# User- and Application-Centric Multihomed Flow Management

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# Outline

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2. Multihomed Flow Management
3. Evaluation and Comparison Scenarios
4. Results
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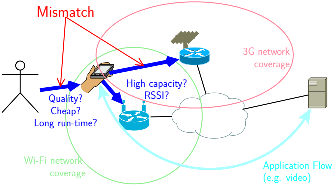
   - Smart-phone example
5. Conclusion and Future Work

# Context and Problem

## Mismatch between network selection algorithms and users' needs

- Mobile devices
  - Computationally powerful
    - Many applications
  - Multiple wireless interfaces
    - Heterogeneous characteristics
  - One or more networks of each technology
    - Other factors, also different
- Problems
  - Choose only the **best network(s?)**
  - Distribute application flows
- What is best?
  - Potential mismatch between users' perception and technical metrics
    - QoS vs. QoE
    - Battery lifetime
    - Price



# Multihomed Flow Management

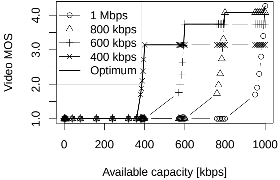
## Privileging users' perceptions and expectations

- Focus on application performance
  - QoS only relevant to the application
  - User experiences the application's output
    - Varies with parameters, codecs, compression,. . .
- Flat battery the worst experience
  - Balance energy consumption
- User's wallet not a bottomless bag
  - Less pricey networks are better
- **Conflicting goals**
  - Need for tradeoffs

# Multihomed Flow Management

## Problem formalisation

- The **Multihomed Flow Management problem**
  - Maximise application quality
    - Adjustable parameters
    - Optional requirements
    - Non-linear QoE/QoS relation (*e.g.*, H.264)




  - Reduce costs
    - Energy consumption of network interfaces
    - Prices to access some networks
- Decision scope
  - Activate relevant interfaces
  - Select most appropriate networks
  - Distribute applications flows
  - Pre-emptively adjust stack parameters (*e.g.*, application or transport)
- More precise constrained formulation in the paper (Eq. 1)

# Evaluation and Comparison Scenarios

## Basic scenarios

- MiniZinc-based constrained optimisation
  - Optimal solution
  - Sometimes very long computation time. . .
- Comparison to more common techniques

  **NS** Single network/interface selection (*i.e.*, iPhones *et al.*; Eq. 3)

  **LB** Load balancing on each interface's best network (Eq. 5)

- Two types of scenarios

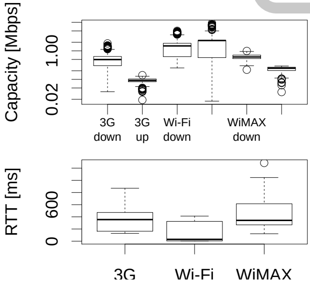
  **Synthetic scenarios** Number of interfaces, networks and flows chosen randomly

  **Smart-phone example** Single Wi-Fi and 3G interfaces, random networks, fixed demand (2 VoIP and video flows, 3 web sessions)

# Evaluation and Comparison Scenarios

## Data sources

- QoS measured from various access networks (Australia, Germany) to know measurement servers (Australia, France)

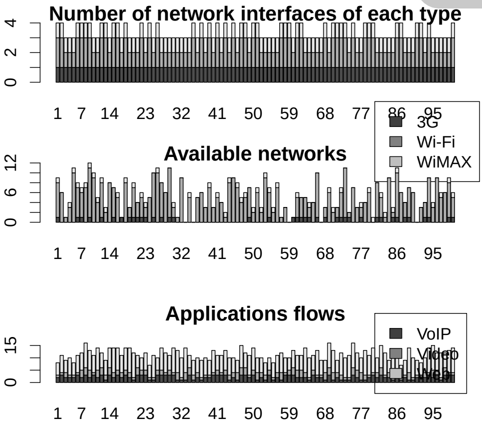



- Quality profiles (MOS) from ITU-T's objective E-Model (VoIP, video conferencing and web browsing)
  - Nota: easily extended given similarly formulated objective profiles
    - Other interactive applications
    - Non-interactive applications with evaluable performance
- Battery consumption and web usage data from Petander (2009; [20] in the paper)
- Access prices surveyed from Australian operators in December 2010

