

Quality of Experience Driven Cross-Layer Optimization for the Future Mobile Internet

Wolfgang Kellerer, Srisakul Thakolsri, DOCOMO Euro-Labs
Shoaib Khan, Eckehard Steinbach, TU München

2nd GI/ITG KuVS Workshop on Future Internet
Karlsruhe, Germany, Nov. 11, 2008

Motivation

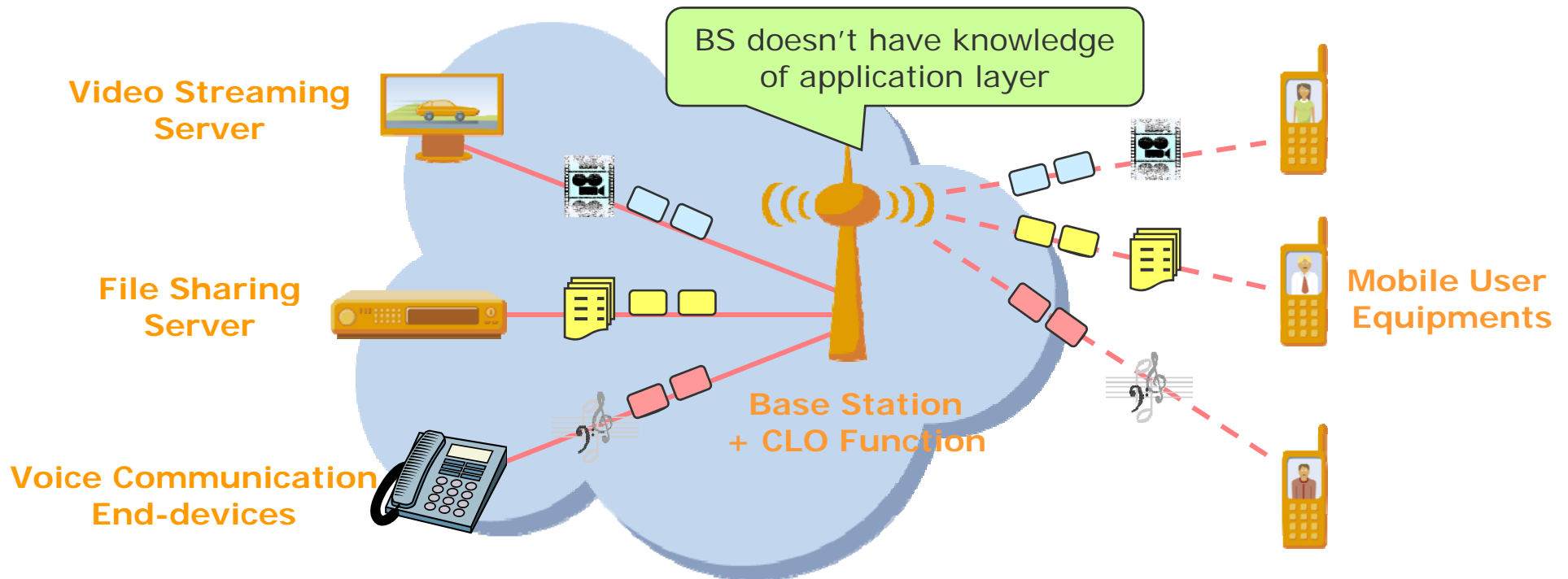
- Future Internet challenge: application-awareness
 - efficient resource management has to take application requirements into account
- "Quality of Service" → "Quality of Experience"
 - *simple QoS schemes are not enough*
 - *taking the user perceived quality into account*
- This talk intends to
 - explain our approach towards application-aware communication in a wireless Internet setting
 - stimulate discussion on how to generalize this approach as a building block for the Future Internet

Outline

- Cross-Layer Optimization (CLO) Framework
- Multi-applications MOS Model
- Greedy Allocation Algorithm
- Simulation Results

