Utility-based Resource Management in LTE and LTE-Advanced Considering QoE

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Agenda

- Introduction
- Utility functions
- Problem formulation and solution algorithms
  1. Traffic shaping, solved Lagrangian method
  2. Centralized radio resources scheduling heuristics
- Simulation results
- Conclusion and outlook

Introduction

- More than 60% of voice calls and 90% of data traffic take place in indoor environments
- Backhaul of femtocells is bounded to the existing user's broadband (e.g. xDSL)

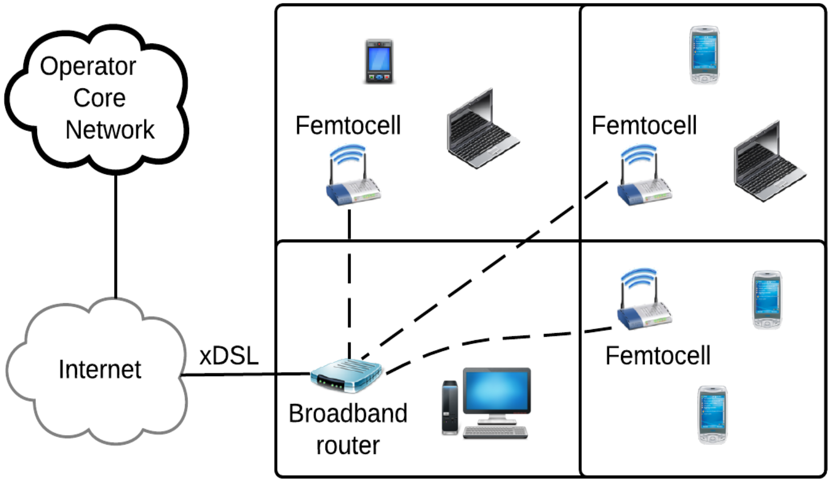


Figure: example of a femtocell cluster

- Traffic shaping can be done at the Core Network per user/bearer level
- The resource allocation can be done for all cells
  - simultaneously in a coordinated manner
  - considers not only the radio resources constraints but also the transport network limitations

Utility-based resource allocation

- Resource Allocation (RRA): the amount of radio resources allocated to different users
  - Make the best use of limited resources under time varying channel conditions
  - Fairness, latency reduction, spectral efficiency and system utilization
- Utility-based Resource Allocation
  - Utility reflects actual users‘ perceived performance (QoE)
  - Optimization problem: Maximize the aggregated utility, subject to limited resources

QoE examples for video traffic

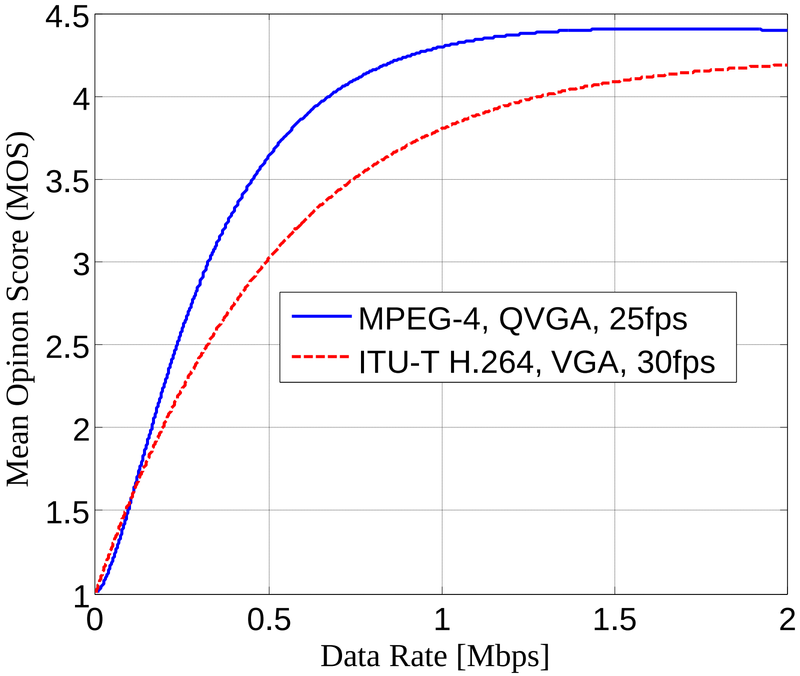


Figure: ITU-T G.1070 [1]

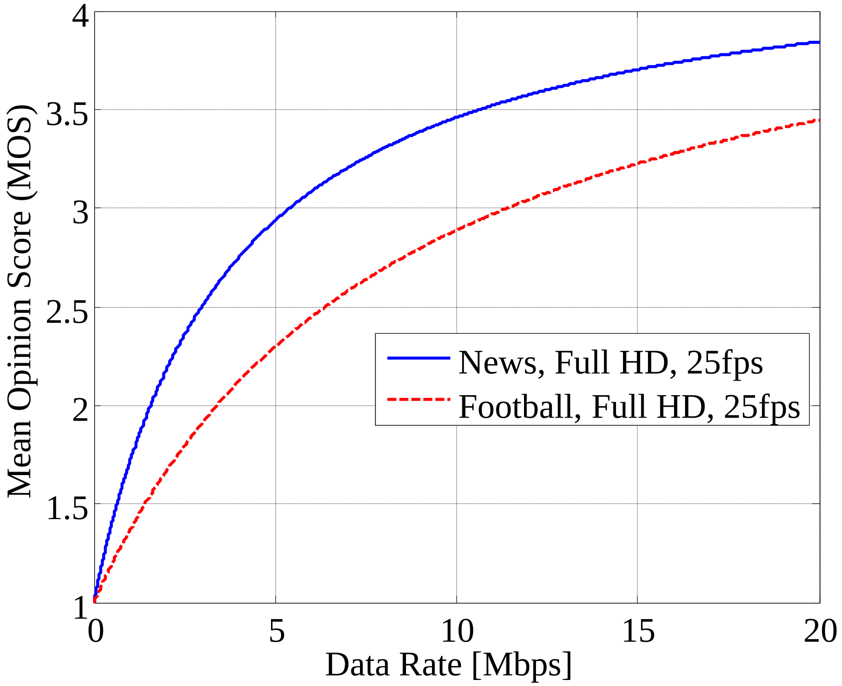


Figure: HD video extending ITU-T G.1070 [2]

QoE examples for Web traffic

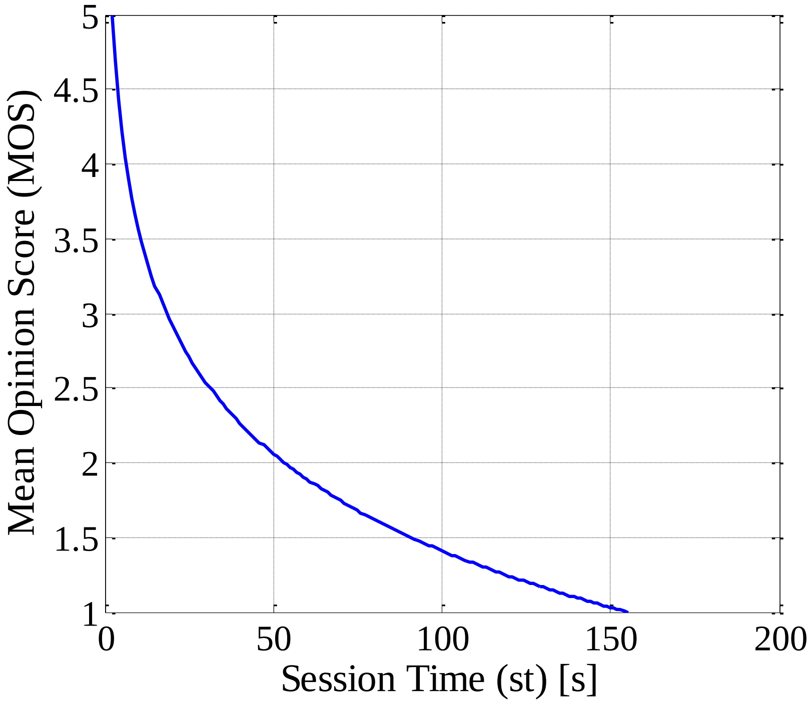


Figure: 60 seconds duration context, ITU-T G.1030 [3]

