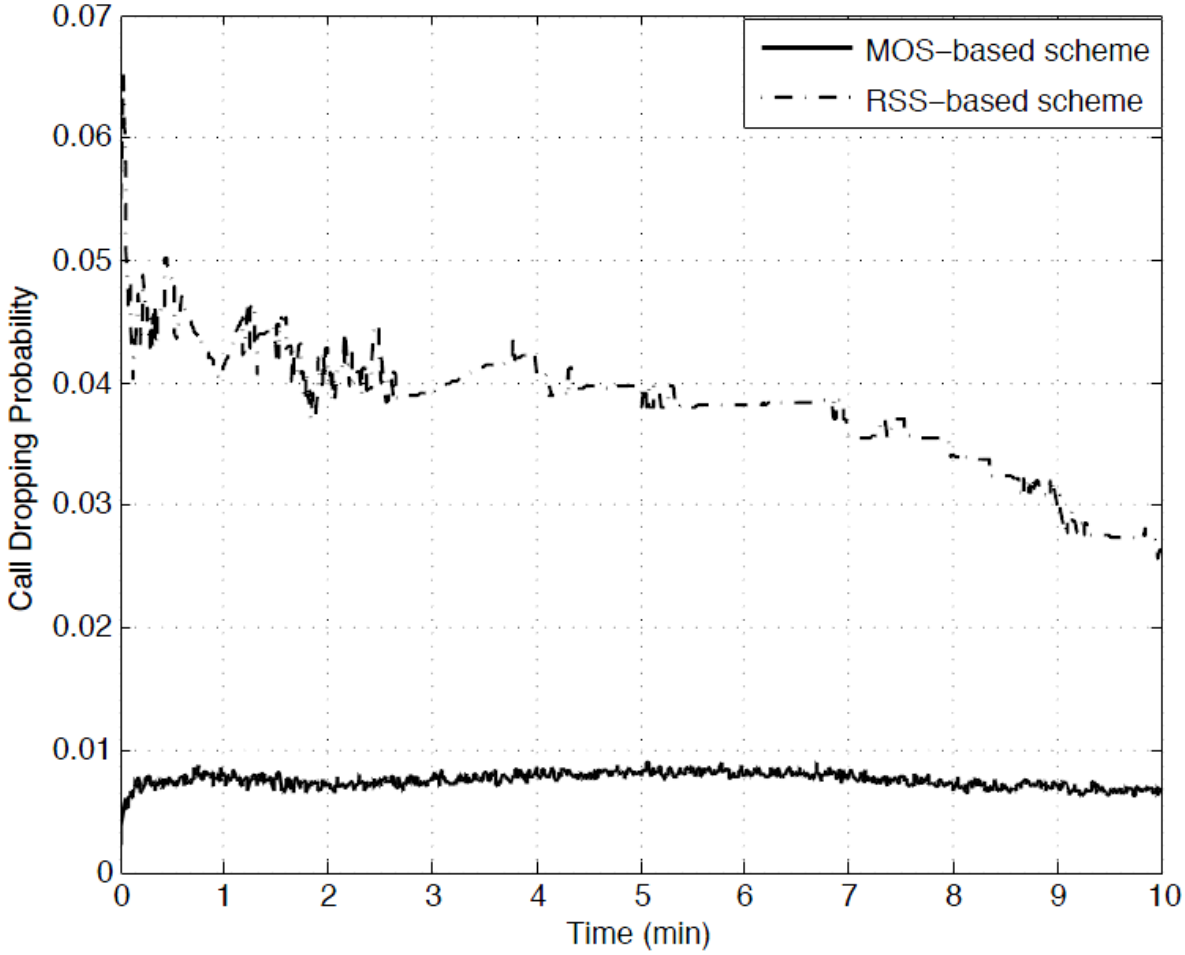
The Algorithm

Base station selection algorithm

input : $B_j = \{b_i : (p_{i,j}, d_{i,j})\}$, b_k, m_j
output: optimal b^*

$p = p_{k,j}$; $d = d_{k,j}$; $M = M_{k,j}$; $b^* = b_k$;
for *each* $b_i : (p_{i,j}, d_{i,j})$ *in* B_j **do**
  if $(p_{i,j} \geqslant p) \& (d_{i,j} \geqslant d)$ **then**
    continue;
  else if $(p_{i,j} \leqslant p)$ ***and*** $(d_{i,j} \leqslant d)$ **then**
    $p = p_{i,j}$; $d = d_{i,j}$; $M = M_{i,j}$, $b^* = b_i$;
  else if $(p_{i,j} \geqslant p \& d_{i,j} \leqslant d)$ ***or*** $(p_{i,j} \leqslant p \& d_{i,j} \geqslant d)$ **then**
    Calculate $M_{i,j}$;
    if $(M_{i,j} \geqslant M)$ **then**
      $p = p_{i,j}$; $d = d_{i,j}$; $M = M_{i,j}$, $b^* = b_i$;
    end
  end
end

Results


MOS–based scheme
RSS–based scheme
Call Dropping Probability
Time (min)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
5
6
7
8
9
10

Example -3

Interference Shaping for Improved QoE for Real-Time Video Streaming

Logarithmic relation between QoE - BW

- For file downloads (size 2.5 MB)

$$\mathrm{QoE} = 0.775 \log(\mathrm{BW}) + 1.268$$

- For web browsing applications

$$\mathrm{QoE} = 5.57 - 1.64 \log(\mathrm{pageloadtime})$$

P. Reichl, S. Egger, R. Schatz, and A. D'Alconzo, "The logarithmic nature of QoE and the role of the Weber-Fechner law in QoE assessment," in *Proc. IEEE International Conference on Communications, pp. 1–5,* May 2010.

