Contributions to Mechanisms for Adaptive Use of Mobile Network Resources

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Introduction

A wireless world

- Prevalence of wireless access
  - Unlicensed: Wi-Fi, Bluetooth, ...
  - Licensed: 2–4G, WiMAX, ...
  - Built-in support for multiple technologies
- New connectivity modes
  - MANETs, VANETs, ...
  - DTNs, UPNs, ...
- "Always best connected" devices [References on slide 38]
- Increase computational power in mobile devices
- Emerging uses
  - Multimedia
    - VoIP, Video streaming, Video conferencing, ...
  - Mobility $\rightarrow$ ITS
    - Route planning, safety, traffic and fleet management, infotainment

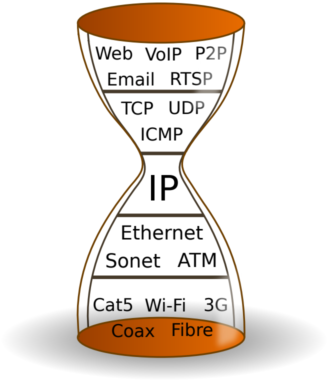
Introduction

Problem statement. . .

How to enable mobile communicating peers to make the best use of the network resources when they are available, and degrade gracefully when they are scarce?

Introduction

State of the stack^Wart



Based on image by Xander89 (CC-BY-SA-3.0-2.5-2.0-1.0)

- Mobility
  - Proposals at every single layer
  - Ubiquitous network layer
    - *MIPv6*
- Cross-layer designs
  - Information/control over multiple layers
  - In-stack too specific
  - *Vertical control plane*
    - Standards: IEEE 802.21, ISO CALM manager, ETSI ITSC management
- Network selection
  - Unclear *which metrics are relevant*
    - S(I)NR, network QoS, prioritising (*e.g.*, Wi-Fi with 3G fallback), . . .
  - Rare *fine grained management of multiple interfaces*

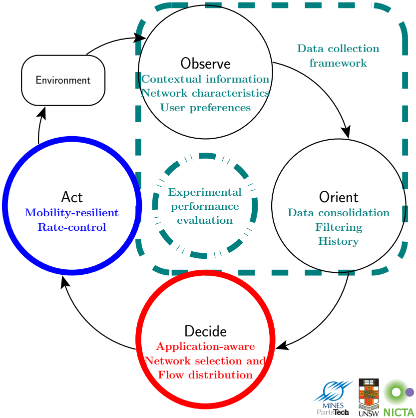
[Selected references on slide 38]

Introduction

Problem statement. . . and how to address it

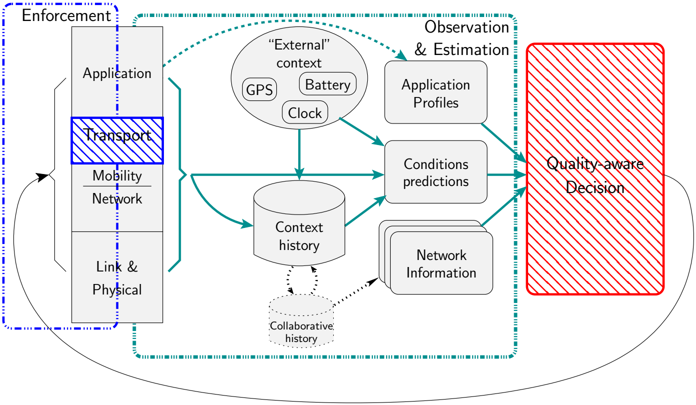
How to enable mobile communicating peers to make the best use of the network resources when they are available, and degrade gracefully when they are scarce?

- Research directions
  - Network selection
  - Adaptation to changes
  - Provide incremental modifications
- Approach: OODA loop
- Contribution axes
  - Optimisation of networks selection and use
  - Improvement of rate control mechanism for mobility
  - Study of measurement platforms and tools



Introduction

Overarching control framework



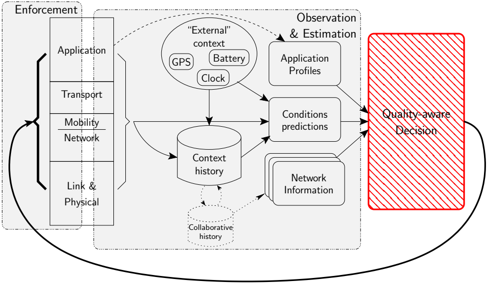
Introduction

Multi-layer Optimisation of Network Choice and Usage

Mobility-aware rate control for transports

Accuracy of a Measurement Instrumentation Library

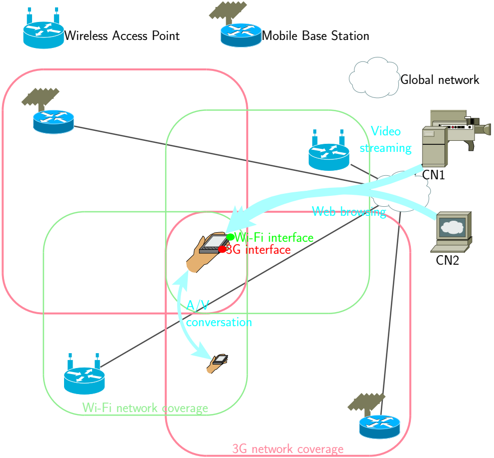
Summary



Multi-layer Optimisation of Network Choice and Usage

Problem of a multihomed mobile node: Mix and match?

