

Evaluating Reliable Streaming in Mobile Networks

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2015/04/28

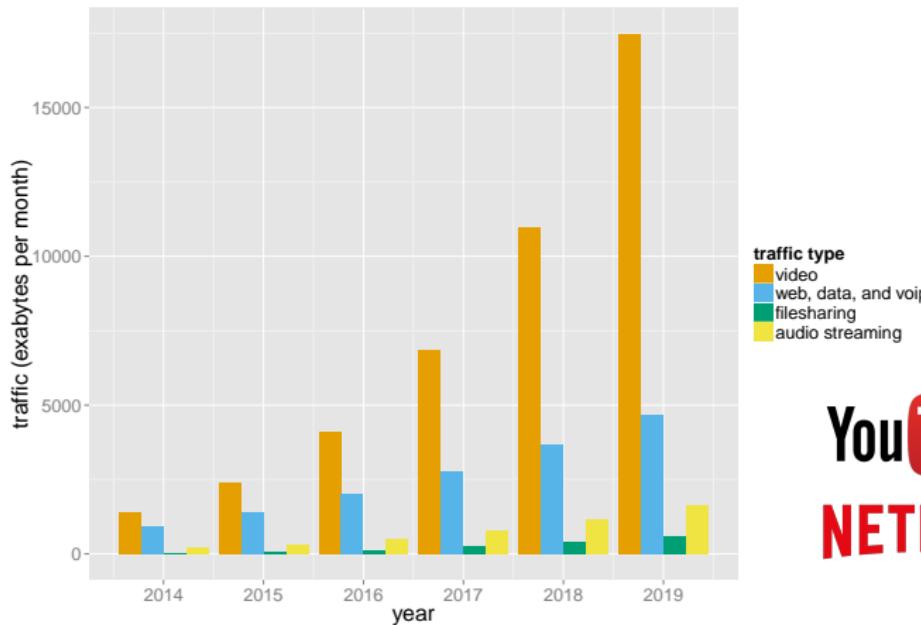
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Section 1

Introduction

Introduction

Impact of (Reliable) Video Streaming Traffic



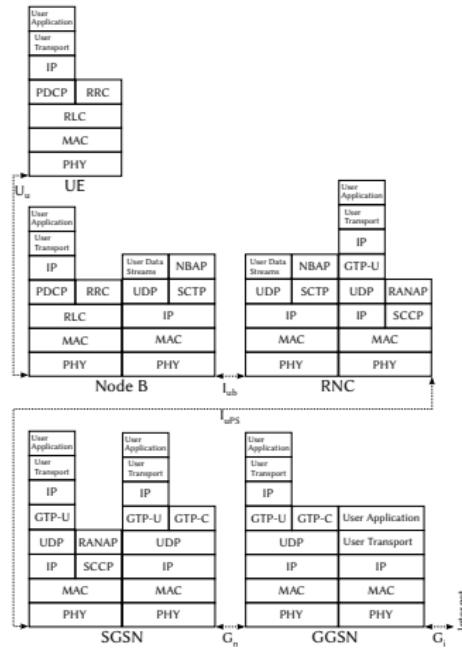
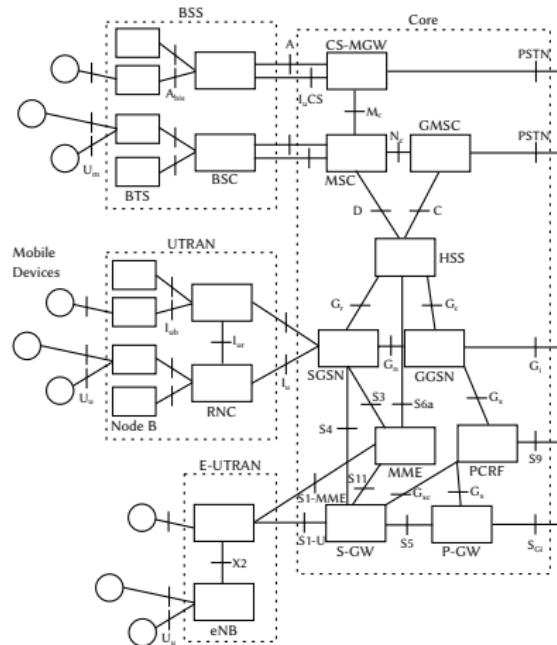
You Tube
NETFLIX

Figure: Cisco's global mobile data traffic forecast (data source: [Cis15]).