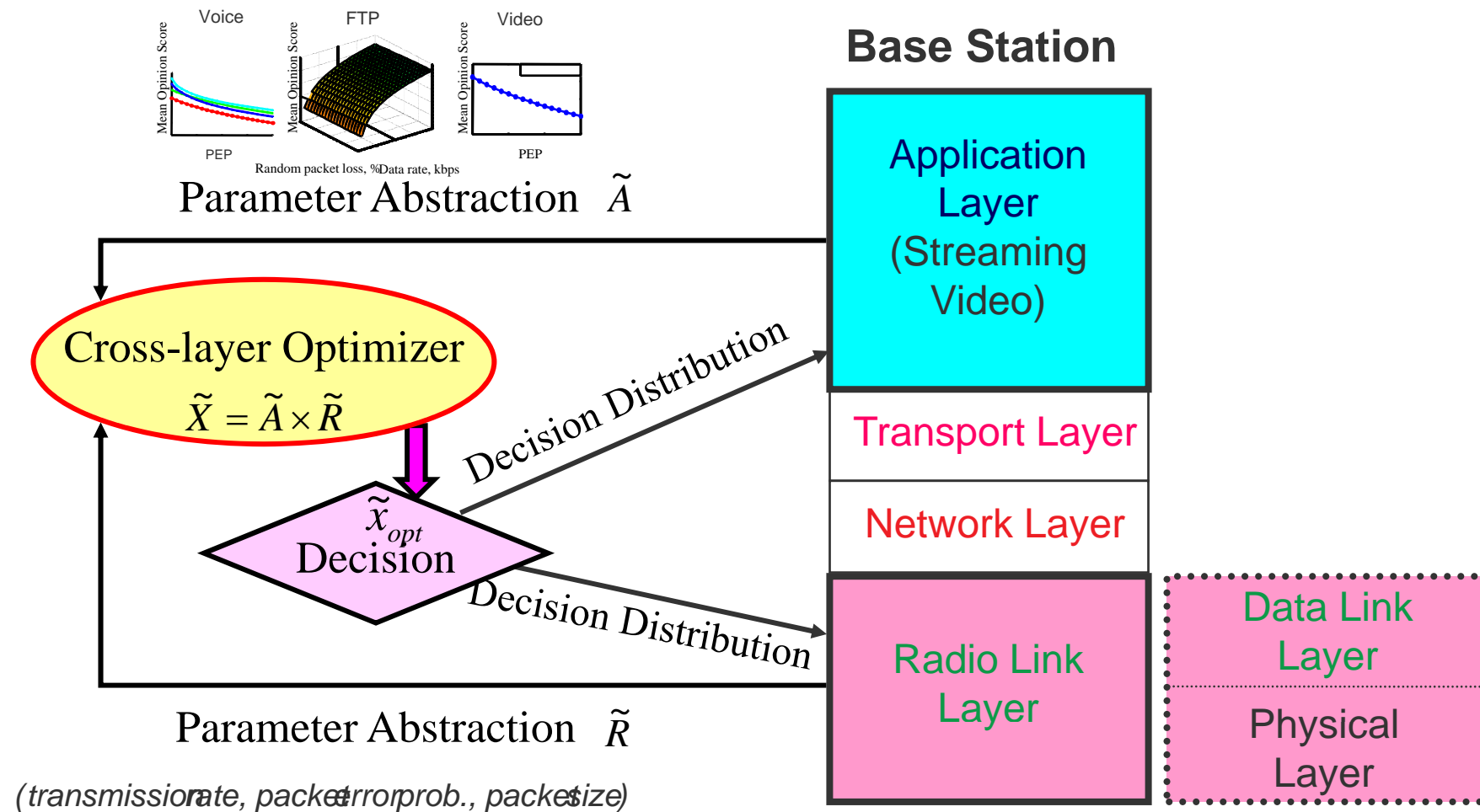
- Future Internet requirement: application awareness
- Generalization of the CLO concept