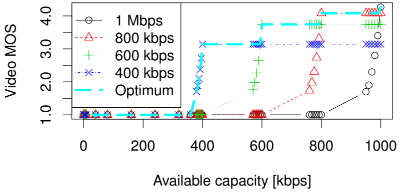
- Multiple networks, interfaces and flows (of different types)
- How to decide
  - *Which interface(s) to use?*
  - *Which network(s) to connect to?* (*e.g.*, BS or ESS)
  - *How to distribute the flows?*
- To optimise. . . *what?*
  - raw QoS (*e.g.*, goodput or delays)?
- *Multihomed Flow Management problem*



Multi-layer Optimisation of Network Choice and Usage

Problem of a multihomed mobile node: Privileging users' perceptions and expectations

- User experiences the application's output
  - QoS *only* directly relevant to the application
    - Adjustable parameters
    - Optional requirements
    - Non-linear QoE/QoS relation (*e.g.*, H.264) [ITU E-Model on slide 42]



- Flat battery the worst experience
- User's wallet not a bottomless bag
- *Conflicting goals*
  - Need for tradeoffs

- Quality-aware Multihomed Flow Management
  - Maximise application quality [UML on slide 41]
  - Reduce costs
    - Energy consumption
    - Access price
  - Decision scope
    - (De)activate interfaces
    - Select most appropriate networks
    - Distribute flows
    - Adjust stack parameters (*e.g.*, application or transport)
- Constrained optimisation model [Notations on slide 43]
  - MiniZinc language
  - Branch-and-bound search
  - Optimal solution

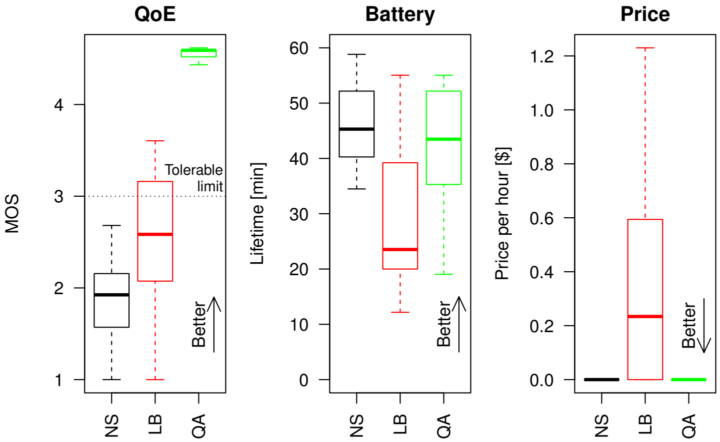
Multi-layer Optimisation of Network Choice and Usage

Evaluation and comparison: Techniques and scenarios

- Comparison to more common techniques
  - **QA** Quality-aware Multihomed Flow Management [Objective function on slide 44]
  - **NS** Single network/interface selection (*e.g.*, iPhones) [Objective function on slide 45]
  - **LB** Load balancing on each interface's best network [Objective function on slide 46]
- Two types of scenarios
  - **Smart-phone example** Single Wi-Fi and 3G interfaces, random networks, fixed demand (2 VoIP and video flows, 3 web sessions)
  - **More generic scenarios** Interfaces, networks and flows chosen randomly

Multi-layer Optimisation of Network Choice and Usage

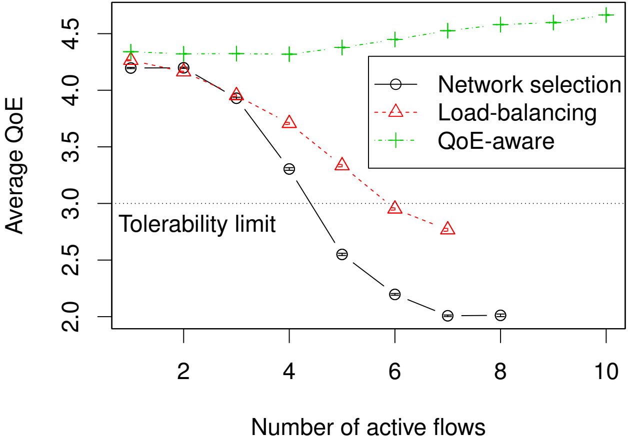
Evaluation and comparison: Smart-phone example



[Data sources on slide 47] [Approach and data quality on slide 48]

Multi-layer Optimisation of Network Choice and Usage

Evaluation and comparison: Generic scenarios



[Battery and price on slide 49] [Medians on slide 50] [Data sources on slide 47]

[Approach and data quality on slide 48]

Multi-layer Optimisation of Network Choice and Usage

Summary and future work

- Summary
  - Mobile-centric model of multihoming
    - Constrained formulation
  - QoE-aware Multihomed Flow Management
    - Evaluation
    - Real data from QoS testbed
- Future work
  - Global stability
  - Finer-grained routes
  - Extension to NEMOs
  - Actual implementation
    - Linear programming formulation
    - Remove simplificating assumptions (*e.g.*, direction of flows, pricing)
    - Prioritisation weights from user

Introduction

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Mobility-aware rate control for transports

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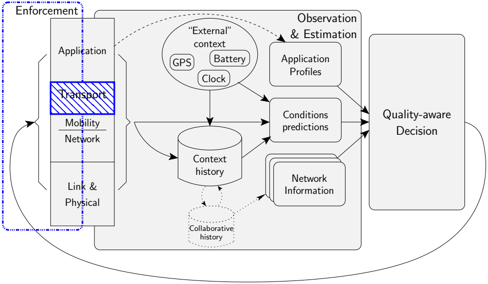