Introduction

And Reliable Streaming in Mobile Networks?

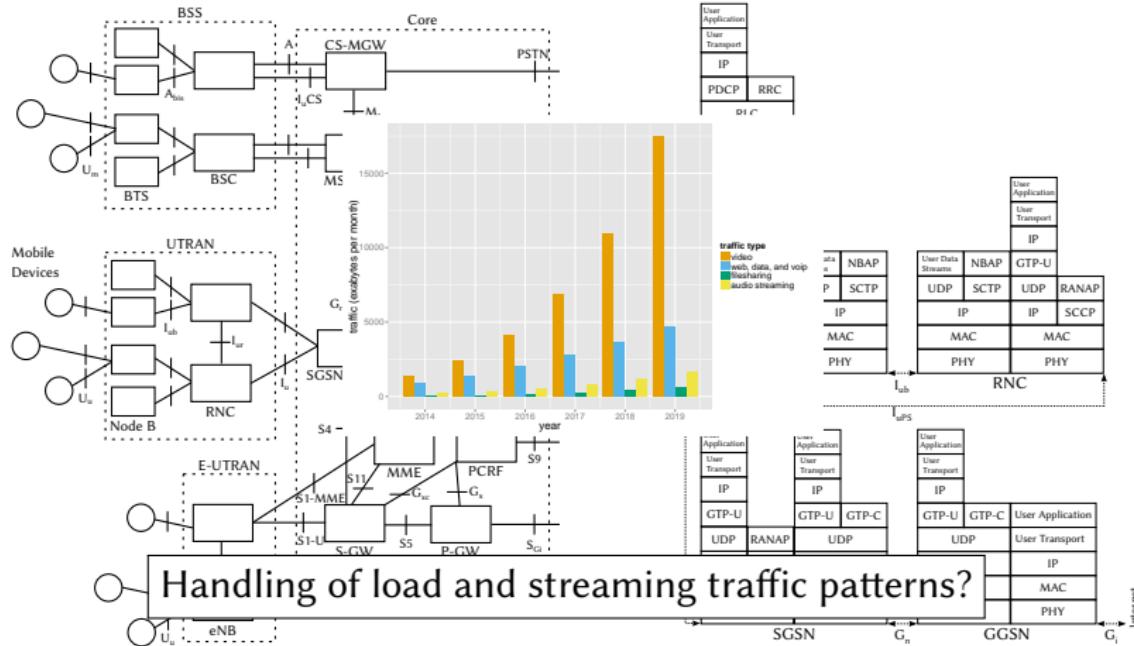
Complexity of current mobile network architectures



Introduction

And Reliable Streaming in Mobile Networks?

Complexity of current mobile network architectures



Introduction

Current State of Affairs

- Complex signaling, separation of user and control plane
- Interactions between reliable streaming and mobile networks
- Requires proper evaluation models and input parameters

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Investigation approach

- Model for reliable streaming measurements and categorization
- (Discussion of influence factors on reliable streaming)
- CN control plane signaling model derived from passive measurements
- Creation of easy-to-use mobile streaming evaluation approaches

Introduction

Thesis Structure

Thesis consists of two intersecting angles

1 Evaluation of a 3G core network

- Investigation and evaluation of the control plane
- Modeling and simulating signaling

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- Protocol survey and classification
- Deriving a model
- Measurements with the model

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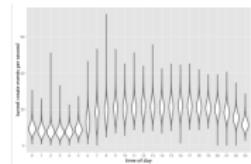
- Protocol survey and classification
- Deriving a model
- Measurements with the model

3 Measuring approaches for video streaming in a 3G network

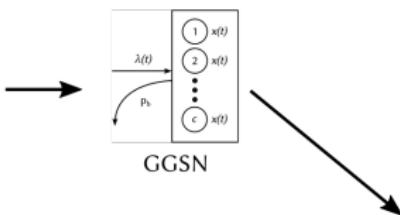
- Investigation of influence factors, potential issues, and solutions
- Comparison of evaluation approaches (active measurements and simulation)
- Mobile streaming simulation framework