Motivation



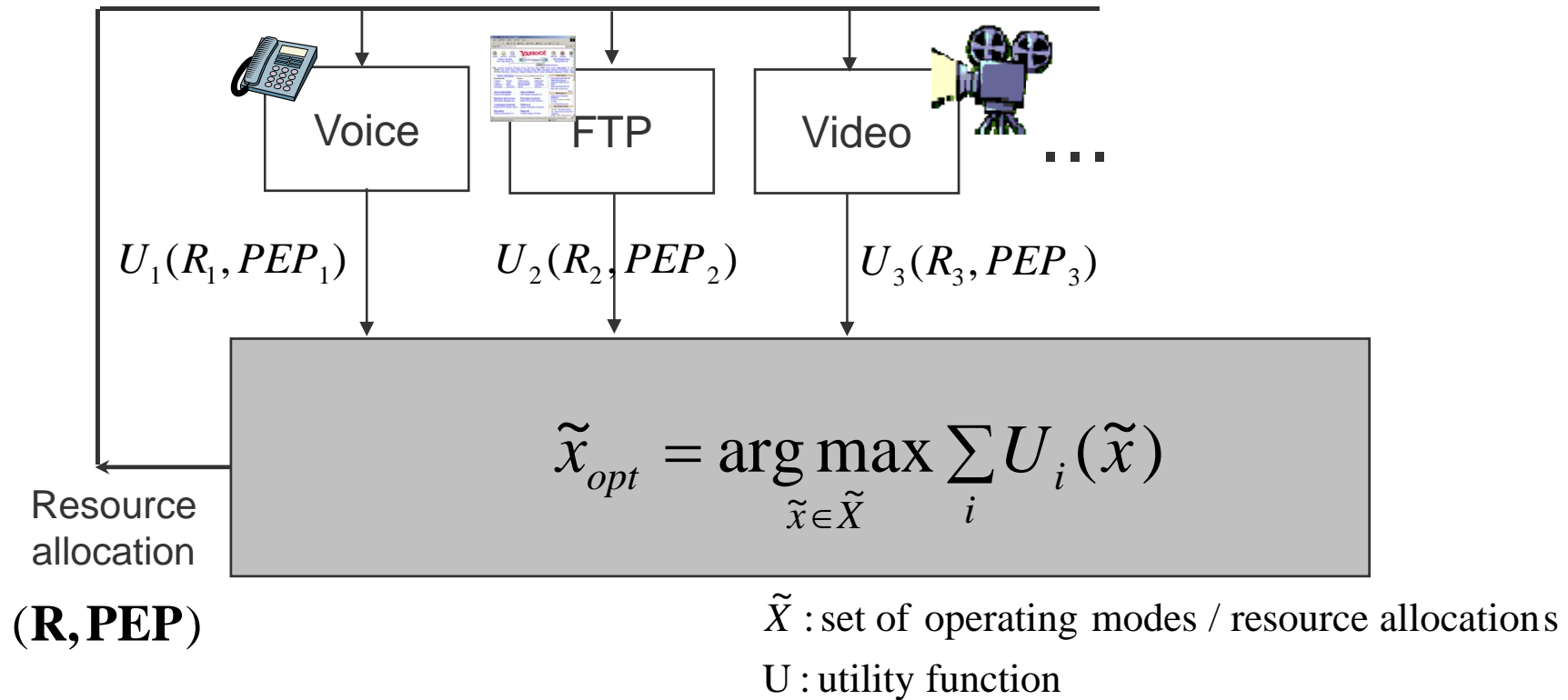
- Multiple users sharing wireless medium, e.g., in a cell, usually run different applications simultaneously
- Impact of losses or rate changes on user's Quality of Experience (QoE) is application-dependent
- Optimizing the system for different users and applications requires:
 1. defining a common metric that quantifies the user satisfaction
 2. mapping network and application parameters onto this metric

Cross-layer Optimization Architecture



Kellerer, Choi, Steinbach, Khan
WPMC'03, ICI'04, IEEE ComMag'06

Cross-layer Optimizer: Maximization of User Satisfaction



Khan, Duhovnikov, Steinbach, SgROI, Kellerer, ISMW '06

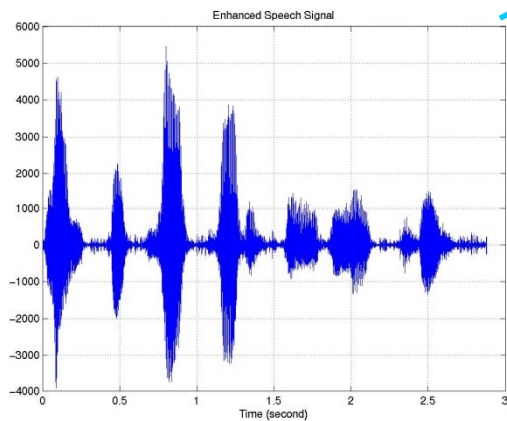
Challenge: estimating utility functions



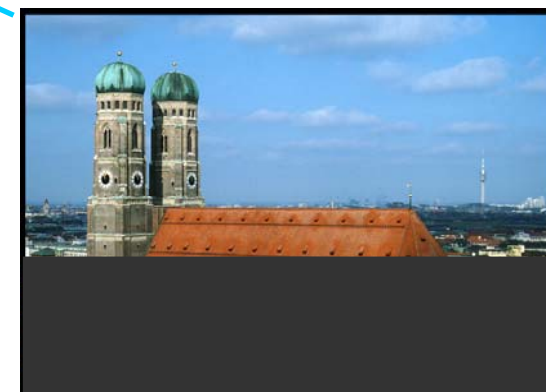
video streaming



video conferencing



voice



FTP(image download)

User Satisfaction MOS

Very Satisfied	4.4
Satisfied	4.3
Some Users Dissatisfied	4.0
Many Users Dissatisfied	3.6
Nearly All Users Dissatisfied	3.1
Not Recommended	2.6
	1.0

Mean Opinion Score

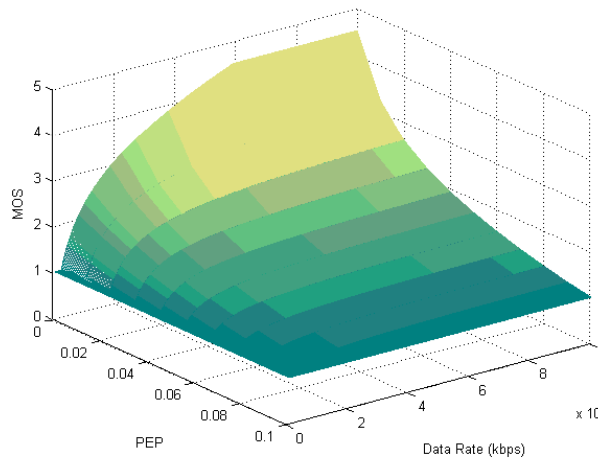
?