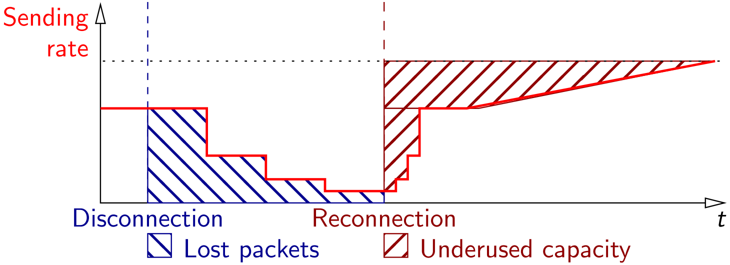
Mobility-aware rate control for transports

Problem: Classical congestion control assumptions broken by mobility

- *TCP-Friendly Rate Control* (TFRC) [References on slide 52]
  - Rate-based congestion control mechanism
    - TCP-fair congestion control
    - Uses packets losses p and RTT R
    - Well adapted to real-time streaming
  - Used with *Datagram Congestion Control Protocol* (DCCP)
    - Unreliable datagrams
    - Real-time traffic over shared networks
- Problems with mobility
  - Losses during hand-off period force a rate reduction
  - Poor adaptability to new network characteristics
- *How much resources are wasted?*
- *How not to?*

Mobility-aware rate control for transports

TFRC during handovers: Modelling losses and wasted capacity



- Sending rate
- Lost packets during disconnection
- "Wasted" capacity after reconnection
- Additional "wasted" capacity on higher capacity networks

[Formulas on slide 53]

Mobility-aware rate control for transports

TFRC during handovers: Analytically derived possible performance improvements

from \ to	UMTS	802.16	802.11 b	802.11 g
Packet losses				
UMTS		3×10^2		
802.16		2×10^3		
802.11b		1×10^3		
802.11g		3×10^3		
Unused capacity [500 B packets]				
UMTS	0	$\ddots$	$\vdots$	
802.16	0	2×10^2–8×10^4		
802.11b	$\vdots$	$\ddots$		$\ddots$
802.11g	0	$\cdots$	0	

[Real numbers on slide 54]

Mobility-aware rate control for transports

Solution: Temporarily "freezing" the transport to avoid losses

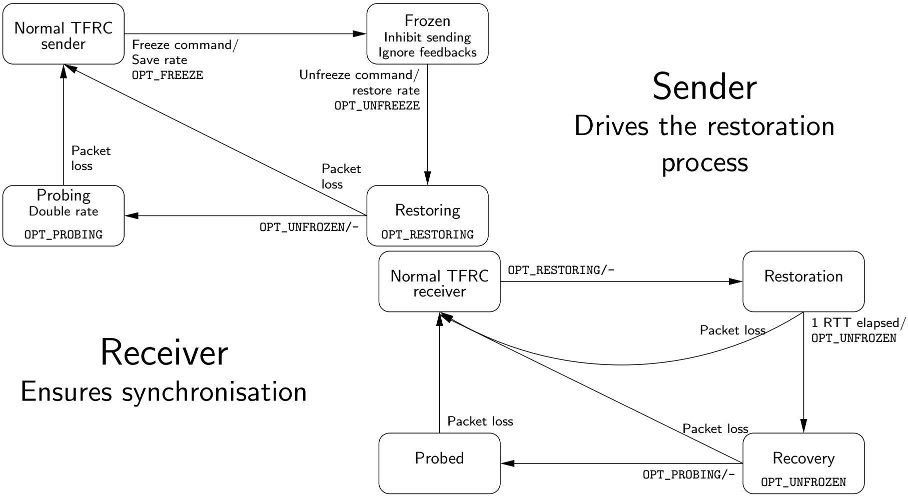
- Freeze-DCCP/TFRC
  - Sender/receiver cooperation
    - DCCP-level options
  - New states supporting
    1. rate restoration
    2. path probing
- Related work: Freeze-TCP [References on slide 55]
  - Predictable disconnections at receiver
  - Suspend TCP traffic
  - Restore rate on reconnection
- Better support for mobility handoffs

  sender-based freezing for mobile senders

  slow-start-like probing for higher new capacities

Mobility-aware rate control for transports

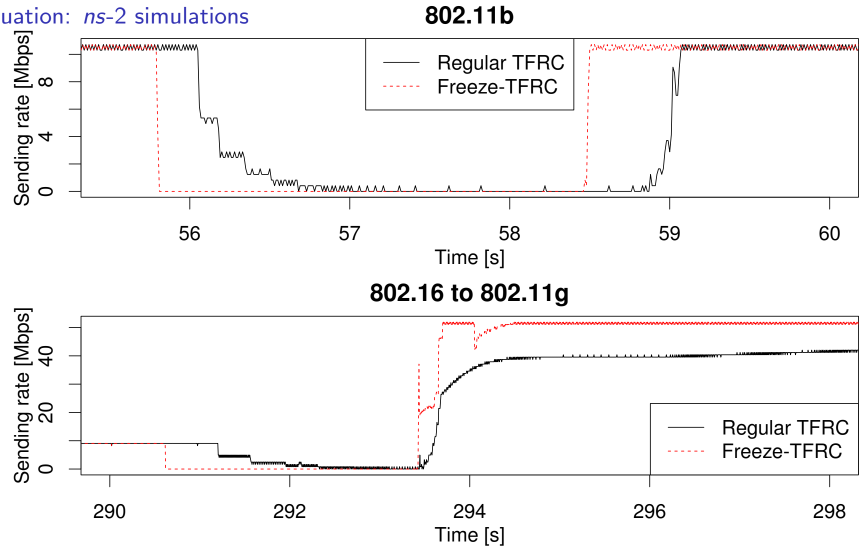
Mobility-Aware extension to TFRC: Additional states and options to support freezing