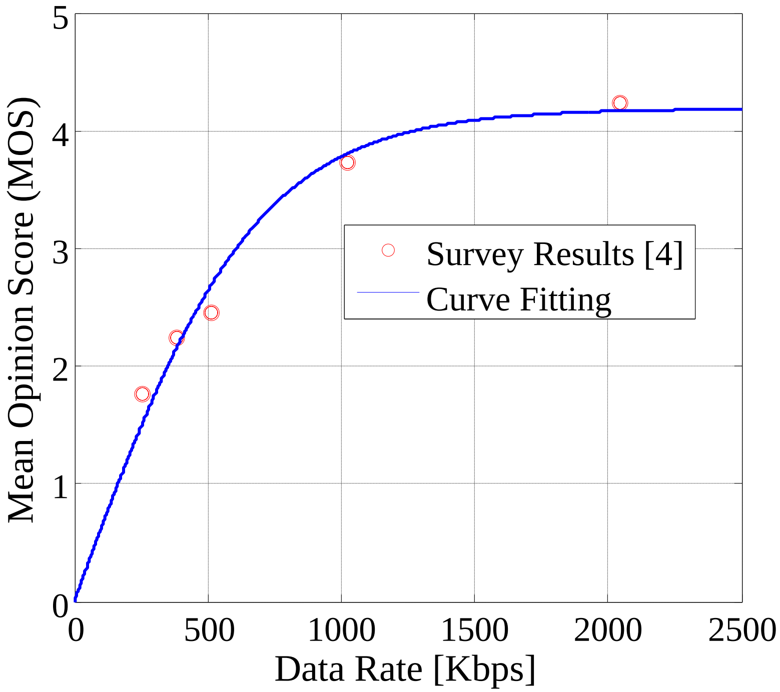
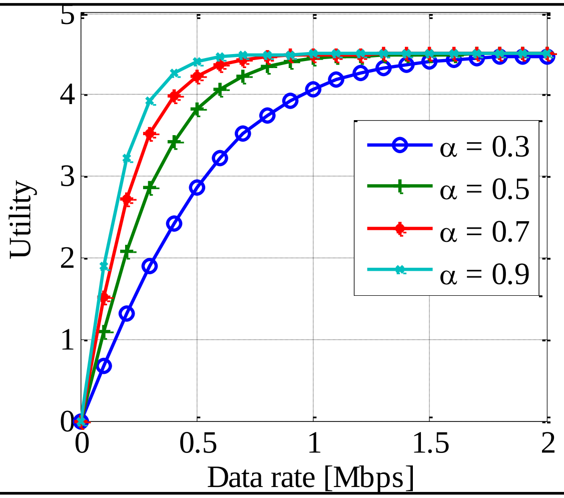


Figure: Curve Fitting for the survey results [4]

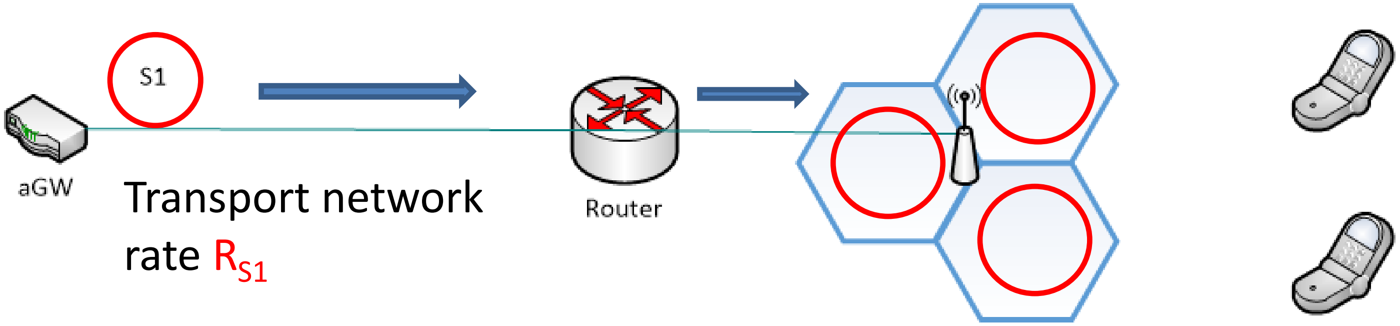
Utility functions for nGBR traffics

Applications	**Elastic traffics;** **Video with transcoding**
Properties	QoE monotonically increases with the data rate; Marginal QoE monotonically decreases with the data rate
Function Type	Sigmoid Function (Concave part)
Utility function	$u(r)=\frac{A}{1+e^{-\alpha\cdot r}}+B=\frac{A}{1+e^{-\alpha\cdot\sigma\cdot b}}+B$
Utility curves	 *with A=9, B=-4.5

General overview

$$\text{Goal: } \max\left\{U=\sum_{c}\sum_{i}u_{i,c}\left(b_{i,c}\right)\right\}$$

Cell bandwidth B_c



Transport network rate R_{S1}

$$\sum_{c}\sum_{i}r_{i,c}=\sum_{c}\sum_{i}b_{i,c}\cdot\sigma_{i,c}\leq R_{S1}$$

$$\sum_{i}b_{i,c}\leq B_c \quad \forall c$$

Case	aGW traffic shaping	Radio scheduler
No S1 bottleneck	-	Optimal algorithm
Only S1 bottleneck	Lagrangian relaxation solved by bisection search	**Two heuristics (Centralized/Coordinated MAC scheduler)**
Both S1 and some cells are bottleneck	**Lagrangian relaxation sovled by projected subgradient method**	

Problem formulation

- The utility function of the user *i* in cell *c*:

$$u_{i,c}\left(b_{i,c}\right)=\frac{A}{1+e^{-\alpha_{i,c}\cdot\sigma_{i,c}\cdot b_{i,c}}}+B=\frac{A}{2}\left[\tanh\left(\frac{\alpha_{i,c}\cdot\sigma_{i,c}\cdot b_{i,c}}{2}\right)+1\right]+B$$

- The goal for the resource allocation is to maximize the aggregated utility, which can be expressed as:

$$\max\left\{U=\sum_{c}\sum_{i}u_{i,c}\left(b_{i,c}\right)\right\}$$

$$s.t.\quad \sum_{i}b_{i,c}\leq B_{c}\quad \forall c;\quad \sum_{c}\sum_{i}b_{i,c}\cdot\sigma_{i,c}\leq R_{S1}$$

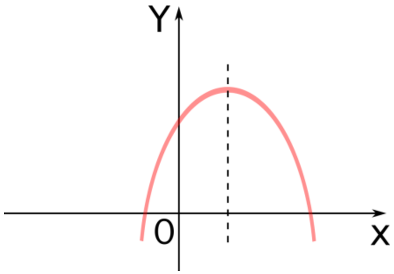
- The problem is convex and has a strong duality, which can be solved optimally using the Lagrangian decomposition method.
  - Hessian matrix positive definite -> Problem is convex
  - Slater’s condition fulfilled -> Strong duality holds

Lagrangian dual problem formulation

- The Lagrangian dual problem is:

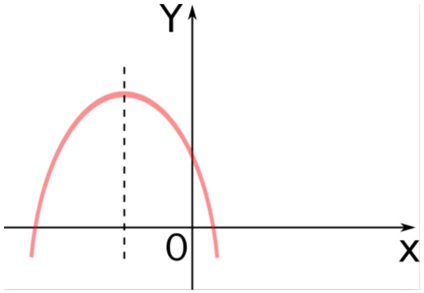
$$f = \min_{\{\boldsymbol{\lambda}\}}\left\{\max_{\{\mathbf{b}\}}\left\{\sum_{c}\sum_{i}u_{i,c}\left(b_{i,c}\right)-\sum_{c}\lambda_{c}\left(\sum_{i}b_{i,c}-B_{c}\right)-\lambda_{0}\left(\sum_{c}\sum_{i}b_{i,c}\cdot\sigma_{i,c}-R_{S1}\right)\right\}\right\}$$

$$=\min_{\{\boldsymbol{\lambda}\}}\left\{\sum_{c}\sum_{i}\max_{\{\mathbf{b}\}}\left\{\overbrace{u_{i,c}\left(b_{i,c}\right)-\left(\lambda_{c}+\lambda_{0}\cdot\sigma_{i,c}\right)b_{i,c}}^{L_{i,c}}\right\}+\sum_{c}\lambda_{c}\cdot B_{c}+\lambda_{0}\cdot R_{S1}\right\}$$



- Consider the problem:

$$\max\left\{L_{i,c}\right\}=L_{i,c}^{*}=\begin{cases}u_{i,c}\left(b_{i,c}^{*}\right)-\left(\lambda_{c}+\lambda_{0}\cdot\sigma_{i,c}\right)b_{i,c}^{*} & \text{if } \left.\dfrac{du_{i,c}\left(b_{i,c}\right)}{db_{i,c}}\right|_{b_{i,c}=0}\geq\left(\lambda_{c}+\lambda_{0}\cdot\sigma_{i,c}\right)\\ u_{i,c}\left(0\right) & \text{if } \left.\dfrac{du_{i,c}\left(b_{i,c}\right)}{db_{i,c}}\right|_{b_{i,c}=0}<\left(\lambda_{c}+\lambda_{0}\cdot\sigma_{i,c}\right)\end{cases}$$



$\forall b_{i,c}\geq 0, L_{i,c}$ is a concave function and has one and only one maximum $L^{*}_{i,c}$. Then the dual problem becomes:

$$f=\min_{\{\boldsymbol{\lambda}\}}\left\{q\right\}=\min_{\{\boldsymbol{\lambda}\}}\left\{\sum_{c}\sum_{i}L_{i,c}^{*}+\sum_{c}\lambda_{c}\cdot B_{c}+\lambda_{0}\cdot R_{S1}\right\}$$

q has one and only one minimum, which is also the optimal solution to the primal problem.

Subgradient projection method

$$f = \min_{\{\boldsymbol{\lambda}\}}\{q\} = \min_{\{\boldsymbol{\lambda}\}}\left\{\sum_{c}\sum_{i} L^{*}_{i,c} + \sum_{c} \lambda_c \cdot B_c + \lambda_0 \cdot R_{S1}\right\}$$

$$\text{s.t. } \boldsymbol{\lambda} \in \mathrm{R}^{+} \bigcup \{0\}$$

- Subgradient projection method is applied
  - an iterative method that starts with some initial feasible vector : $\boldsymbol{\lambda}^{(0)} \geq 0$

$$\boldsymbol{\lambda}^{(k+1)} = P\left(\boldsymbol{\lambda}^{(k)} - \mathbf{t}^{(k)}\mathbf{s}^{(k)}\right) = \begin{cases} \boldsymbol{\lambda}^{(k)} - \mathbf{t}^{(k)}\mathbf{s}^{(k)} & \boldsymbol{\lambda}^{(k)} - \mathbf{t}^{(k)}\mathbf{s}^{(k)} \geq 0 \\ 0 & \boldsymbol{\lambda}^{(k)} - \mathbf{t}^{(k)}\mathbf{s}^{(k)} < 0 \end{cases}$$

  - with modified Polyak's step size

$$\mathbf{t}^{(k)} = \gamma \cdot \frac{f\left(\boldsymbol{\lambda}^{(k)}\right) - \hat{f}^{(k)}}{\|\mathbf{s}^{(k)}\|^{2}} \quad \text{with} \quad \hat{f}^{(k)} = \min_{0 \leq j \leq k} f\left(\boldsymbol{\lambda}^{(k)}\right) - \delta$$

$\|\mathbf{s}_k\|$ is the *Euclidean distance*: $\|\mathbf{s}^{(k)}\|^{2} = s_1{}^{2} + s_2{}^{2} + \ldots + s_n{}^{2}$

  - Convergence rule

$$f\left(\boldsymbol{\lambda}^{(k)}\right) - \min_{0 \leq j \leq k} f\left(\boldsymbol{\lambda}^{(k)}\right) \leq o \qquad o : \text{a predefined value regarding to accuracy}$$

Subgradient projection method

$$f = \min_{\{\boldsymbol{\lambda}\}} \{q\} = \min_{\{\boldsymbol{\lambda}\}} \left\{ \sum_{c} \sum_{i} L^{*}_{i,c} + \sum_{c} \lambda_c \cdot B_c + \lambda_0 \cdot R_{S1} \right\}$$