# Evaluation and Comparison Scenarios

## Data quality

- 95 synthetic scenarios
- 57 smart-phone scenarios

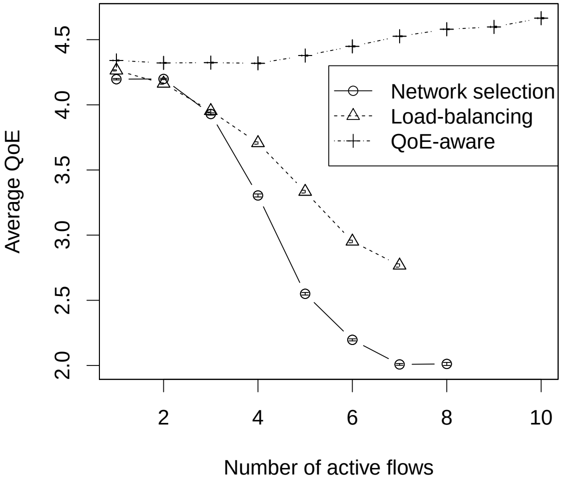


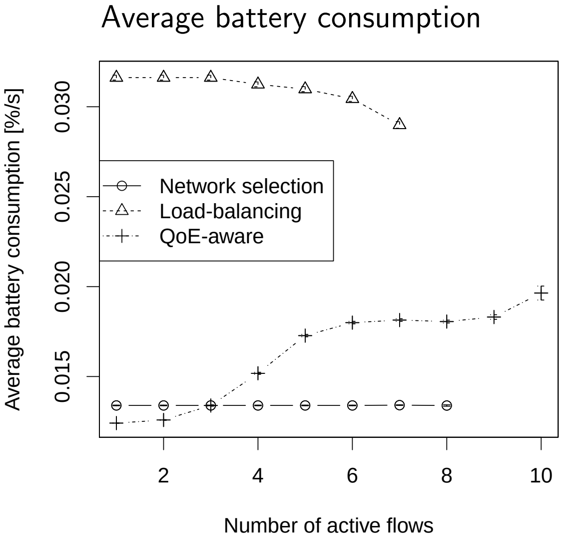

- Results averaged over at least 20 data points, or discarded
- For 7 flows, usually not more than 20 s
    - Not quite real-time. . .

