A Measurement-Based Algorithm to Maximize the Utility of Wireless Networks

Julien Herzen

joint work with

Adel Aziz, Ruben Merz, Seva Shneer and Patrick Thiran

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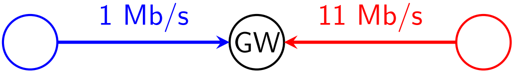
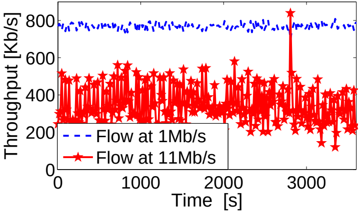
Context

Inefficient situations in wireless LANs

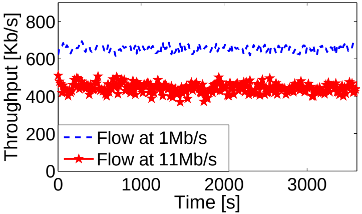
- **Example**, performance anomaly:



UDP

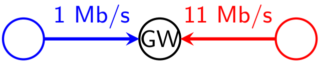


TCP



- **Intuition:** Send slightly fewer packets at 1 Mb/s, so that the flow at 11 Mb/s can send many more

Approach



- **Formalization:** Capture the efficiency and the fairness of the network using a utility function

$$U = \sum_i u_i(x_i),$$

x_i: throughput of flow i

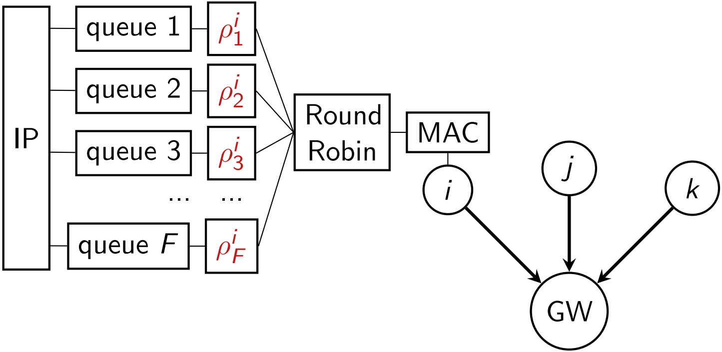
Examples

$$U_{max} = \sum_i x_i$$

$$U_{prop} = \sum_i \log x_i$$

Network Stack

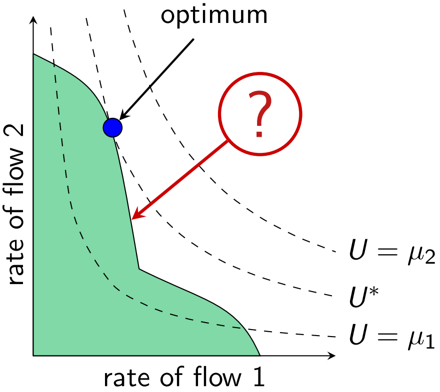
- Backward compatibility → runs on top of IEEE 802.11
- Congestion control → throttle each flow
- One limiter per IP source in the network



How to throttle the flows?

- Find the rate allocation $\boldsymbol{\rho}$ that maximizes the utility U
- **Problem: We do not know the feasible rate region!**
  - hard to predict or measure

$$\boxed{U = \sum \log x_i}$$



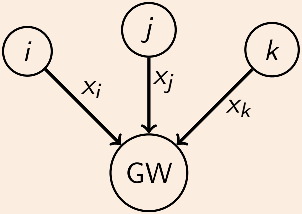
Decide at the gateway

The gateway knows

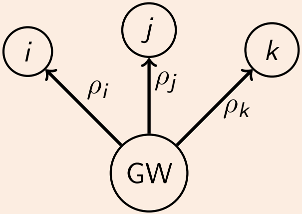
- The throughput achieved by the flows: $\mathbf{x}$
- The current utility of the network: $U(\mathbf{x}) = \sum u_i(x_i)$
- If $\mathbf{x} = \boldsymbol{\rho}$, then $\boldsymbol{\rho}$ belongs to the rate region

Measure and Decide loop

- Measure each flow
- Decide
- Broadcast decision



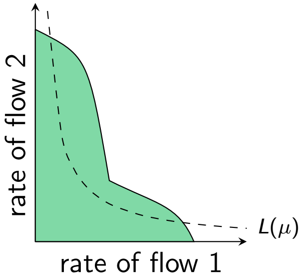
?