Thesis Components

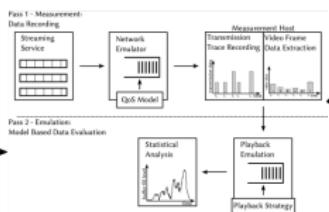
Measurement Data



GTP tunnels



Models

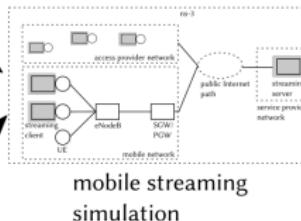


streaming measurement



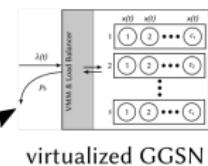
streaming

Optimization Potential

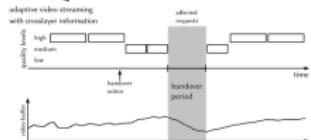


mobile streaming simulation

Optimization Potential

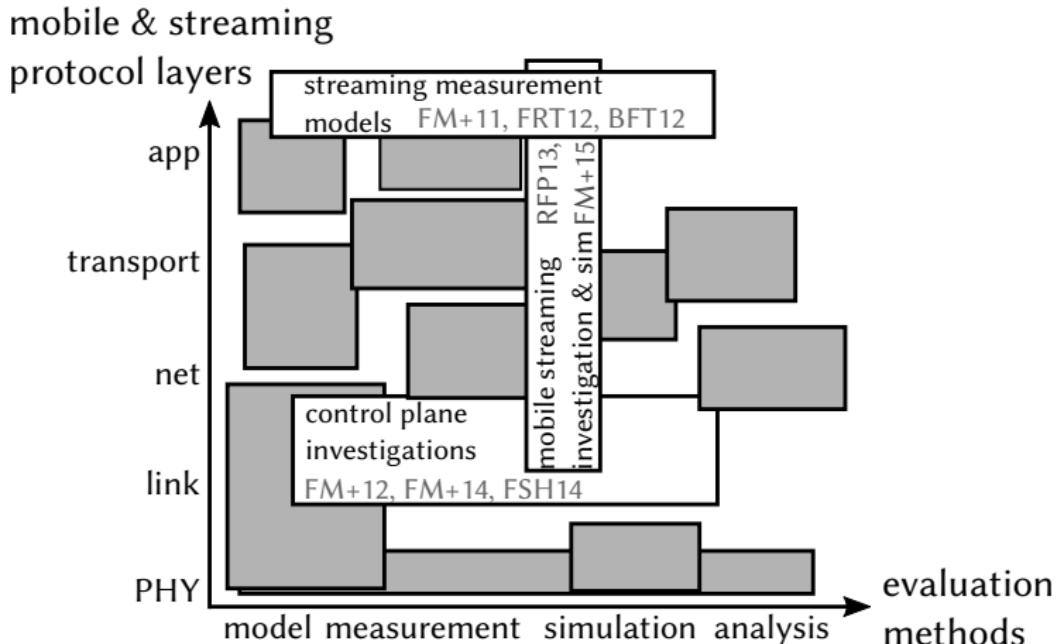


virtualized GGSN



cross-layer context factors

Placing the Thesis



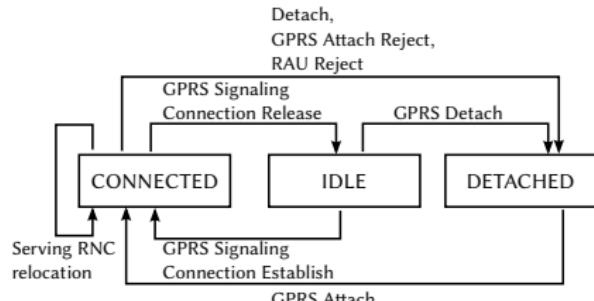
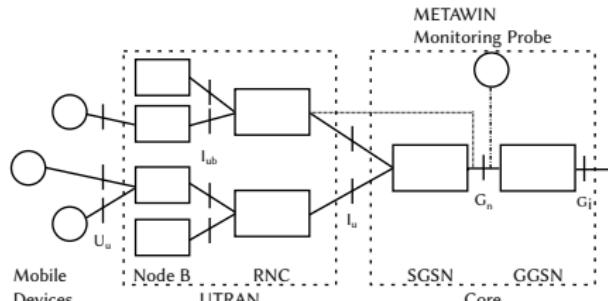
Section 2