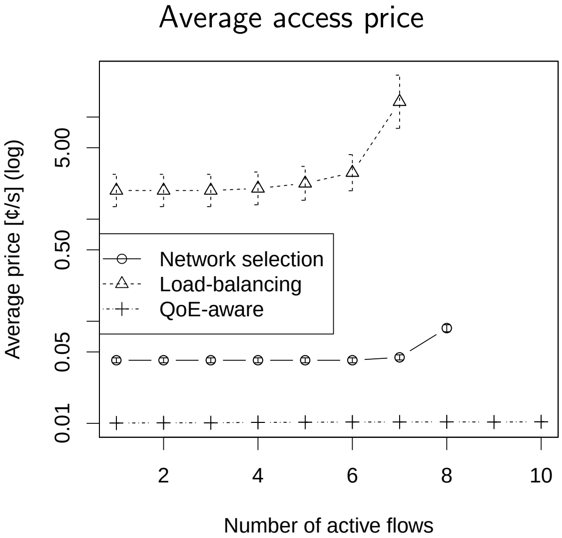
# Results

## Synthetic scenarios

Average application quality



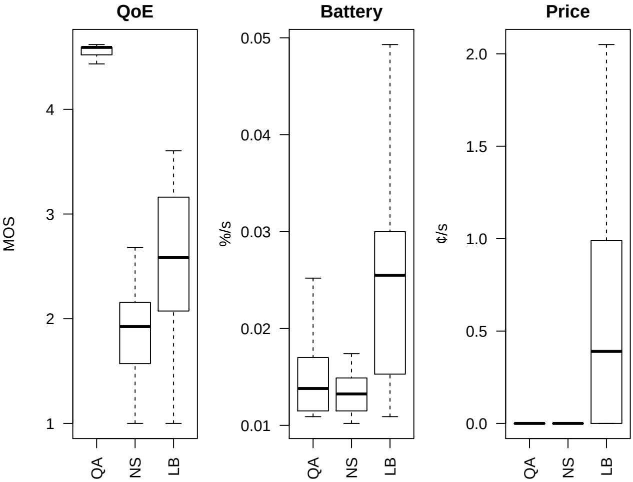

Average battery consumption
Average battery consumption [%/s]
0.015
0.020
0.025
0.030
2
4
6
8
10
Number of active flows
Network selection
Load-balancing
QoE-aware



Average access price
Average price [¢/s] (log)
0.01
0.05
0.50
5.00
2
4
6
8
10
Number of active flows
Network selection
Load-balancing
QoE-aware

# Smart-phone example

## Smart-phone example



# Conclusion and Future Work

- **User- and application-centric approach much more appropriate than QoS-based methods**
  - Keeps the **real** performance metrics on the front line
  - Balances conflicting goals
- Assumptions of our evaluation
  - No power usage data available for WiMAX, used Wi-Fi's
  - Timed-only price for 3G and WiMAX (not per volume or contract), Wi-Fi all free
- Towards large-scale simulation and expermimental evaluation on real platforms
  - Optimisation of the constrained problem formulation for better solving times
  - Linear programming approach
  - Consider user feedback for weighting

# Questions?

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Thanks.

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## References


Datasets Henrik Petander. "Energy-aware Network Selection Using Traffic Estimation". In: **MICNET 2009**. 2009. ISBN: 978-1-60558-753-0. DOI: 10.1145/1614255.1614268. URL: http://www.nicta.com.au/research/research_publications/show?id=2159

MOS ITU-T Recommendation P.800. **Methods for Subjective Determination of Transmission Quality**. ITU-T SG12. 1996. URL: http://www.itu.int/rec/T-REC-P.800-199608-I/en

VoIP ITU-T Recommendation G.107. **The E-Model, a Computational Model for Use in Transmission Planning**. ITU-T SG12. 2005. URL: http://www.itu.int/rec/T-REC-G.107-200904-I/en

Video ITU-T Recommendation G.1070. **Opinion Model for Video-Telephony Applications**. ITU-T SG12. 2007. URL: http://www.itu.int/rec/T-REC-G.1070-200704-I/en

Web ITU-T Recommendation G.1030. **Estimating End-to-End Performance in IP Networks for Data Applications**. ITU-T SG12. 2006. URL: http://www.itu.int/rec/T-REC-G.1030-200511-I/en

VoIP $R = 93.193 - I_s - I_d - I_{e-eff}$

Video $V_q = 1 + I_{coding} \exp\left(\frac{P_{plV}}{D_{PplV}}\right)$ (linear combination for A/V)

Web $MOS_{\mathrm{web}} = 5 + 4 \cdot \frac{\ln(WeightedST) - \ln(Min)}{\ln(Min) - \ln(Max)}$,
$WeightedST = 0.98 \cdot T_3 + 1.76 \cdot T_4$ (discarding search phase)

# Backup

## Notations

| | |
|---|---|
| | **Set of networks** $N$ |
| $\mathrm{None} \in N$ | null network to represent unassociated interfaces |
| | **Set of interfaces** $I$ |
| $\vec{A}, \lvert\vec{A}\rvert = \lvert I \rvert$ | network association vector where $A_i \in N, \forall i \in I$ |
| | **Set of links** $L \subseteq I \times N$ |
| $QoS(l)$ | achievable QoS achievable on link $l \in L$ |
| $Pw(l)$ | power consumption of link $l$ |
| $Pr(l)$ | access price of link $l$ |
| | **QoS tuple** $q = \langle c, r, e, s, \ldots \rangle$ |
| $C(q) = c$ | available capacity |
| $R(q) = r$ | round-trip time |
| $e$ | link error rate |
| $s$ | security index |
| $\ldots$ | other metrics relevant to an application |
| | **Set of flows** $F$ |
| $\vec{D}, \lvert\vec{D}\rvert = \lvert F \rvert$ | flow distribution vector where $D_f \in L, \forall f \in F$ |
| $\vec{p}, \lvert\vec{p}\rvert = \lvert F \rvert$ | application-specific parameters ($p_f$ for flow $f$) |
| $Q(f, p_f, q_f)$ | quality profile of flow $f \in F$ under QoS $q_f$ |
| $q_{\mathrm{req}}(f, p_f)$ | min. required QoS to maximise $Q(f, p_f, q_{\mathrm{req}}(f, p_f))$ |