?

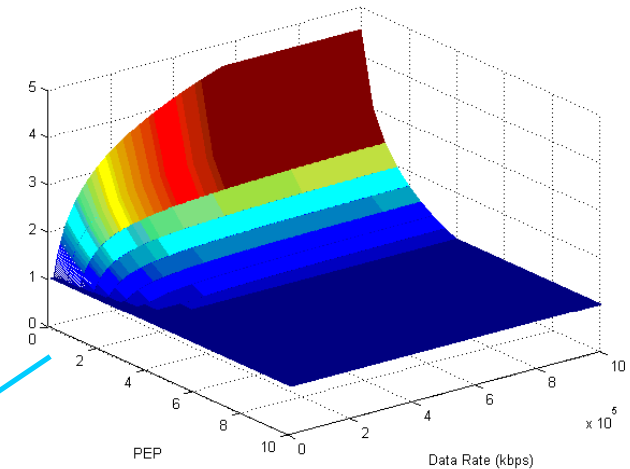
?

?

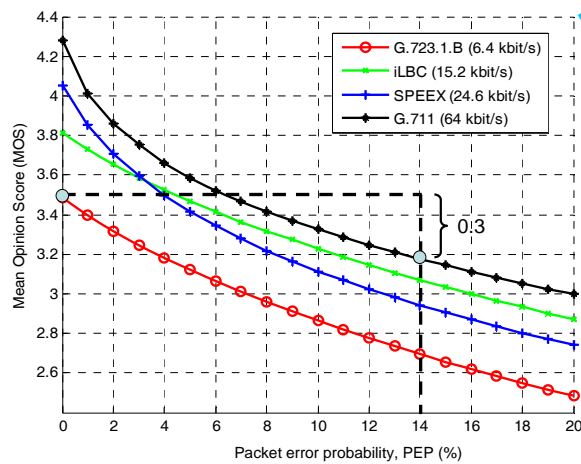
Application Layer Utility (MOS)



video streaming



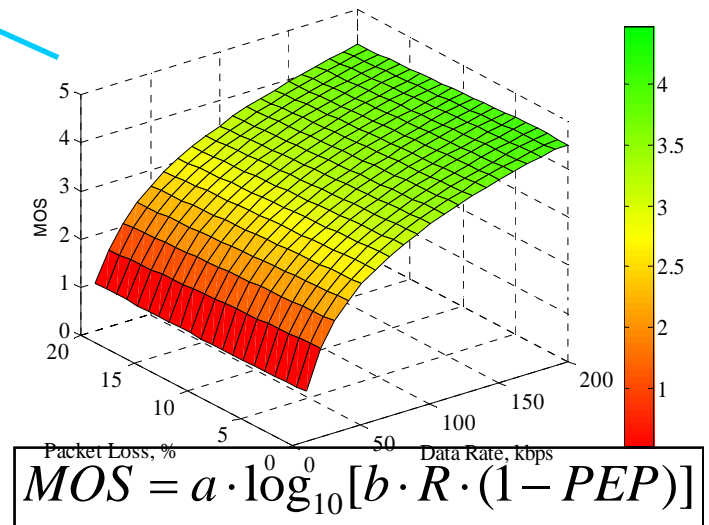
video conferencing



voice

User Satisfaction	MOS
Very Satisfied	4.4
Satisfied	4.3
Some Users Dissatisfied	4.0
Many Users Dissatisfied	3.6
Nearly All Users Dissatisfied	3.1
Not Recommended	2.6
	1.0

Mean Opinion Score



$$MOS = a \cdot \log_{10} [b \cdot R \cdot (1 - PEP)]$$

FTP (image download)