Mobile Core Network Architecture

3G Core Network and Control Plane Overview

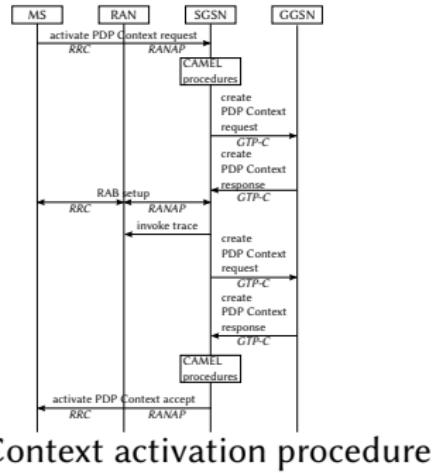
GTP Tunneling and Signaling Concept

- 3G user traffic is encapsulated into tunnels
 - Radio bearer to the device
 - GPRS Tunneling Protocol (GTP) at L4 SGSN ↔ GGSN
- State (PDP Context) held at and signaled between core nodes
- Additional overhead and load
 - Network: signaling messages, headers
 - Memory: state keeping
 - CPU: state changes



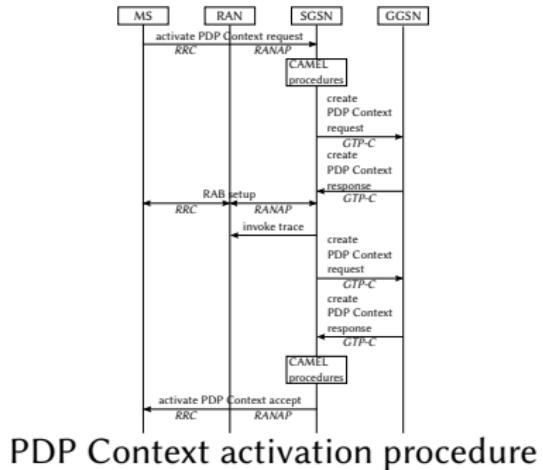
Mobile Network Signaling Evaluation

- Widely known signaling storm scenario
(e.g. ‘Angry Apps’[Sch+13])
- Search for control plane bottlenecks in the core



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Reasoning for GGSN as bottleneck

- Single instance responsible for whole (or complete region) network
- Handles PDP Context signaling and state for each device/tunnel
- Involved in almost all network-wide signaling procedures
- GTP Mobility Management signaling from SGSN

Signaling Influencing Factors

Many sources of influence, both internal as well as external

Network-centric factors

- Specific interaction of state machines and protocols
- Inactivity timers (e.g. moving device from connected to idle/detached)

User-centric factors

- Type and OS of device, access technology
- Installed and active applications
- Specific usage, time-of-day, and traffic patterns

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Signaling evaluation approach

Investigate signaling at **GGSN** on the basis of **GTP tunnel characteristics**

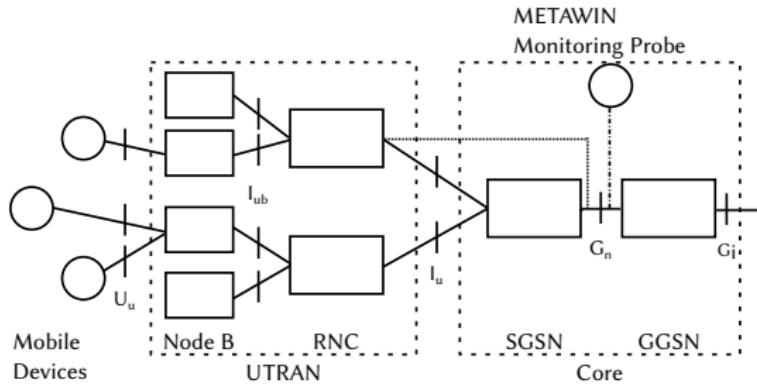
Section 3

Evaluating Mobile Signaling Traffic and Load

Trace Evaluation

Recorded dataset

- One week long passive measurements in an operator's core network (METAWIN, April 2011)
- 2.2Bn user traffic records, 410M GTP tunnel management messages
- Trace data anonymized, reduced to select fields per signaling interactions
- Device and OS identification through TAC