$$\text{s.t. } \boldsymbol{\lambda} \in \mathrm{R}^{+} \cup \{0\}$$

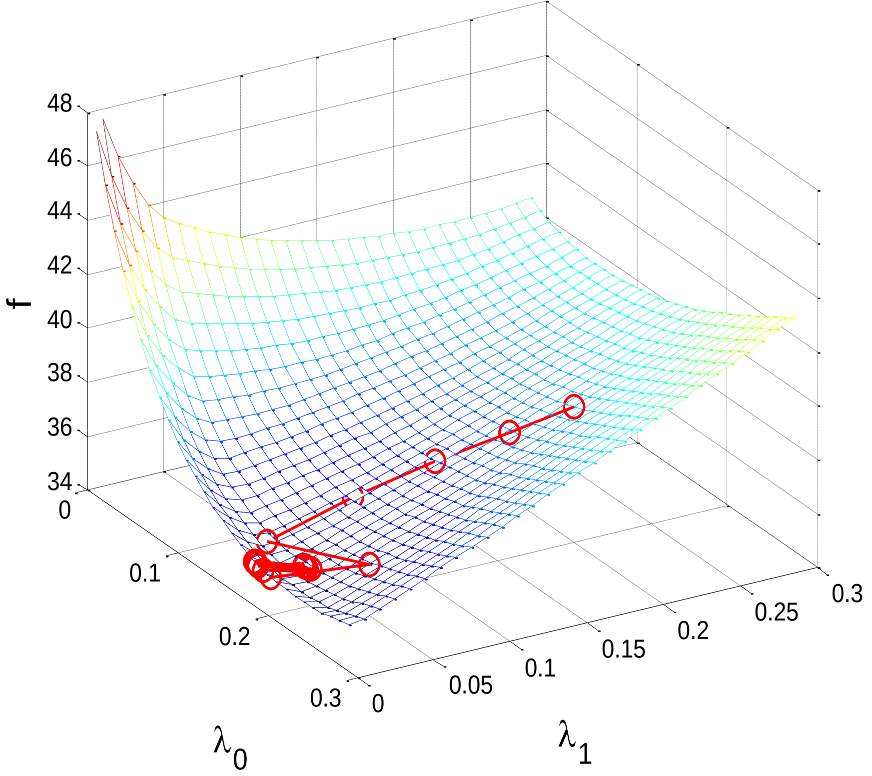


Figure: Visualization of the subgradient method

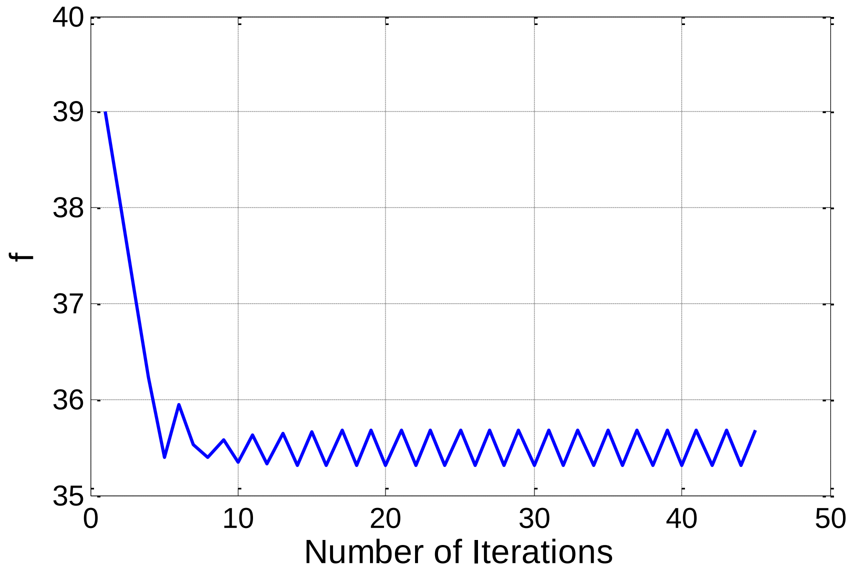


Figure: Visualization of convergency

Radio scheduler heuristics

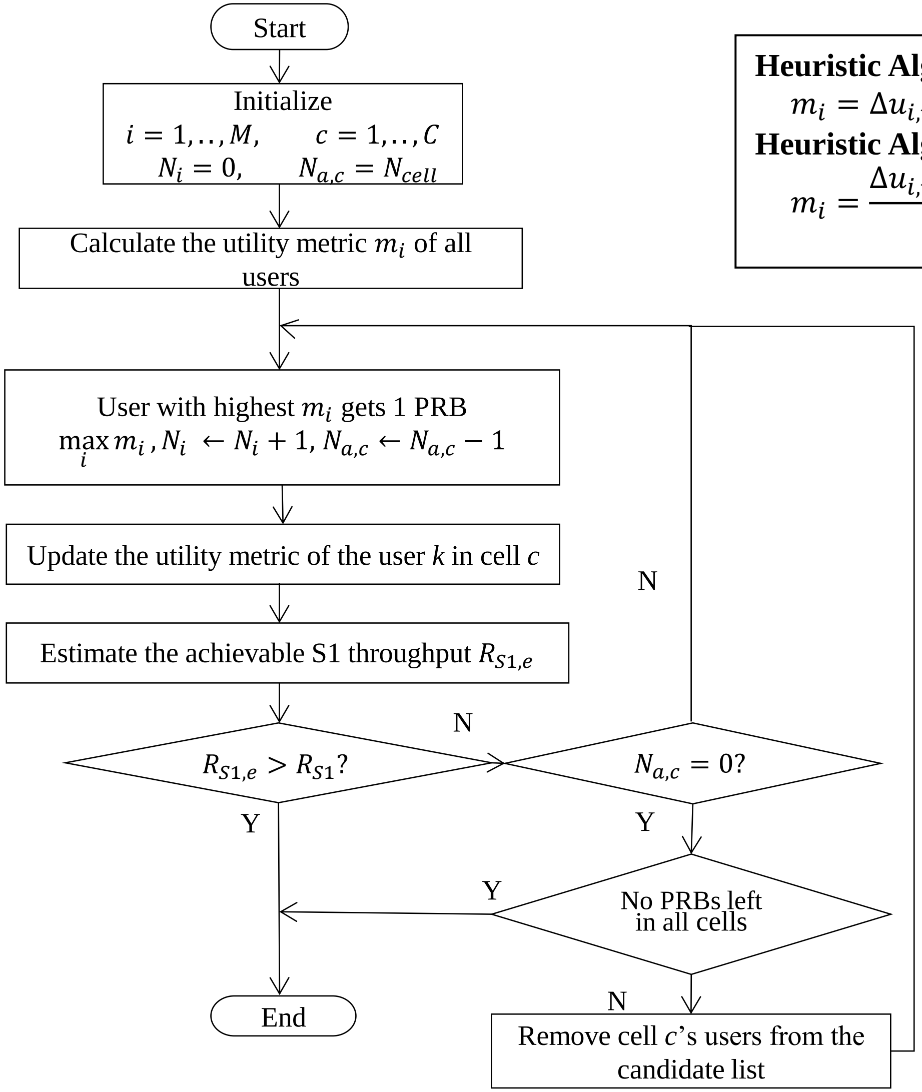


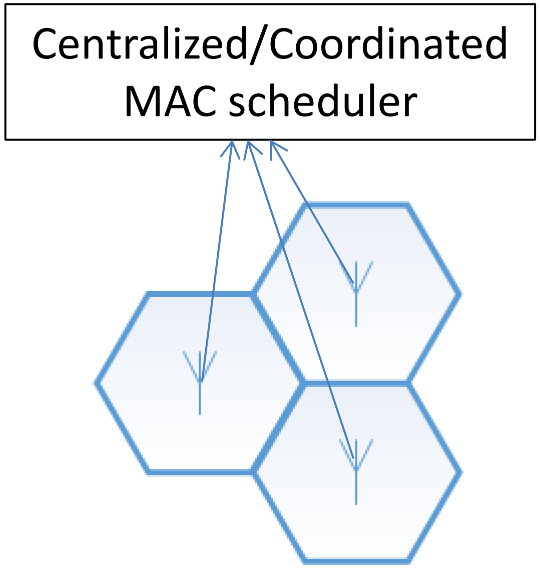
Figure: The algorithm of the proposed heuristic

Heuristic Algorithm 1:

$$m_i = \Delta u_{i,n+1} - \Delta u_{i,n}$$

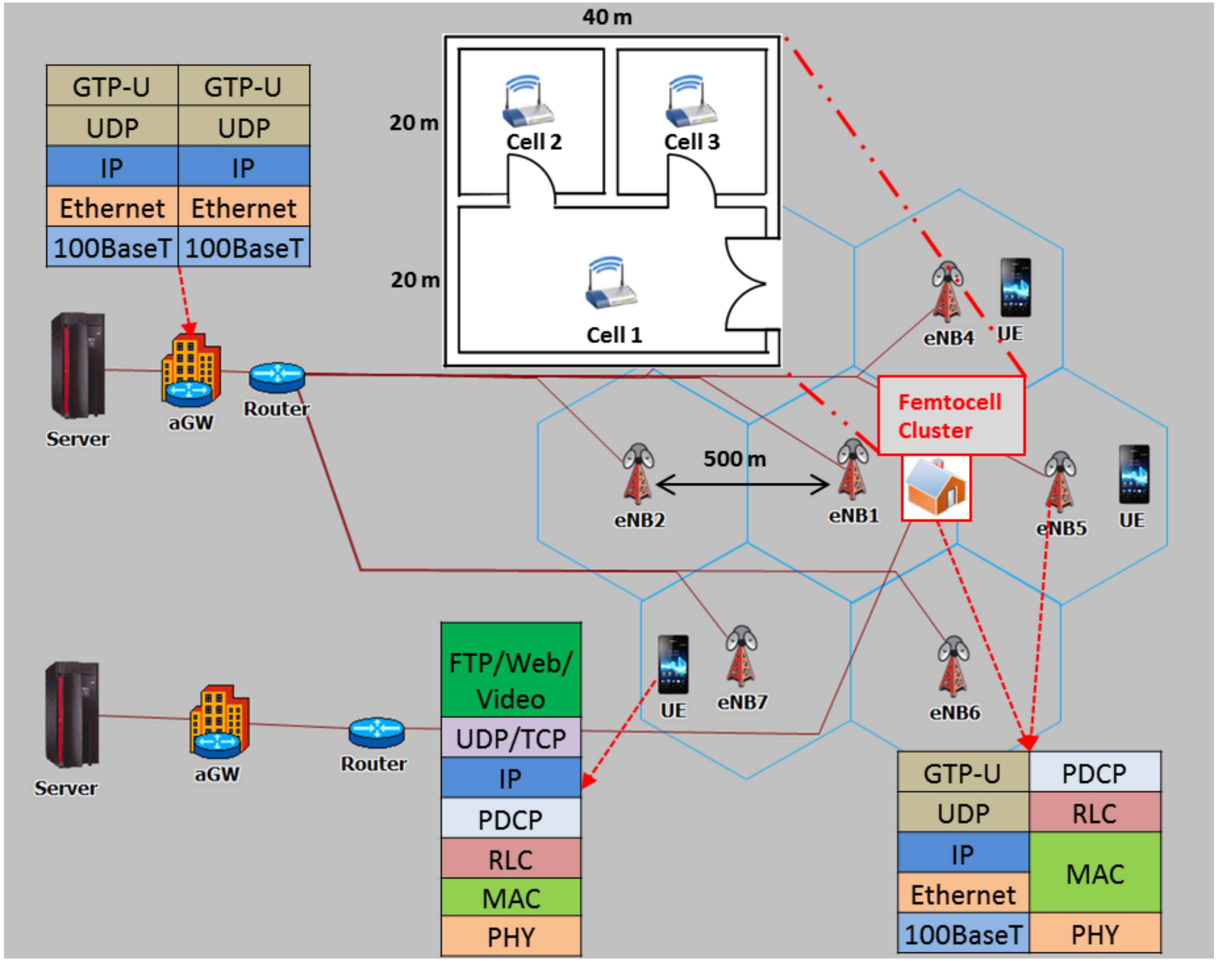
Heuristic Algorithm 2:

$$m_i = \frac{\Delta u_{i,n+1} - \Delta u_{i,n}}{\sigma_i}$$



i,c	User index; Cell index
$M;C$	Number of users; Number of cells
N_i	Number of PRBs allocated to user *i*
$N_{a,c}$	Total available PRBs in the cell *c* after HARQ (Hybrid Automatic Repeat Request)
N_{cell}	Number of PRBs in the cell
m_i	QoE metric of user *i*
u_i	QoE of user i
$\Delta u_{i,n}$	Marginal QoE of user *i* with *n* PRBs
σ_i	Channel quality indicator of user *i*
R_{S1}	Transport network capacity in Mbps
$R_{S1,e}$	Estimated achievable throughput on S_1

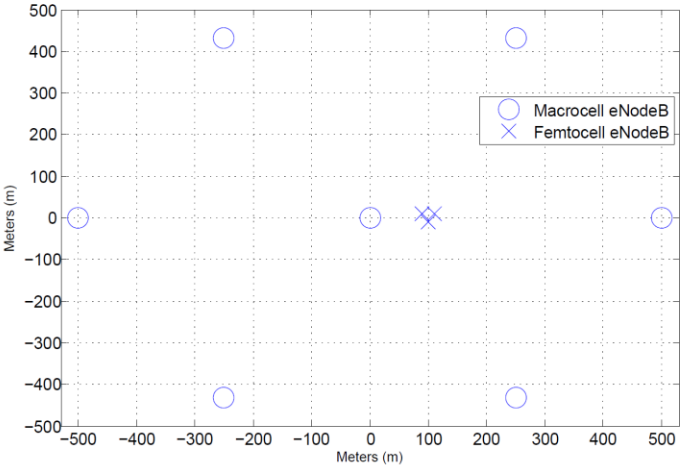
Simulation tool and scenario



Use OPNET discrete event simulation software (v17.5)

Includes modeling of

- E-UTRAN and EPC entities
- Full protocol stack including MAC, RLC, PDCP, GTP etc.
- Mobility models
- IP DiffServ



Simulation settings

Parameter	Settings
Macro eNBs (cells) settings (fully loaded)	7 eNBs with hexagonal coverage, 500ms inter-eNB distance (center eNB located at the original point (0m, 0m)) Path loss: 130.5 + 37.6log10(R), R in Km [5] Slow fading: Correlated Log normal, zero mean, 8db std. and 50 m correlation distance Small scale fading: 3GPP Pedestrian A Transmission power: 23dBm per PRB
Femtocell cluster settings	Building size with 40mx40m, center coordinate: (200m,0m) 3 femtocell station coordinates: (210m, -10m), (190m, 10m), (210m,10m) Penetration loss (interference from macro eNBs) over the wall: 12dB mean with 8dB std. Path loss: 41.1 + 16.9*log10(R), R in Km [5] Small scale fading: 3GPP Pedestrian A Transmission power: 0dBm per PRB
TCP version	New Reno with 64Kbytes receiver buffer size
Traffic types	VoIP: GSM EFR, codec rate 12.2 kbps Video Streaming: TCP based full buffer streaming HTTP: 2MB page size, Inter arrival time: exp. distributed with mean: 50s FTP: 10MB file size, Inter arrival time: exp. distributed with mean: 50s
Mobility model	5Km/h, Random waypoint
aGW shaper	Token Bucket algorithm, maximum token bucket size: 64KB
Transport limitation	16Mbps or 6 Mbps (aGW->femtocell cluster); 1Mbytes buffer size
Number of PRBs	25 PRBs (5MHz spectrum at 2.6 GHz)
Simulation time	1000s (5 runs with different seeds) with warm up period of 300s

QoE functions

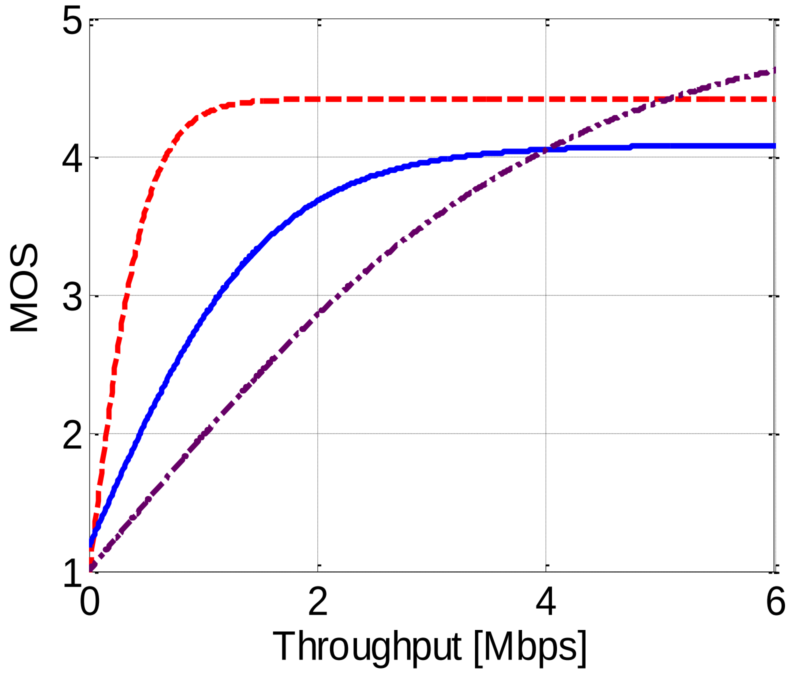


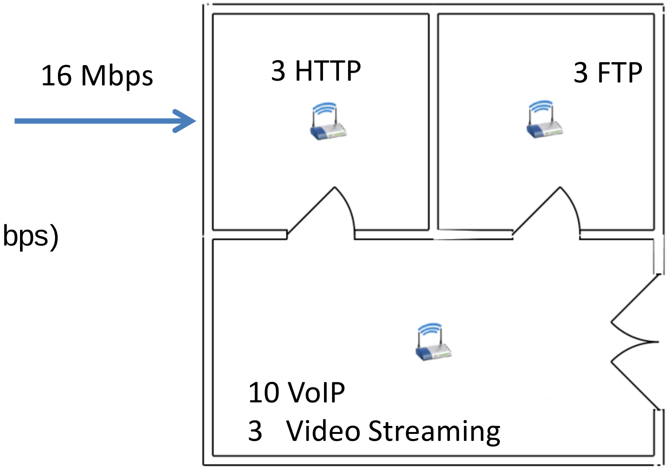
Fig. QoE functions used in the simulation [1][3]