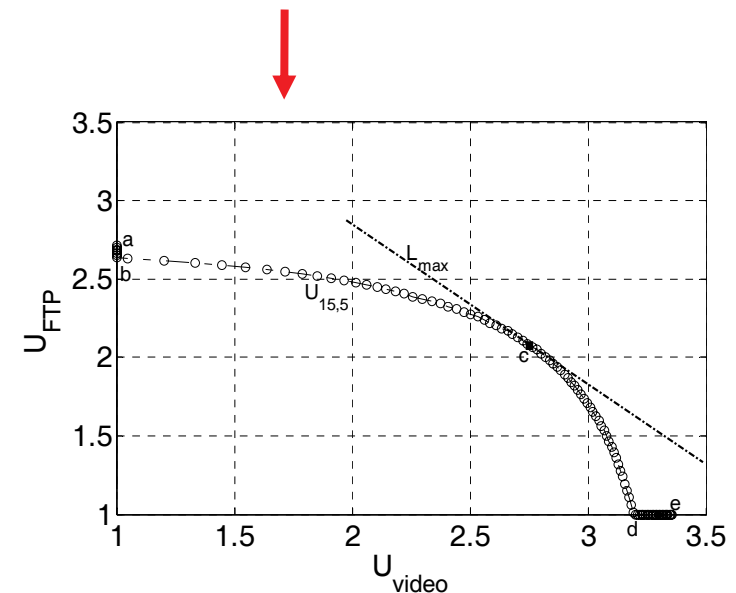
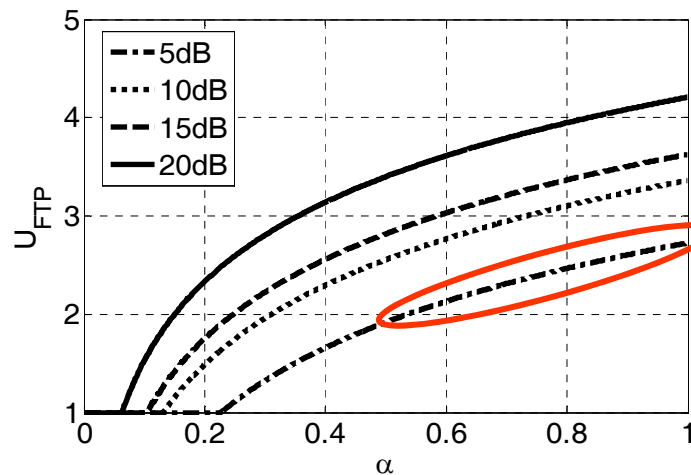
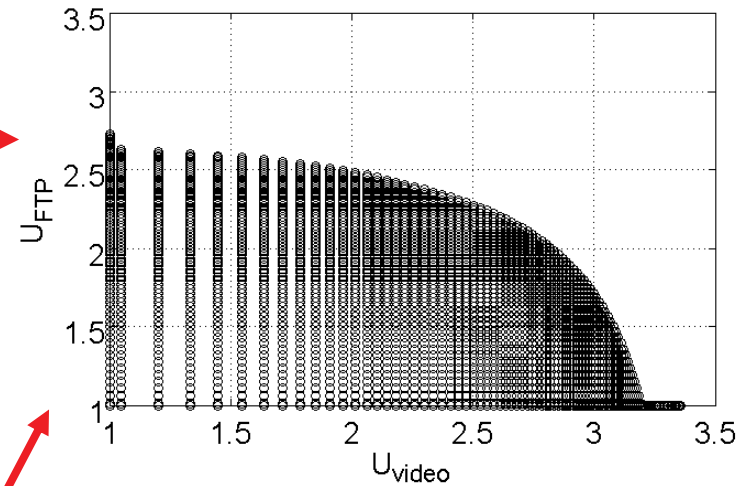
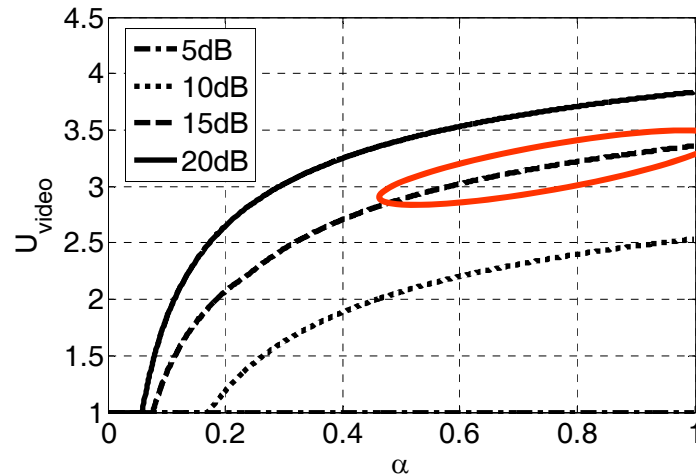
Optimization: Complexity Issues

- Optimal Mode:
 - Full search through all possible modes of K users
 - Maximize Mean MOS: $\arg \max_{\tilde{x} \in \tilde{X}} \frac{1}{K} \sum_{k=1}^K MOS_k(R_k(\tilde{x}), PEP_k(\tilde{x}))$
- Transmission policies:
 - K_U voice users: $T_U^{K_U}$ possible transmission policies
 - K_V FTP users: $T_V^{K_V}$ possible transmission policies
 - K_W video streaming users: $T_W^{K_W}$ possible transmission policies
 - Total number of possible transmission policies is $T_U^{K_U} \cdot T_V^{K_V} \cdot T_W^{K_W}$
- An example:
 - 3 voice users, 2 FTP users, 2 video users
 - Each user has 10 transmission policies
 - There are 10^7 transmission policies to be computed in order to find the optimal resource allocation