Model

At time slot n:

- Measured throughput: $\mathbf{x}[n] \in \mathbb{R}_+^F$
- Rate allocation vector: $\boldsymbol{\rho}[n] \in \mathbb{R}_+^F$
- Last stable rate allocation: $\mathbf{r}[n] \in \mathbb{R}_+^F$
- Utility function: $U(\mathbf{x}) = \sum_i u_i(x_i)$

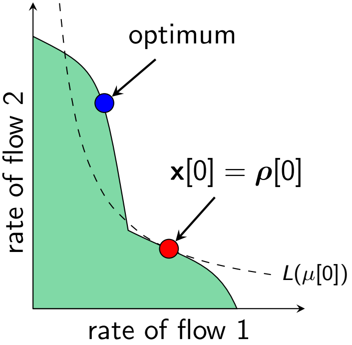


- Level set: $L(\mu[n]) = \{\mathbf{x}[n] : U(\mathbf{x}[n]) = \mu[n], \mathbf{x}[n] \in \mathbb{R}_+^F\}$

Step 1 - Start from IEEE 802.11 allocation

- $\boldsymbol{\rho}[0] \leftarrow \mathbf{x}[0]$
- Current level set: $L(U(\mathbf{x}[0]))$
- Remember allocation $\mathbf{r}[0] \leftarrow \mathbf{x}[0]$

$$\boxed{U = \sum \log x_i}$$

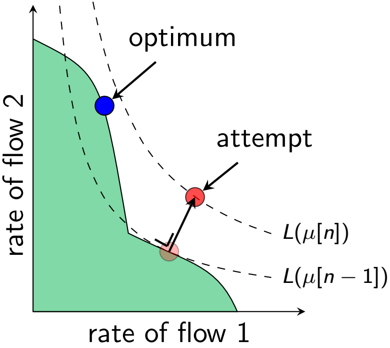


Step 2 - Enhance phase

Time step n:

- If $\mathbf{x}[n-1] = \boldsymbol{\rho}[n-1]$:
  - Obtain a new target utility $\mu[n]$ by a **full size gradient ascent**
- Else:
  - Obtain a new target utility $\mu[n]$ by **halving the size of the gradient ascent**
- Go to Explore phase (next slide)

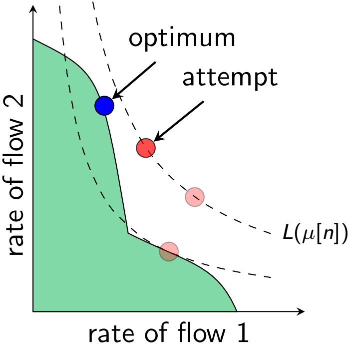
$$\boxed{U = \sum \log x_i}$$



Step 3 - Explore phase

- If $\mathbf{x}[n-1] = \boldsymbol{\rho}[n-1]$:
  - Remember $\mathbf{r}[n] = \boldsymbol{\rho}[n-1]$
  - Go to Enhance phase
- Else:
  - Keep target utility: $\mu[n] = \mu[n-1]$
  - Pick $\boldsymbol{\rho}[n]$ randomly in $L(\mu[n])$
  - Repeat explore phase at most N times, then move to Enhance phase (and **reduce the size of the gradient ascent**)

$$\boxed{U = \sum \log x_i}$$



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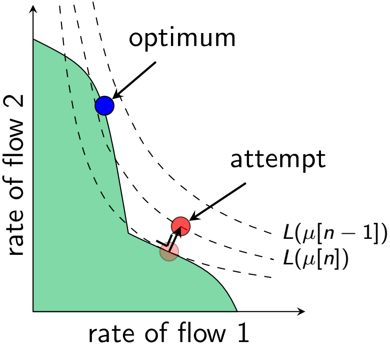

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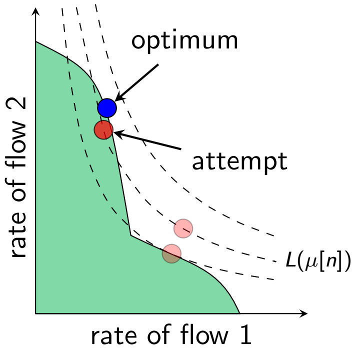

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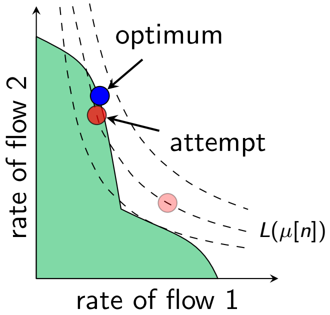
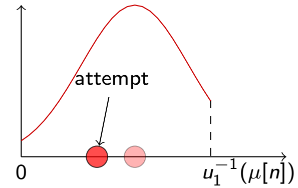


truncated Gaussian PDF for picking ρ_1:



Optimality result

Assumptions

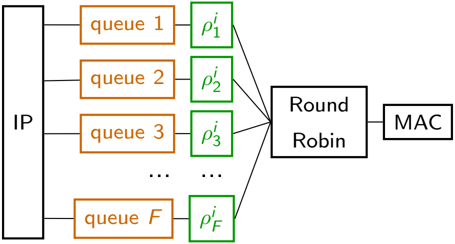
- Fixed rate region $\Lambda[n] = \Lambda$
- Coordinate-convex rate region
    - **Much weaker than convexity!**