[Complete state diagram on slide 56]

Mobility-aware rate control for transports

Evaluation: *ns*-2 simulations

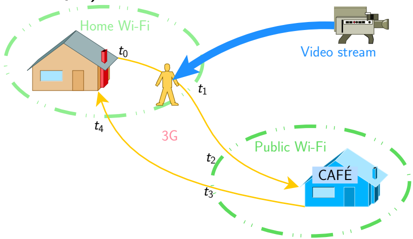


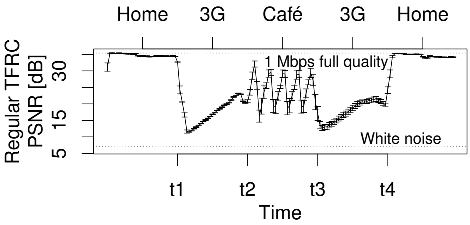
[Numbers on slide 57]

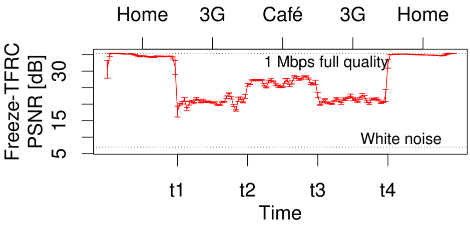
Mobility-aware rate control for transports

Evaluation: Experiments with emulated handovers

- Video streaming (H.264, 1 Mbps)







- QoE metric: PSNR
- Linux kernel code
- Emulated links and handovers [References on slide 55]
  - Home: 1 Mbps, 52 ms
  - 3G: 500 kbps, 250 ms
  - Café: 700 kbps, 70 ms

- Summary
  - Model TFRC in vertical handovers
  - Freeze-TFRC protocol within DCCP
    - *ns*-2
    - Linux
    - Evaluation
- Future work
  - Robustness of state machine
  - Decouple freezing and probing to cater for “make before break”
  - Stopping criteria for probing
    - Information from decision framework

Introduction

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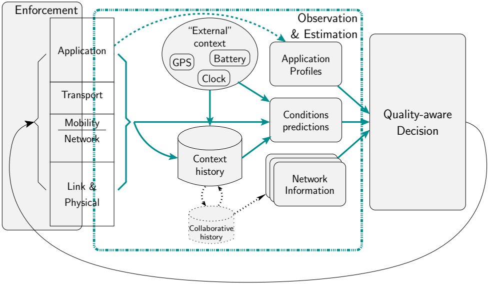
Summary



Accuracy of a Measurement Instrumentation Library

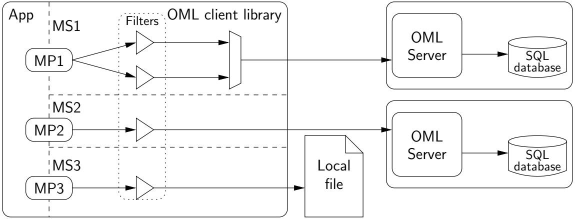
Problem: Obtaining accurate measurements

- Network measurements needed at every step
  - **design** based on observations
  - **monitoring** of the world
  - **experimentation** to evaluate performance
- Requirements for network measurement tools
  - **generic** multiple different experiments
  - **validated** confidence in the measurements
  - **extensible** as many variables as possible
- *Needed for the information reporting loop of the framework*

Accuracy of a Measurement Instrumentation Library

Problem: Obtaining accurate measurements

- OMF Measurement Library (OML) [References on slide 62]
  - Open Source C library (MIT licensed)
  - Timestamped samples
  - Unified output format (SQL databases)
  - Instrumentation of *already existing applications*
  - In-line filtering and aggregation
  - Domain-free (*cf.* SNMP for network, DTrace for systems)

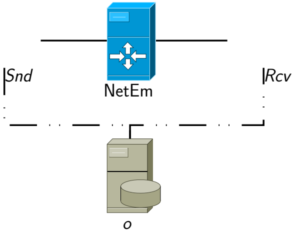


- *Are reports using OML trustworthy?*

Accuracy of a Measurement Instrumentation Library

OML's Impact on Instrumented Applications: Experimental setup

- Instrumented measurement tools
  - Active: `iperf(1)`
  - Passive: `pcap(3)`-based packet capture
  - System load
- Generic experiments
- Various factors
  - `iperf(1)`: traffic rate, OML support, threads [Some results on slide 63]
  - `pcap(3)`: traffic rate, OML support [Some results on slide 64]
- Statistical tests
  - (PERM)ANOVA
  - Data usability: Standard error, independence, normality, homoskedasticity



- Summary
  - First evaluation of OML's operation ranges
  - Non-threaded reporting performs equally to a threaded application
  - Bottleneck in passive measurement beyond 50 Mbps when all packets are reported
  - Seems adequate for the proposed framework
- Future work
  - Instrument more applications
  - Remove bottleneck

Summary
Contributions

- Models, validation and evaluation
  - Multihomed device
  - Quality-based decision
  - TFRC in handovers
- Protocols and software
  - Freeze-DCCP/TFRC (Linux, *ns*-2)
  - Freeze-TCP (Linux, *ns*-2)
  - Ported other *ns*-2 patches (DCCP, MobiWan)
  - Additions to OML codebase
- Experimental evaluation
  - Freeze-DCCP/TFRC
  - OML

[Publications on slide 36]

Summary

Future work and perspectives

- Future Work
  - Framework implementation
  - Applicability of the results
    - Relation to ITS standards?
- Perspectives
  - Evolution-limiting factor
    - Direct application access to `socket`(2) interface
    - Higher-level interface needed (*e.g.*, hide network names, provide service exposure and discovery or perform local and remote firewall configuration)
  - Internet Hourglass' waist too narrow, transport too deep
    - Network layer should expose more information (*e.g.*, detected paths or congestion)
    - Transport should be split: Per peer path-to-host congestion management (channel), per channel packet scheduling and high level semantics (transport)

Questions?