Greedy Resource Allocation Algorithm

- Initialization: $\boxed{\sum_{k=1}^K S_k = S^*} \longrightarrow \boxed{\sum_{k=1}^K \alpha_k = 1}$
 - S^* total symbol-rate, K total number of users, S_k assigned symbol rate to user k , α_k fraction of assigned symbol rate to user k
- Procedure:
 - Given a change of resource share $\Delta\alpha$ and a min. of expected utility change ΔU_{\min}
 - Iterations: $\max_{(i,j) \in \{1, \dots, K\}} \frac{\Delta U_i}{\Delta U_j}, \quad i \neq j \quad \text{till} \quad \Delta U_i < \Delta U_{\min}$
 - ΔU_i : Utility change due to an increase of $\Delta\alpha$
 - ΔU_j : Utility change due to a decrease of $\Delta\alpha$

An example: Greedy Resource Allocation Algorithm



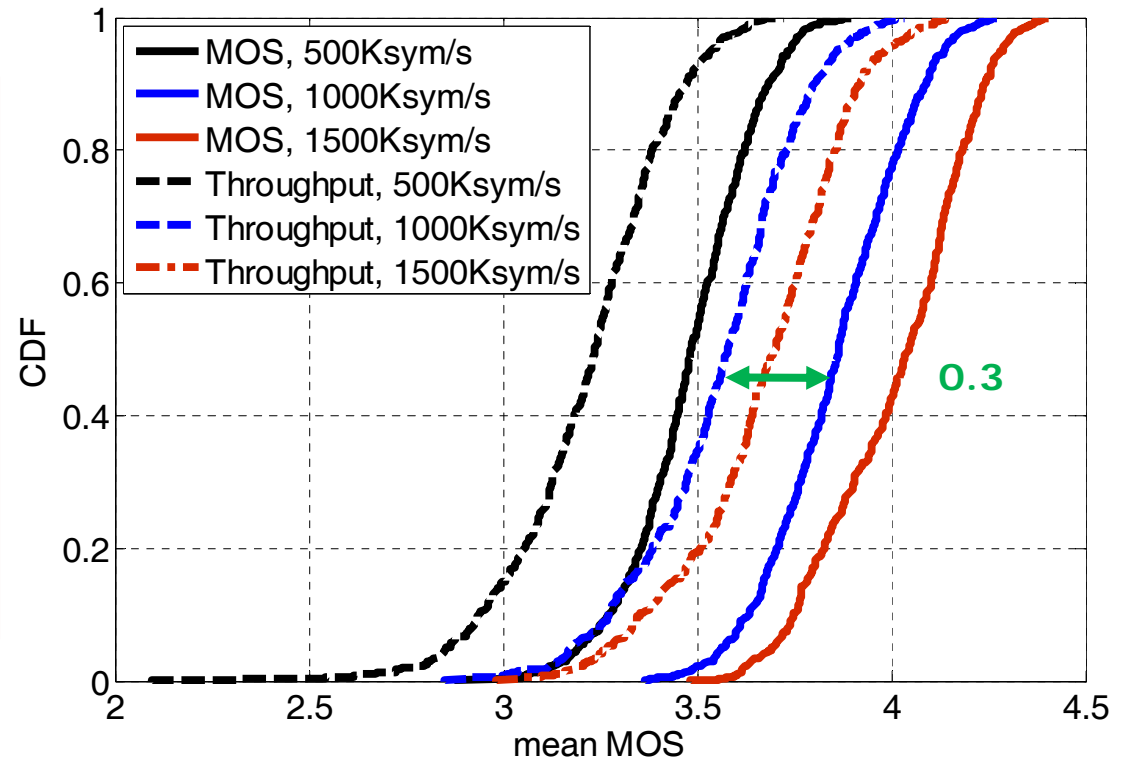
Performance of Utility-based optimization with full-search (1)

- Maximize mean MOS:

$$\arg \max_{\tilde{x} \in \tilde{X}} \frac{1}{K} \sum_{k=1}^K MOS_k(R_k(\tilde{x}), PEP_k(\tilde{x}))$$

- Maximize Throughput:

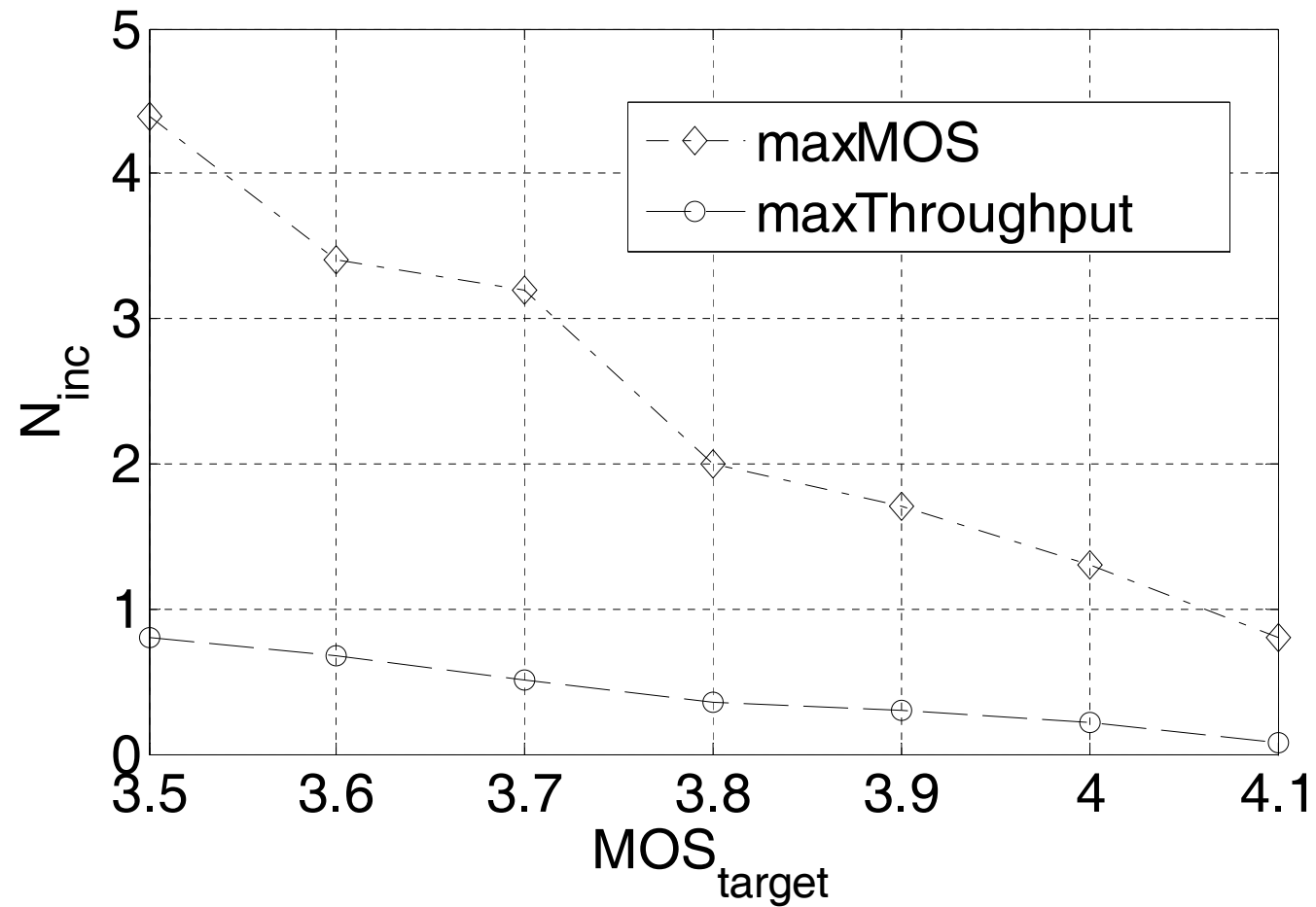
$$\arg \max_{\tilde{x} \in \tilde{X}} \sum_{k=1}^K R_k(\tilde{x}) \cdot (1 - PEP_k(\tilde{x}))$$