$$\max_{\vec{A},\vec{D},\vec{p}} \left( \sum_{f \in F} W_f\, Q(f, p_f, q_{\mathrm{req}}(f, p_f)) - W_b \sum_{i \in I} Pw(l_i) - W_p \sum_{i \in I} Pr(l_i) \right) \tag{1}$$

$$\begin{cases} \forall f \in F, \exists i \in I \quad A_i \neq \mathrm{None} \wedge D_f = l_i, & \text{(2a)} \\ \forall i \in I \quad \displaystyle\sum_{f \in F | D_f = l_i} C(q_{\mathrm{req}}(f, p_f)) \leq C(QoS(l_i)) & \text{(2b)} \end{cases}$$

$$\max_{\vec{A}} \sum_{i \in I} C(I_i)$$
$$\text{s.t.} \begin{cases} \exists i \in I \quad A_i \neq \text{None} \\ \forall j \in I - \{i\} \quad A_j = \text{None} \end{cases} \tag{3}$$

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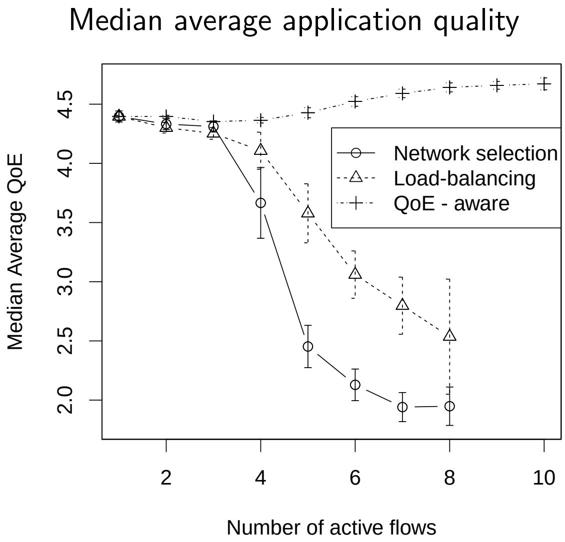
$$Lr(l) = \sum_{f \in F | D_f = l} C(q_{\mathrm{req}}(p_f)) / C(l)$$

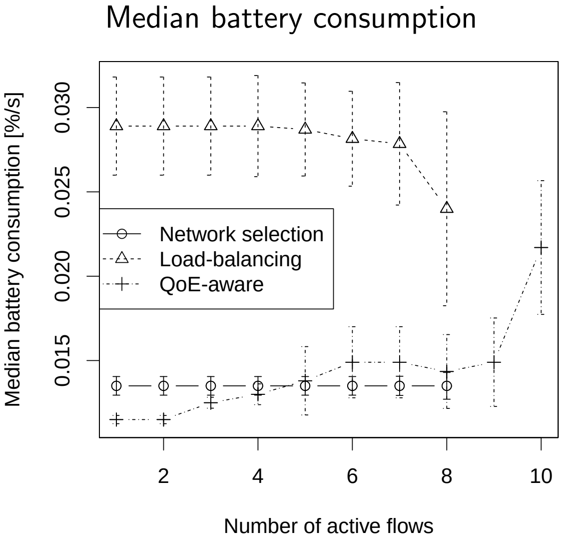
$$F_r = \frac{\left(\sum_{i \in I} Lr(l_i)\right)^2}{|I| \sum_{i \in I} Lr(l_i)^2} \tag{4}$$

$$\max_{\vec{A}, \vec{D}} \left( W_c \sum_{i \in I} C(l_i) + W_f F_r \right) \tag{5}$$

More results



More results



## More results