Thanks

Backup

Publications

Selected references

Multihomed Flow Management

Freeze-TFRC

OML

Backup: Publications

- QA-MFM
  - Olivier Mehani, Roksana Boreli, and Thierry Ernst. "Context-Adaptive Vehicular Network Optimization". In: *ITST 2009, 9th International Conference on Intelligent Transport Systems Telecommunications*. Ed. by Marion Berbineau, Makoto Itami, and GuangJun Wen. Lille, France: IEEE Computer Society, Oct. 2009, pp. 186–191. ISBN: 1-4244-1178-5. URL: `http://hal.inria.fr/inria-00426451/`
  - Olivier Mehani, Roksana Boreli, Michael Maher, and Thierry Ernst. "User- and Application-Centric Multihomed Flow Management". In: *LCN 2011, 36th IEEE Conference on Local Computer Networks*. Ed. by Tom Pfeifer and Anura Jayasumana. IEEE Computer Society. IEEE Computer Society, Oct. 2011, pp. 26–34. ISBN: 978-1-61284-928-7. URL: `http://www.nicta.com.au/pub?id=4578`

Backup: Publications

- Freeze-TFRC

  - Olivier Mehani and Roksana Boreli. "Adapting TFRC to Mobile Networks with Frequent Disconnections". In: *CoNEXT 2008, 4th ACM International Conference on emerging Networking EXperiments and Technologies, Student Workshop*. Ed. by Benoit Donnet et al. ACM SIGCOMM. Madrid, Spain: ACM, Dec. 2008. ISBN: 978-1-60558-264-1. DOI: `10.1145/1544012.1544049`. URL: `http://conferences.sigcomm.org/co-next/2008/CoNext08_proceedings/StudentWorkshopPapers/8.pdf`
  - Olivier Mehani, Roksana Boreli, and Thierry Ernst. "Analysis of TFRC in Disconnected Scenarios and Performance Improvements with Freeze-DCCP". In: *MobiArch 2009, 4th International Workshop on Mobility in the Evolving Internet Architecture*. Ed. by Jörg Ott and Kun Tan. ACM SIGMOBILE. Kraków, Poland: ACM, June 2009. ISBN: 978-1-60558-688-5/09/06. URL: `http://www.nicta.com.au/research/research_publications/show?id=1405`
  - Olivier Mehani, Roksana Boreli, Guillaume Jourjon, and Thierry Ernst. "Mobile Multimedia Streaming Improvements with Freeze-DCCP". In: *MobiCom 2010, 16th Annual International Conference on Mobile Computing and Networking, Demonstration Session*. Ed. by Romit R. Choudhury and Henrik Lundgren. ACM

Backup: Publications

- OML
  - Olivier Mehani et al. *Characterisation of the Effect of a Measurement Library on the Performance of Instrumented Tools*. Tech. rep. 4879. NICTA, May 2011. URL: http://www.nicta.com.au/research/research_publications/show?id=4879

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- Others

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  - Terence Chen, Olivier Mehani, and Roksana Boreli. "Trusted Routing for VANET". In: *ITST 2009, 9th International Conference on Intelligent Transport Systems Telecommunications*. Ed. by Marion Berbineau, Makoto Itami, and GuangJun Wen. Lille, France: IEEE Computer Society, Oct. 2009, pp. 647–652. ISBN: 1-4244-1178-5. URL: http://www.nicta.com.au/research/research_publications/show?id=2152
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Freeze-TFRC

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Publications

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Multihomed Flow Management

Freeze-TFRC

OML

Backup: Multihomed Flow Management

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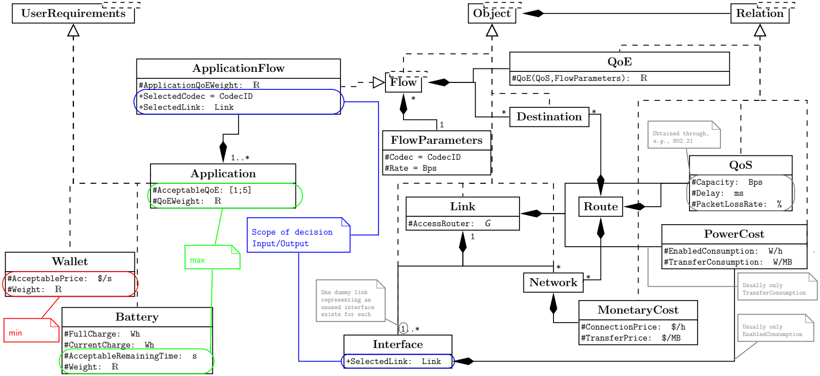
Backup: Multihomed Flow Management

UML model



Constraints:

Associations' multiplicity is 1 unless otherwise stated.

$$\sum_{f\in F | f.\texttt{SelectedLink}=l} \text{FlowParameters}(f.\texttt{SelectedCodec}).\texttt{Rate} \leq l.\texttt{Capacity}\ \forall l \in L$$

$$\sum_{f\in F | Network(f.\texttt{SelectedLink})=n, Destination(f)=d} \text{FlowParameters}(f.\texttt{SelectedCodec}).\texttt{Rate} \leq n.\texttt{Capacity}\ \forall n \in N,\ d \in D$$

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Backup: Multihomed Flow Management

ITU-T's QoE

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)