Logarithmic relation between QoE - BW

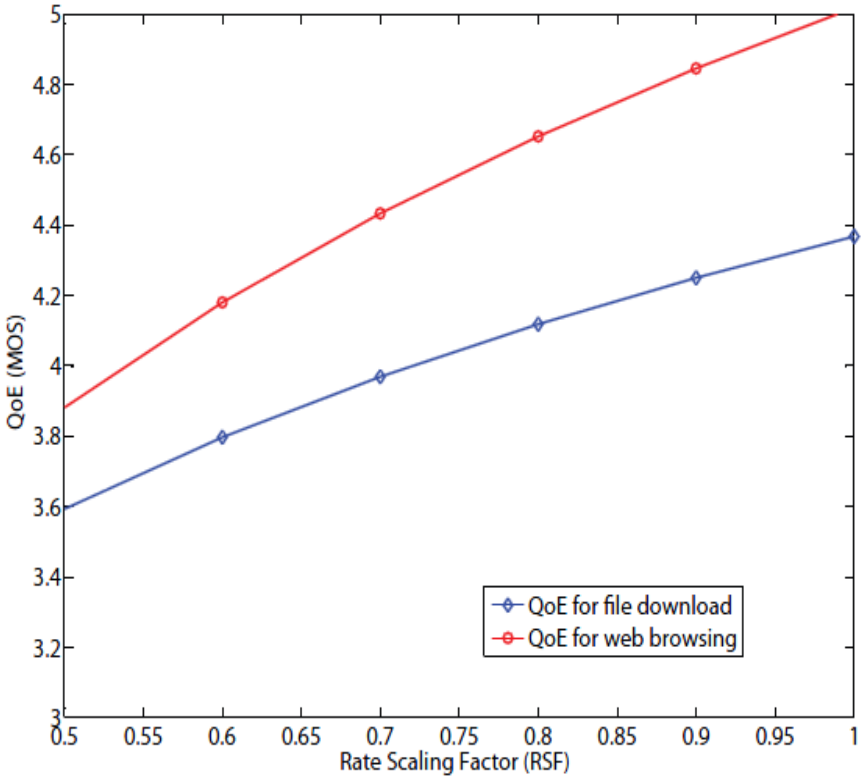
Interference shaping: Temporal smoothing of the interference power through power/rate scaling of the interfering BSs' bursty best effort data.

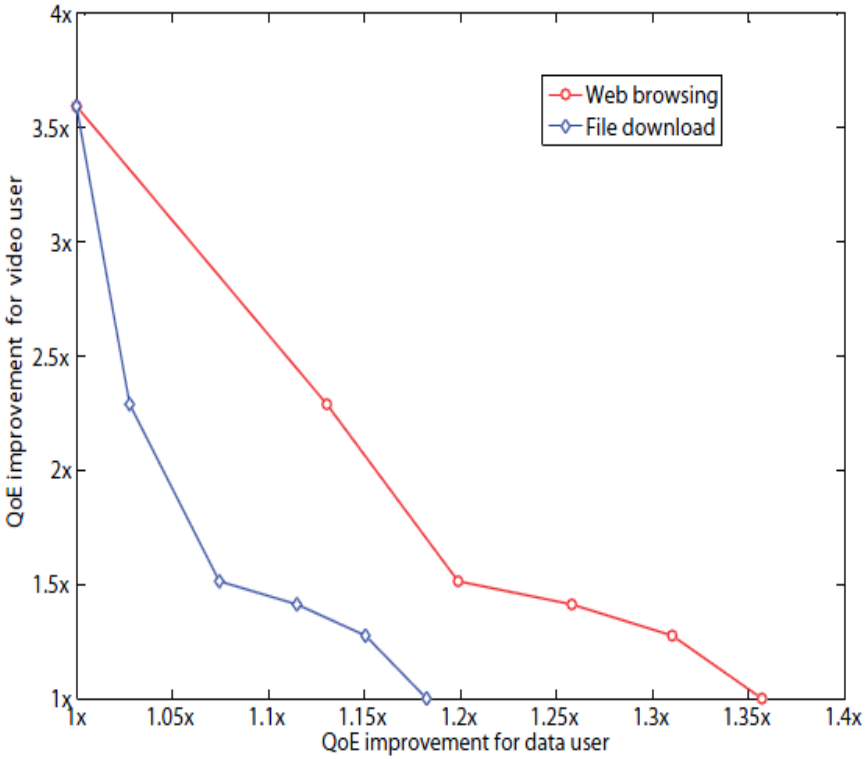
Rate Scaling Factor (RSF) : (a) is a scalar value between 0 and 1 which is used to donate the linear reduction in rate achieved from reducing the transmit power.

$$\mathrm{QoE} = 0.775 \log(\alpha) + 1.268 \quad \mathrm{QoE} = 5.57 - 1.64 \log\left(\frac{1}{\mu R(\alpha)}\right)$$

Singh, S.; Andrews, J.G.; De Veciana, G., "Interference Shaping for Improved Quality of Experience for Real-Time Video Streaming," *Selected Areas in Communications, IEEE Journal on* , vol.30, no.7, pp.1259,1269, August 2012

Results


QoE (MOS)
Rate Scaling Factor (RSF)
QoE for file download
QoE for web browsing


QoE improvement for video user
QoE improvement for data user
Web browsing
File download

Thank you!