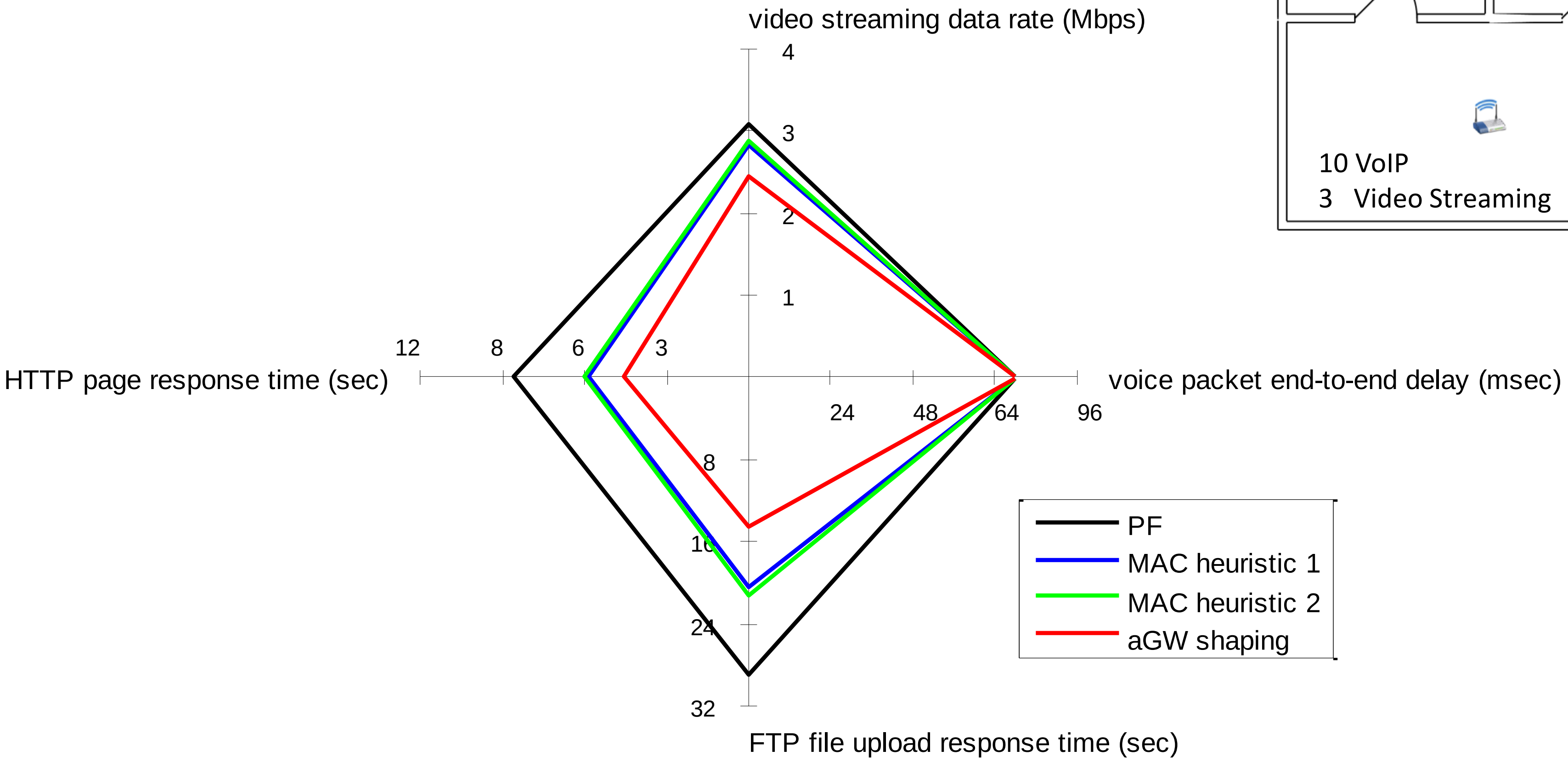
$$u = \frac{A}{1 + e^{-\alpha \cdot r}} + B$$