[References on slide 40]

Backup: Multihomed Flow Management

Notations

	Set of networks N
$\text{None} \in N$	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
$q_{\text{req}}(f, p_f)$	min. required QoS to maximise $Q(f, p_f, q_{\text{req}}(f, p_f))$

Backup: Multihomed Flow Management

Multihomed Flow Management objective

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

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

[Notations on slide 43]

Backup: Multihomed Flow Management

Network Selection objective

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

[Notations on slide 43]

Backup: Multihomed Flow Management

Load Balancing objective

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

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

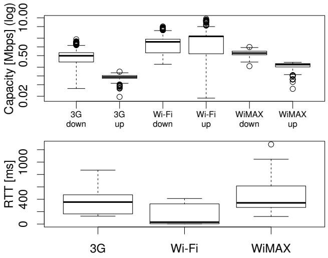
$$\max_{\vec{A},\vec{D}} \left(W_c \sum_{i \in I} C(l_i) + W_f F_r \right) \quad (5)$$

[Notations on slide 43]

Backup: Multihomed Flow Management

Supporting data

- QoS measurement testbed
  - Wi-Fi, WiMAX, 3G (Australia, Germany)
  - Know measurement servers (Australia, France)
  - Sep.–Nov. 2010

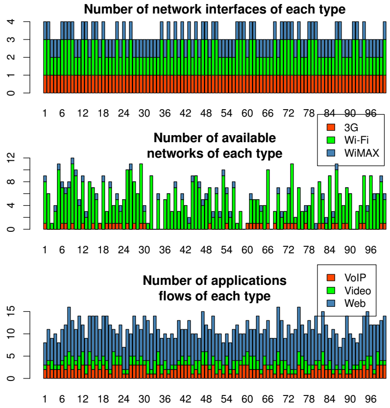


- Quality profiles
  - MOS from ITU-T's objective E-Model [Formulas on slide 42]
  - VoIP, video conferencing, web browsing
  - Easily extended given similarly formulated objective profiles
    - Other interactive applications
    - Non-interactive applications with evaluable performance
- Battery consumption and web usage data from Petander (2009) [References on slide 40]
- Access prices surveyed from Australian operators in Dec. 2010

Backup: Multihomed Flow Management

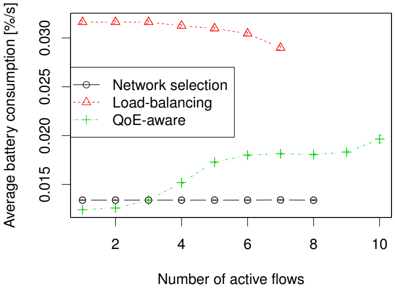
Approach and data quality

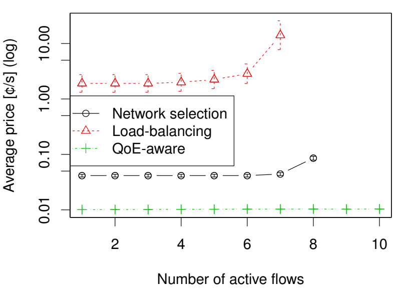
- Scenarios
  - Smart-phone (subset): 57
  - Synthetic (total): 95
- Run from 1 to *n* flows
  - Evaluate behaviours with increasing load
  - For 7 flows, usually not more than 20 s
    - Not quite real-time…
- Statistical significance of averages
  - At least 20 data points
  - Discarded otherwise



Backup: Multihomed Flow Management

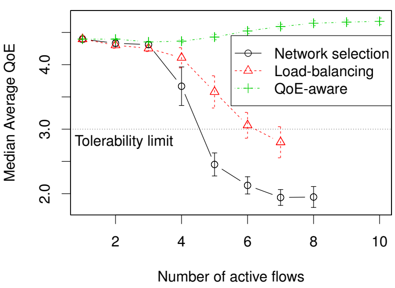
Generic scenarios, battery and price results

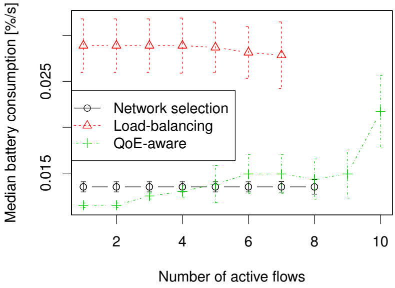


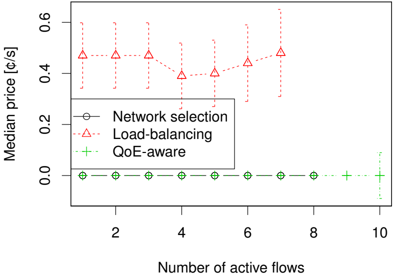


Backup: Multihomed Flow Management

More results







Publications

Selected references

Multihomed Flow Management

Freeze-TFRC

OML

Backup: Freeze-TFRC

References

TCP Reno model Jitendra Padhye, Victor Firoiu, Don Towsley, and Jim Kurose. "Modeling TCP Throughput: A Simple Model and Its Empirical Validation". In: *SIGCOMM Computer Communication Review* 28.4 (Oct. 1998). Ed. by Martha Steenstrup, pp. 303–314. ISSN: 0146-4833. DOI: 10.1145/285243.285291. URL: http://dx.doi.org/10.1145/285243.285291

- $X_{\mathrm{Bps}}(p, R) = \frac{s}{R\sqrt{\frac{4p}{3}} + t_{\mathrm{RTO}}\sqrt{\frac{27p}{8}}\,p(1+32p^2)}$