Theorem

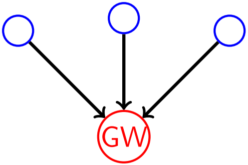
The Enhance & Explore algorithm guarantees that, for any initial rate allocation $\mathbf{r}[0]$*, the utility of the last stable rate allocation* $\mathbf{r}[n]$ *converges to the maximal utility for* $n \to \infty$*.*

Practical implementation

- Based on *Click*[1] with *MultiflowDispatcher*[2]



- Creation of 4 new *Click* elements
  - MFQueue
  - MFLeakyBucket
  - EEadapter
  - EEscheduler
- Evaluation with
  - Asus routers
  - *ns-3*

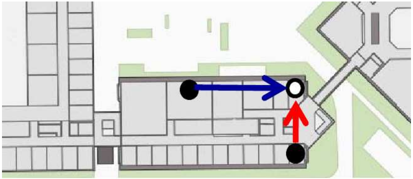


[1] Kohler et al., Transactions on Computer Systems, 2000

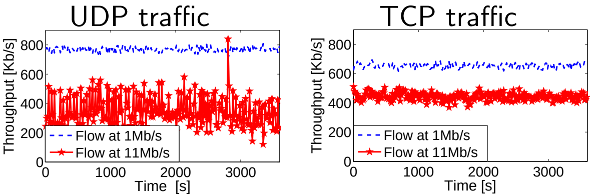
[2] Schiöberg et al., SyClick, 2009

Experimental results

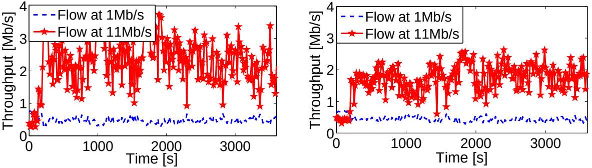
- Deployment map:



- Without E&E:



- With E&E (U_{prop}):



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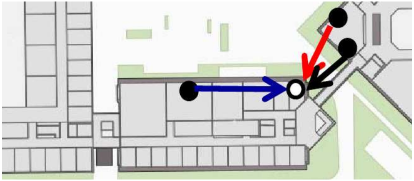

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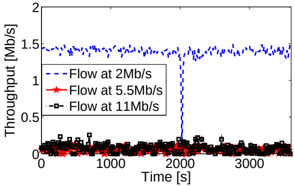

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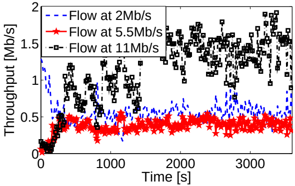
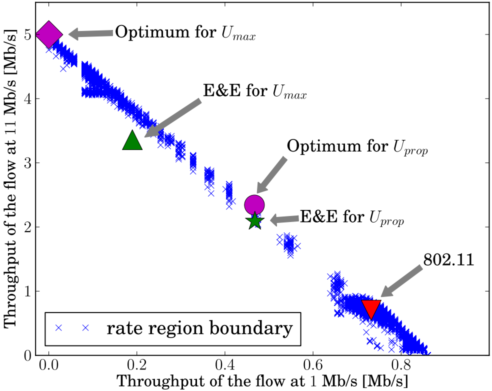
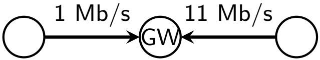


Simulation results

ns-3 simulator

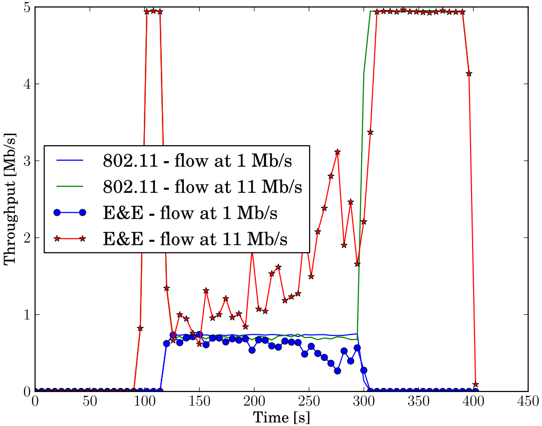
- Re-use of the same *Click* elements
- More controlled environment
- Possible estimation of the rate region
- Computation of optima





Simulation results

- Adaptivity to time-varying traffic
- Cyclic validation of last stable allocation $\mathbf{r}[n]$



Conclusion

Problem

- Inefficient and/or unfair situations in WLANs
- Capture efficiency and fairness using a utilility function
  - **The feasible rate region is unknown!**

Solution

- Successive decisions and measurements by the GW
- Optimal for a fixed rate region
- When rate region changes, keeps adapting
- More details in [1], with an extension to multi-hop networks

Future work:

- Downlink traffic
- Rate adaptation

[1] Aziz et al., Mobicom 2011