Trace Evaluation

Initial Findings

- Link load of control traffic insignificant
 - GTP messages contribute max. 0.7 % to total traffic
- 18 % of devices cause signaling without transmitting any user traffic
- High user traffic volume ≠ high amount of signaling messages
 - E.g. 3G dongles responsible for 75 % of traffic, but only 10 % of GTP signaling messages

Trace Evaluation

Initial Findings

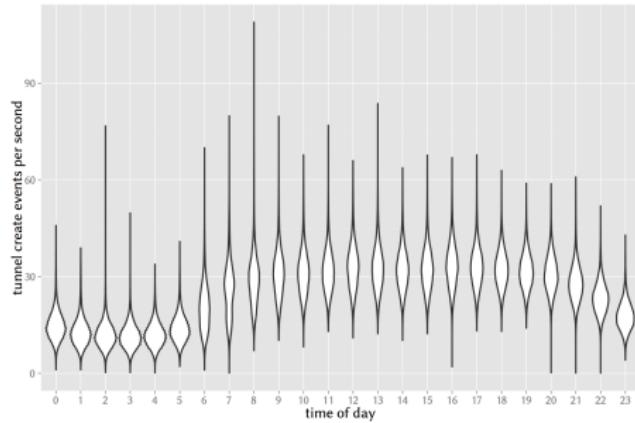
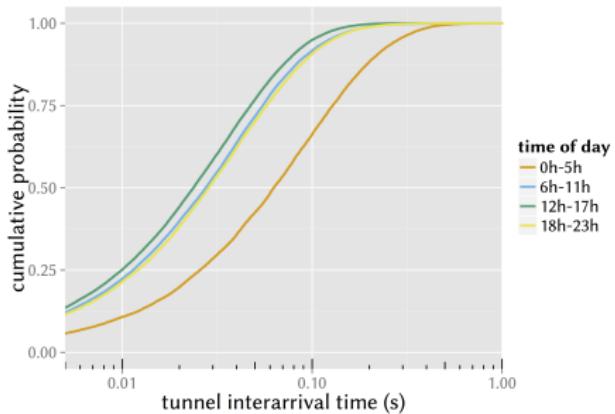
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Further investigations for signaling characterization

- Closely investigate tunnel arrival and service process
- Derive distributions for these processes
- Build a queuing theory system model for GTP tunnels at the GGSN

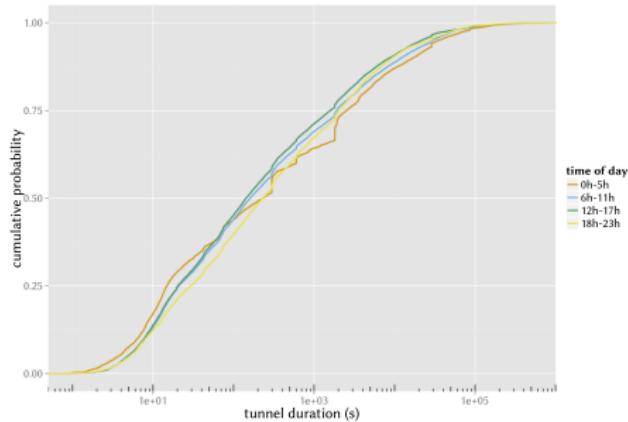
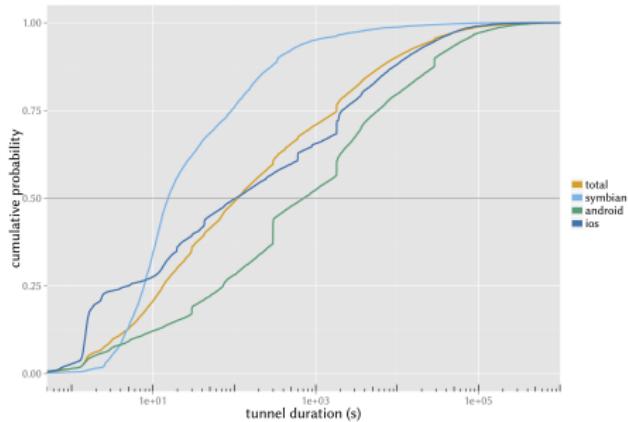
Tunnel Arrivals