TFRC Sally Floyd, Mark Handley, Jitendra Padhye, and Jörg Widmer. *TCP Friendly Rate Control (TFRC): Protocol Specification*. RFC 5348. RFC Editor, Sept. 2008. URL: http://www.rfc-editor.org/rfc/rfc5348.txt

DCCP Eddie Kohler, Mark Handley, and Sally Floyd. *Datagram Congestion Control Protocol (DCCP)*. RFC 4340. RFC Editor, Mar. 2006. URL: http://www.rfc-editor.org/rfc/rfc4340.txt

Mobility and adaptability Deepak Bansal, Hari Balakrishnan, Sally Floyd, and Scott Shenker. "Dynamic Behavior of Slowly-Responsive Congestion Control Algorithms". In: *SIGCOMM 2001, Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*. Ed. by Rene Cruz and George Varghese. San Diego, CA, USA: ACM, Aug. 2001, pp. 263–274. ISBN: 1-58113-411-8. DOI: 10.1145/383059.383080. URL: http://nms.lcs.mit.edu/papers/slowcc-sigcomm01.html

Backup: Freeze-TFRC

Modelling losses and capacity wastage

$$X^i = \begin{cases} \frac{X_d}{2^i} & \text{if } 0 \leq i < i_x, \\ \frac{s}{t_{\mathrm{mbi}}} & \text{otherwise,} \end{cases}$$

$$n_{\mathrm{lost}} = \begin{cases} \left\lfloor \frac{7}{8} \frac{t_D X^0}{s} \right\rfloor & (t_D \leq t^0_{\mathrm{RTO}}) \\ \left\lfloor \frac{7}{8} \frac{t^0_{\mathrm{RTO}} X^0}{s} + \sum_{i=1}^{i_D - 1} \frac{t^i_{\mathrm{RTO}} X^i}{s} + \frac{t^{i_D}_{\mathrm{RTO}} X^{i_D}}{2s} \right\rfloor & (\text{otherwise}) \end{cases} \tag{6}$$

$$n_{\mathrm{wasted}} = \frac{1}{s} \left(t_{\mathrm{idle}} \cdot X_d + \sum_{i=0}^{n_{\mathrm{ss}}} R_{\mathrm{new}} \left(X_d - 2^i X_c \right) \right) \tag{7}$$

$$n'_{\mathrm{wasted}} = \frac{1}{s} (X_{\max} - X_d) \left(t_{\mathrm{idle}} + t_{\mathrm{ss}} \right) + \frac{R_{\mathrm{new}}}{s} \sum_{i=0}^{n_{\mathrm{grow}}} \left(X_{\max} - X^i \right) \tag{8}$$

Backup: Freeze-TFRC

TFRC during handovers: Analytically derived possible performance improvements

from \ to	UMTS	802.16	802.11 b	802.11 g
Packet losses				
UMTS	306	236	226	224
802.16	2760	2614	2614	2614
802.11b	1080	1078	1078	1078
802.11g	2909	2907	2907	2907
Unused capacity [500 B packets]				
UMTS	0	82938	263	109541
802.16	0	471	155	1029
802.11b	0	0	1085	54674
802.11g	0	0	0	4699

[Simulation results on slide 57] [Link characteristics on slide 58]

Backup: Freeze-TFRC

References

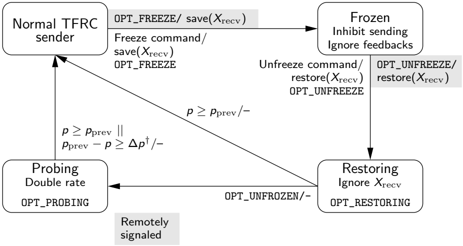
Freeze-TCP Tom Goff, James Moronski, Dhananjay S. Phatak, and Vipul Gupta. "Freeze-TCP: A True End-to-end TCP Enhancement Mechanism for Mobile Environments". In: *INFOCOM 2000, 19th Annual Joint Conference of the IEEE Computer and Communications Societies*. Ed. by Raphael Rom and Henning Schulzrinne. Vol. 3. Tel-Aviv, Israel: IEEE Computer Society, Mar. 2000, pp. 1537–1545. ISBN: 0-7803-5880-5. DOI: 10.1109/INFCOM.2000.832552. URL: http://www.cs.umbc.edu/~phatak/publications/ftcp.pdf

Wireless emulation Andrei Gurtov and Sally Floyd. "Modeling Wireless Links for Transport Protocols". In: *SIGCOMM Computer Communication Review* 34.2 (Apr. 2004). Ed. by John Wroclawski, pp. 85–96. ISSN: 0146-4833. DOI: 10.1145/997150.997159. URL: http://dx.doi.org/10.1145/997150.997159

Handover durations Jun S. Lee, Seok J. Koh, and Sang H. Kim. "Analysis of Handoff Delay for Mobile IPv6". In: *VTC2004-Fall, 60th IEEE Vehicular Technology Conference*. Ed. by Tien M. Nguyen. Vol. 4. IEEE Computer Society, Sept. 2004, 2967–2969 Vol. 4. ISBN: 0-7803-8521-7. DOI: 10.1109/VETECF.2004.1400604. URL: http://dx.doi.org/10.1109/VETECF.2004.1400604

Backup: Freeze-TFRC

Mobility-Aware extension to TFRC: Additional states and options to support freezing

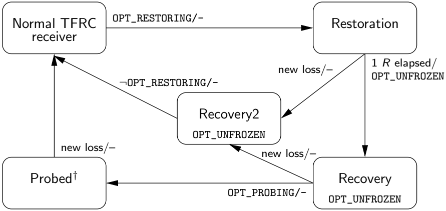


Sender

Drives the restoration process

Receiver

Ensures synchronisation



†When a packet is lost, the receiver computes and reports a p equivalent to the currently observed X_{recv}.