	A	B	α
Video	6.954	-2.542	4.104
Web	5.815	-1.735	1.294
FTP	8	-3	0.5

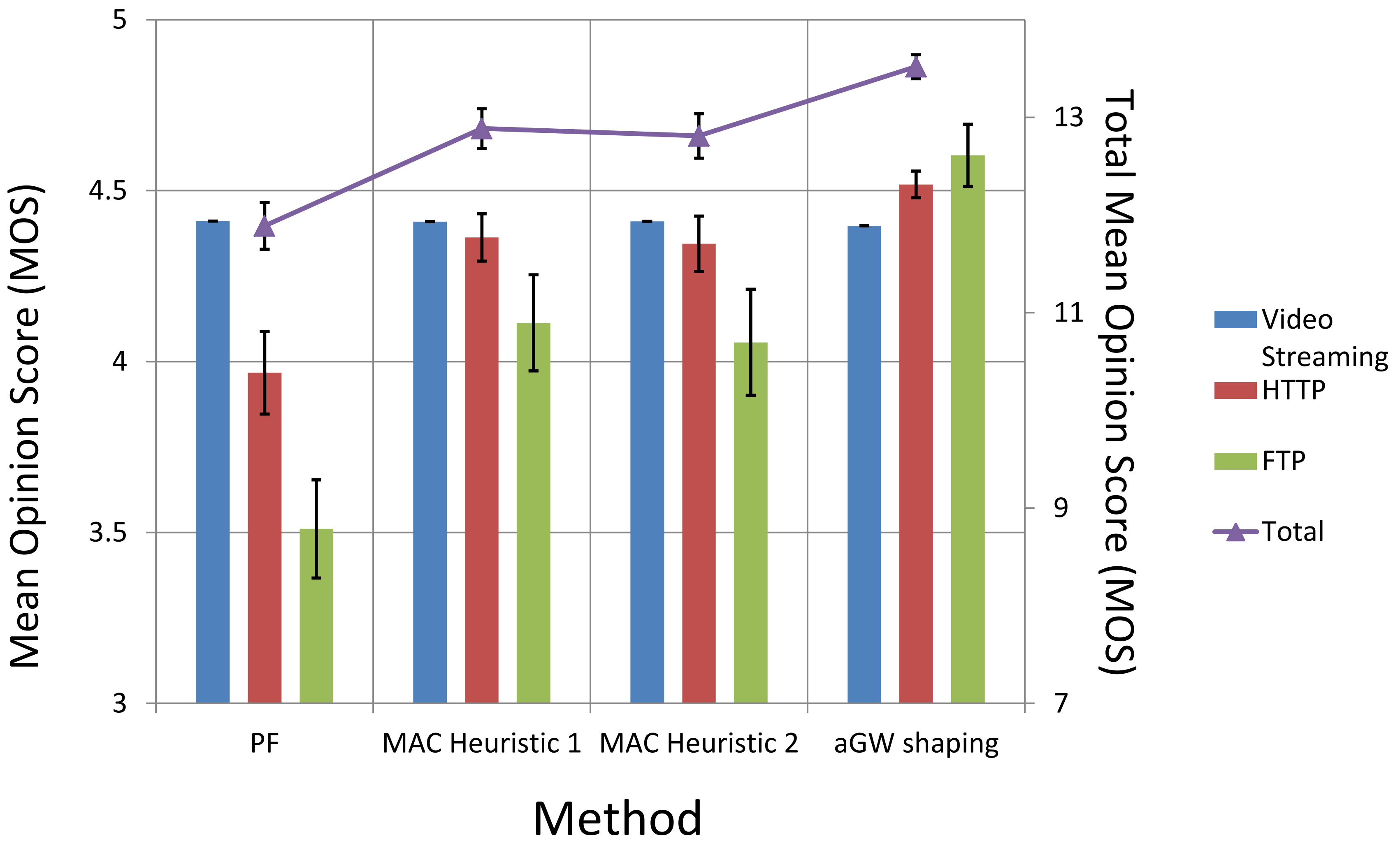
Table: Parameters for QoE Functions

Scenario 1 - Low Load





Scenario 1 - Low Load



Scenario 2 – High Load

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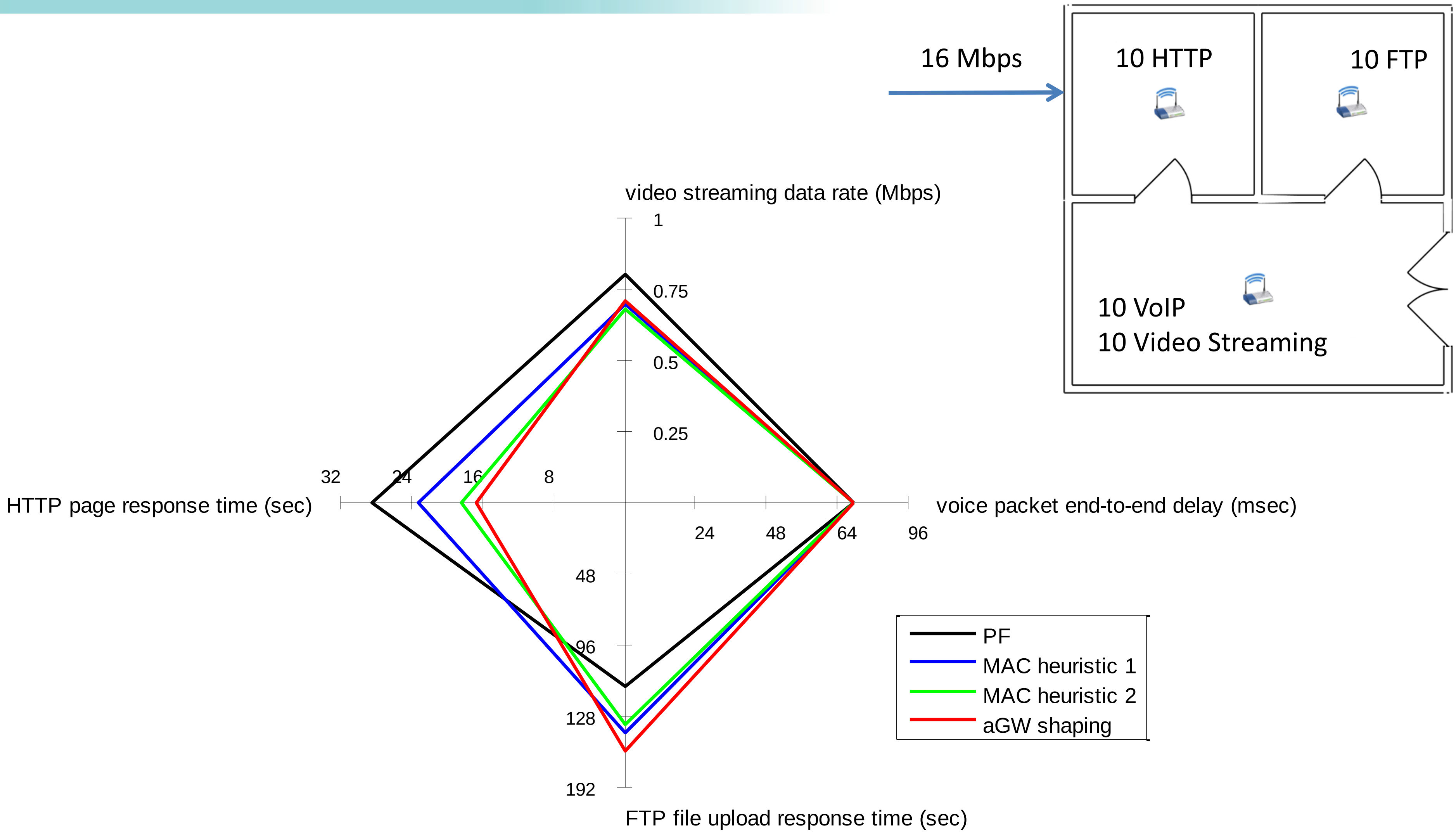
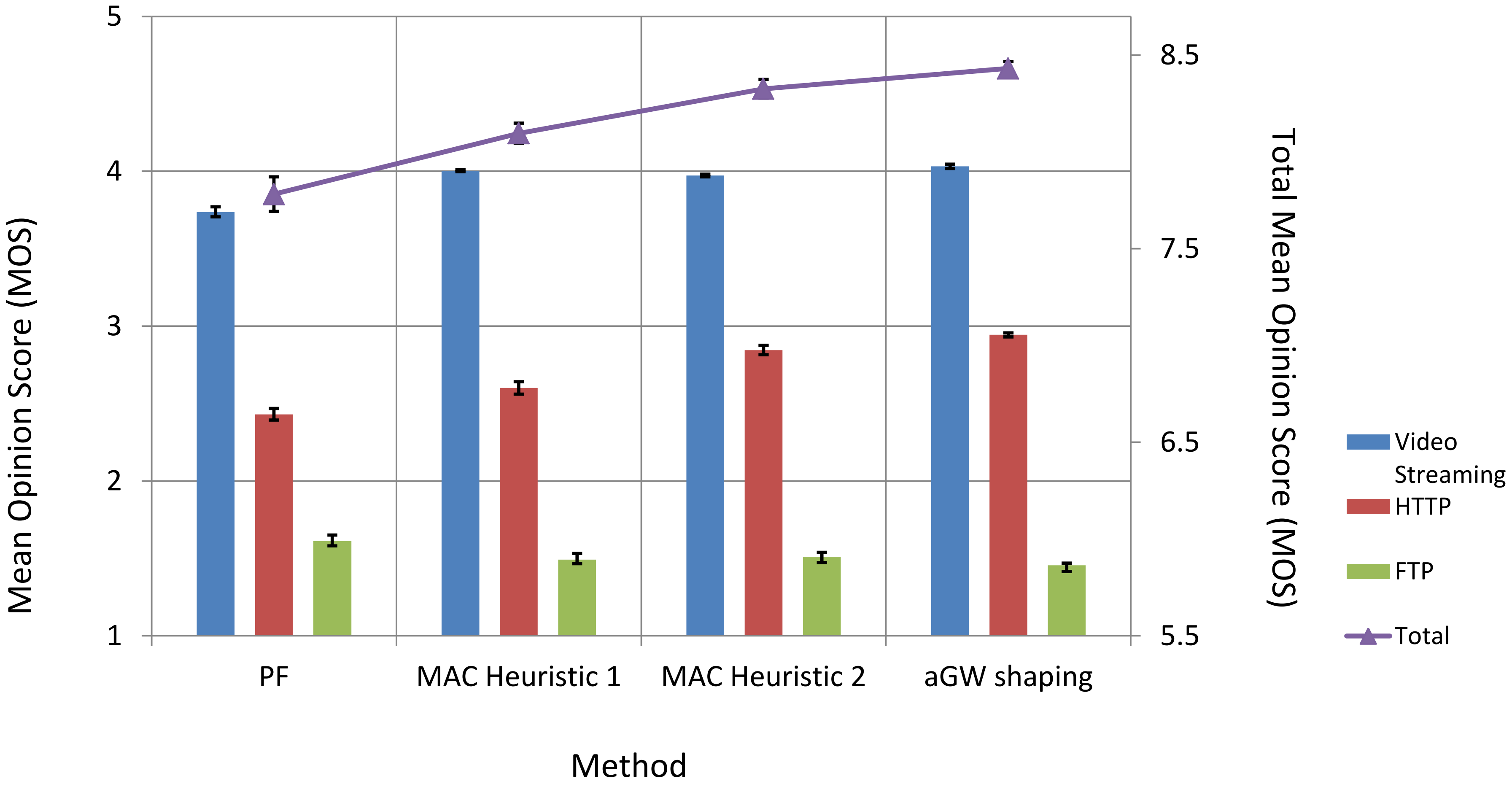