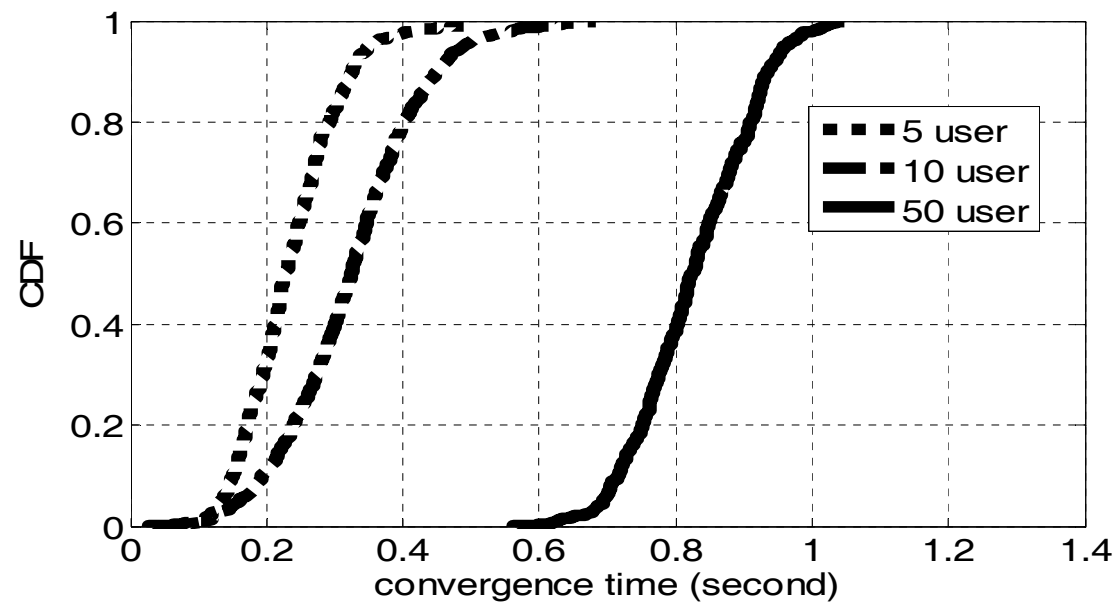
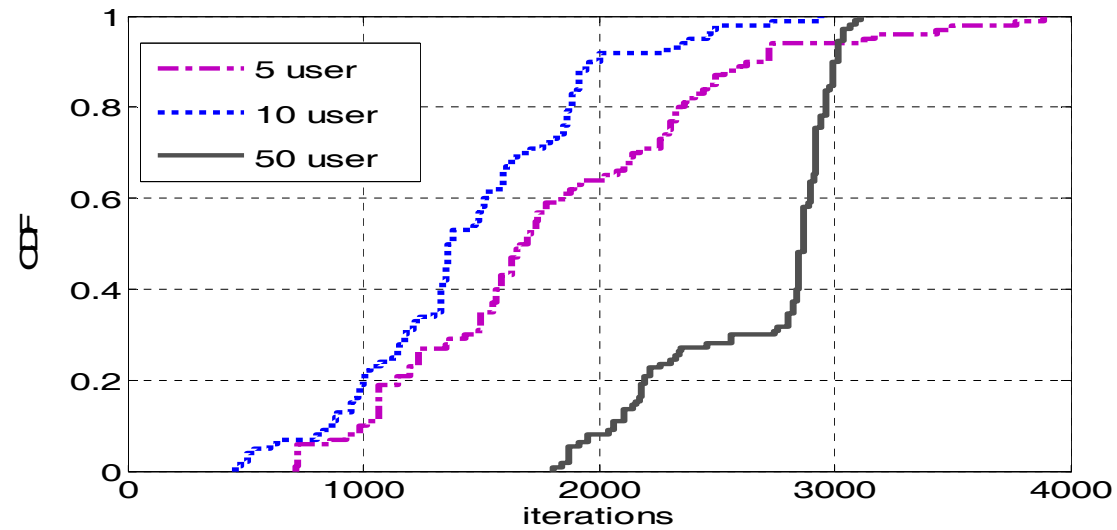
- Seven users: 3 voice users, 2 FTP users, 2 video users
- Total system rates **500, 1000, and 1500 ksymbols/sec**
- Session duration: 30 sec
- Resource allocation update: every 1 second

Performance of Utility-based optimization with full-search (2)

Optimization target: number of (additional) users



Performance of greedy search algorithm



Summary Modeling and CLO

- Using MOS as a unifying optimization metric across different types of application in order to optimize the wireless resource usage
- Results show advantages of using the QoE-based approach (comparing with throughput max.)
 - Significant improvements in terms of user-perceived quality
 - Accommodation more users in the system

Towards Future Internet (1)

- The future Internet needs to be flexible in respect with the existing and emerging set of applications
- QoS classes are not enough (if they are implemented at all)
- Application-awareness provides the opportunity to make decisions in an application favourable way → QoE

- Resource allocation decisions can be done
 - By signalling to the application server
 - Through rate shaping or transcoding in the network
- Decisions can be made at the base station or in any network element

Towards Future Internet (2)

- Application-awareness = cross-layer information exchange
 - Supports an evolutionary approach towards a future Internet (signaling of application/MOS models needed)
- Further consideration: use the application models to design new routing protocols → cross layer re-design of the protocol stack
 - Utility-aware routing

Mobile Adventure

Thank you

Wolfgang Kellerer, Srisakul Thakolsri
{kellerer, thakolsri}@docomolab-euro.com

DOCOMO Communications Laboratories Europe GmbH
Landsberger Strasse 312 – 80687 Munich, Germany
Phone: +49 (89) 56824-0 | www.docomolab-euro.com

^{NTT}**docomo**
DOCOMO Euro-Labs