Backup: Freeze-TFRC

Evaluation: *ns*-2 simulations

from \ to	UMTS	802.16	802.11 b	802.11 g
Packet losses (DCCP/TFRC only)				
UMTS	253.3	269.8	273.6	275.4
802.16	1732.3	1734.6	1734.6	1734.6
802.11b	856	855.5	855.3	855.3
802.11g	2470.9	2470.4	2470.2	2470.1
Unused capacity [500 B packets]				
UMTS	50.5	54018.05	2209.5	92156.1
—	13.4	3607.9	*9342.75*	89328.6
802.16	12.45	1827.95	603.05	4185.75
—	5	591.15	150.9	1520.35
802.11b	150.45	28314	2101.75	57970.65
—	0	15278	47.45	1045.05
802.11g	42.5	2104.3	943.4	4313
—	0	*7172.75*	46.5	188.45

[Analytical predictions on slide 54] [Fairness on slide 60] [Link characteristics on slide 58] [Handover durations on slide 59] [References on slide 55]

Backup: Freeze-TFRC

Commonly accepted link characteristics

Technology	Capacity [bps]	Delay [s]
UMTS	384 k	125 m
802.11b/g	11 M/54 M	10 m
802.16	9.5 M	40 m

[References on slide 55]

Backup: Freeze-TFRC

Handover durations

$$T_{\text{handoff}} = 2.5 + RTT_{\text{wireless}} + RTT_{\text{wired}}$$
$$= 2.6 + 2Delay_{\text{wireless}}$$

Destination network	T_{handoff} **[s]**
UMTS	2.85
802.16	2.68
802.11b/g	2.62

[References on slide 55] [Link characteristics on slide 58]

Backup: Freeze-TFRC

Fairness

- Single TCP flow from *AR* to *CN*
- Wait for settlement of rate after reconnection
- 100 s samples afterwards

from \ **to**	UMTS	802.16	802.11 b	802.11 g
UMTS	0.6	0.3	0.2	0.1
802.16	1.6	1.3	1.1	0.9
802.11b	1.3	1	0.9	0.7
802.11g	1.5	1.2	1	1.1

- Values in $[0.5, 2]$ considered “reasonably fair”
- Closely similar to DCCP/TFRC in the same conditions

[Link characteristics on slide 58] [Handover durations on slide 59]

Backup: OML

References

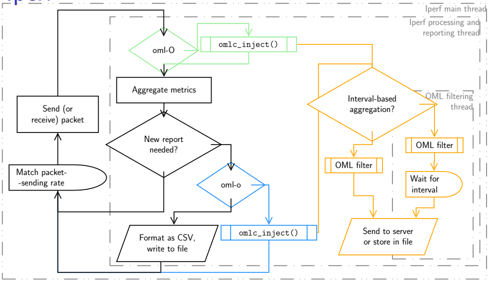
OML Jolyon White, Guillaume Jourjon, Thierry Rakotoarivelo, and Max Ott. "Measurement Architectures for Network Experiments with Disconnected Mobile Nodes". In: *TridentCom 2010, 6th International ICST Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities*. Ed. by Anastasius Gavras, Nguyen Huu Thanh, and Jeff Chase. Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering. ICST. Berlin, Germany: Springer-Verlag Berlin, May 2010. URL: http://www.nicta.com.au/research/research_publications/show?id=3298

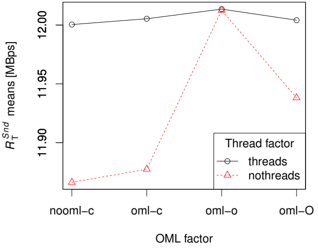
SNMP David Harrington, Randy Presuhn, and Bert Wijnen. *An Architecture for Describing Simple Network Management Protocol (SNMP) Management Frameworks*. RFC 3411. RFC Editor, Dec. 2002. URL: http://www.rfc-editor.org/rfc/rfc3411.txt

DTrace Bryan M. Cantrill, Michael W. Shapiro, and Adam H. Leventhal. "Dynamic Instrumentation of Production Systems". In: *USENIX 2004*. Ed. by Andrea Arpaci-Dusseau and Remzi Arpaci-Dusseau. Boston, MA, USA: USENIX Association, June 2004, pp. 15–28. URL: http://www.usenix.org/event/usenix04/tech/general/full_papers/cantrill/cantrill_html/

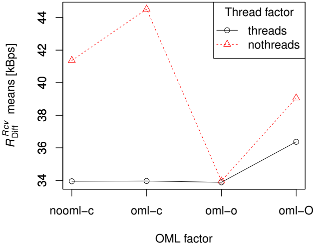
Backup: OML

Active measurement, Iperf





Actual sending rate at 95 Mbps

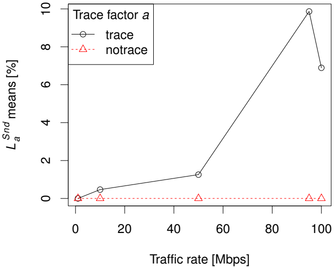


Difference in report at 50 Mbps

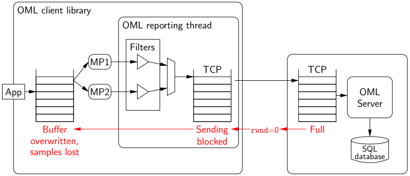
Backup: OML

Passive measurement, libpcap

- Number of unreported packets



- Hints at potential bottleneck with high-speed reporting



  - Coherent with Iperf
  - Mitigated by in-line filtering