Scenario 2 – High Load



Scenario 3 – Very High Load

ComNets
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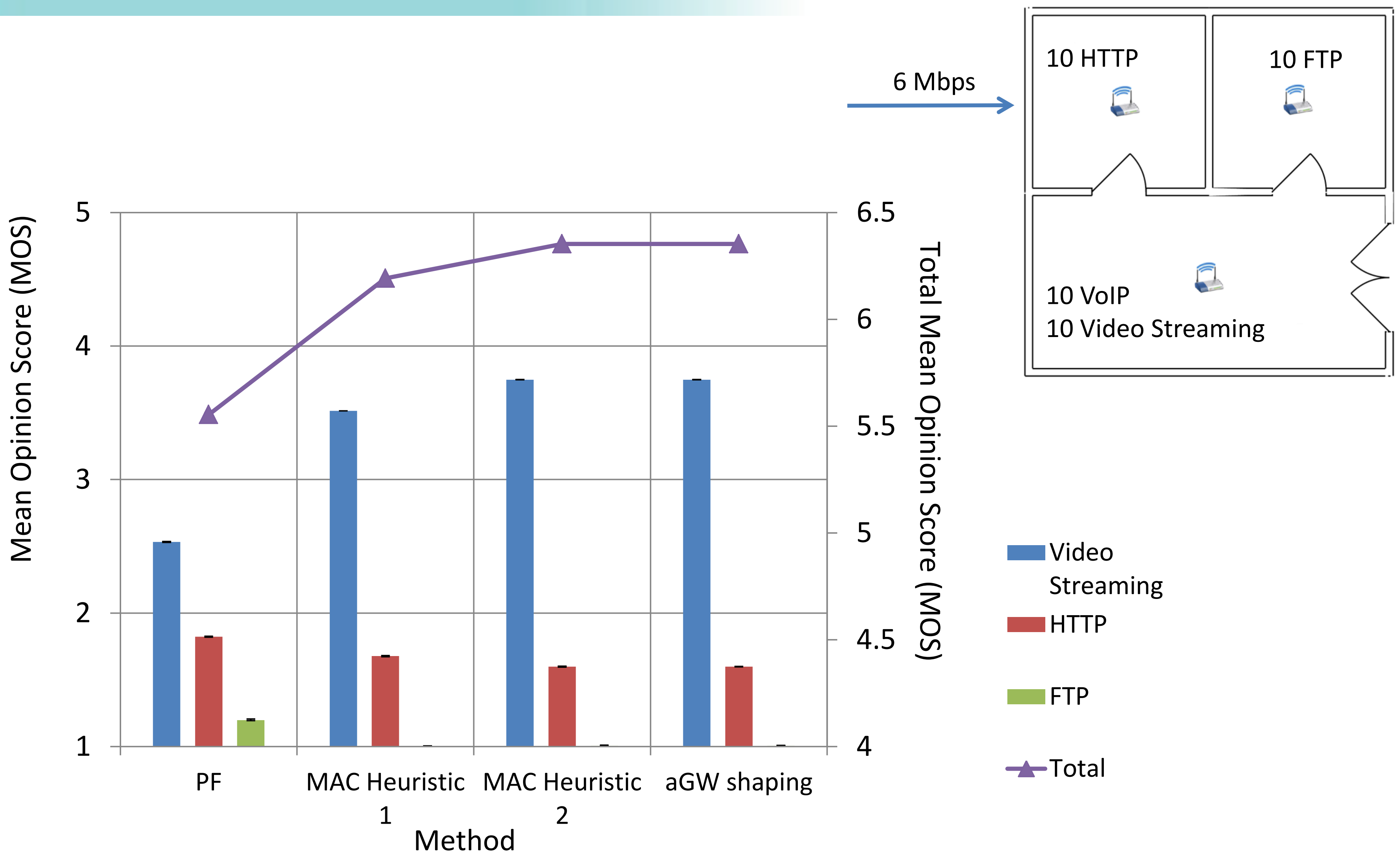
TUHH



Summary

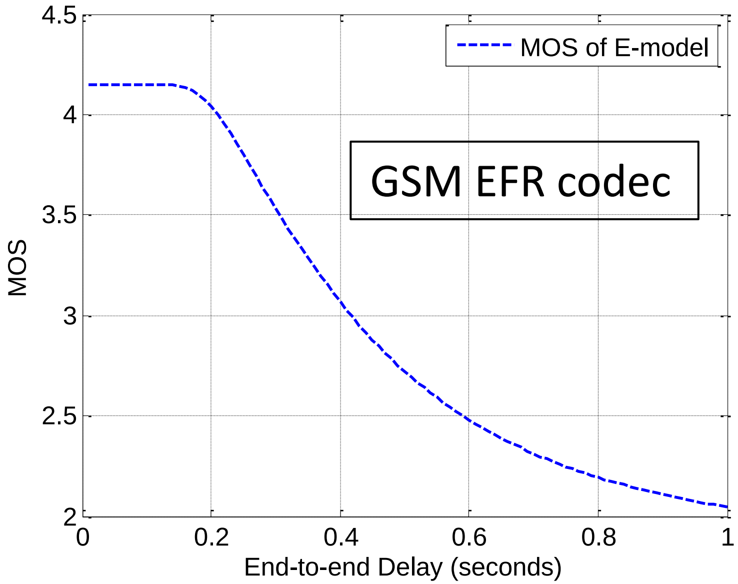
- A utility based resource allocation framework for LTE is proposed.
- The problem is formulated as a convex optimization problem and analytically solved using Lagrangian decomposition method.
- The approach is implemented in the simulator. The performance of utility based approach is compared against PF scheduler.

Case	aGW traffic shaping	Radio scheduler
Both S1 and some cells are bottleneck	Lagrangian relaxation Sovled by projected subgradient method	Two heuristics (Centrilized/Coordinated MAC scheduler)
Advantages	1. Give the best performance 2. No need to modify the radio scheduler	1. Low computational power 2. Good performance, heuristic 2 is better than 1 in high load scenarios
Disadvantages	1. Signallings between eNB and aGW 2. High computational power	1. Need a centrilized/coordinated scheduler among the cells sharing the same transport link

Ongoing Works

$$\max \left\{ U = \sum_{c} \sum_{i} w_{i,c} \cdot u_{i,c}\left(r_{i,c}\right) \right\}$$

Traffic Type	**Delay sensitive traffics (Real-time)**	**Rate sensitive traffics (Non Real-time)**
Utility Functions	$u_{i,c}\left(r_{i,c}\right) = \frac{\left\lvert u'\left(d_{i,c}\right)\right\rvert}{\lambda_{i,c}} \cdot r_{i,c}$	$u_{i,c}\left(r_{i,c}\right) = \frac{A}{1+e^{-\alpha_{i,c} \cdot r_{i,c}}} \cdot r_{i,c} + B$
Optimatizon Model	Linear Programming	Concave Optimatization



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Thanks and any Questions?

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