By Time of Day



- Strong time of day dependence with busy hour in the early afternoon
- Bimodal character of arrival rate over the total time of day
- Poisson tunnel arrival process with rate $\lambda(t)$ fitted with trace data, $R \geq 0.98$

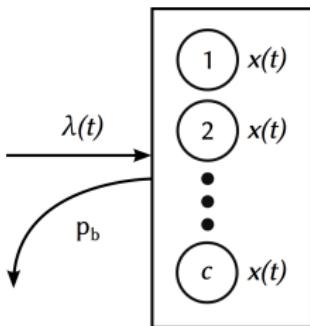
Tunnel Durations



- Strong influence of user device type and OS on duration
- “Signalling storm” visible in CN: many short tunnels for specific devices
- Time of day dependence
- Tunnel duration $x(t)$ fitted with rational function, $R \geq 0.99$

Deriving a Model

GGSN Queuing Model



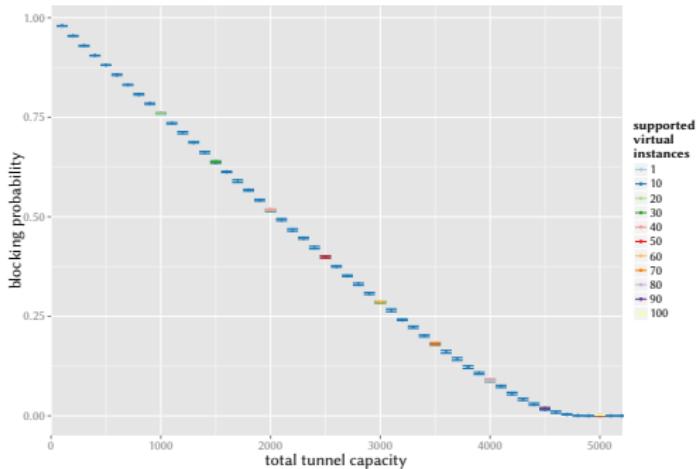
- Model for GGSN dimensioning based on tunnel arrivals
- GGSN can serve c tunnels in parallel, limited by resources (net/cpu/mem) and signaling/state overhead
- If GGSN is full, reject new tunnels, leads to blocking probability p_b
 - Non-stationary Erlang loss model $M(t)/G(t)/c/0$

Model Evaluation/Simulation

- No tractable analytic solution for $M(t)/G(t)/c/0$ models
- Use queuing simulation with the fitted distributions
- Evaluate blocking probability based on tunnel capacity

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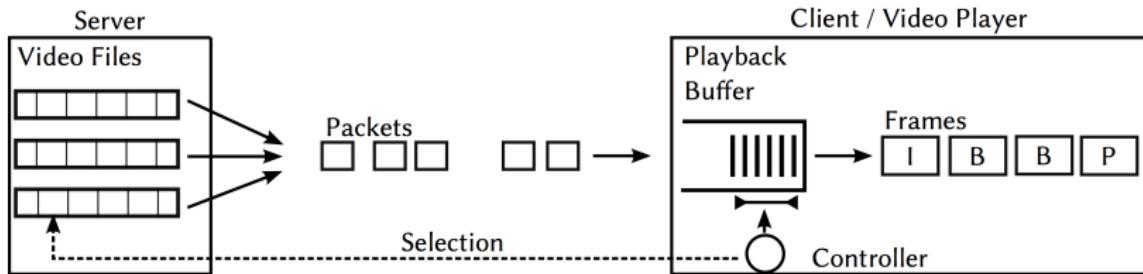
- Usage as GGSN dimensioning tool for operators
- Virtualized GGSN with better scaling options possible

Section 4

Modeling Reliable Streaming

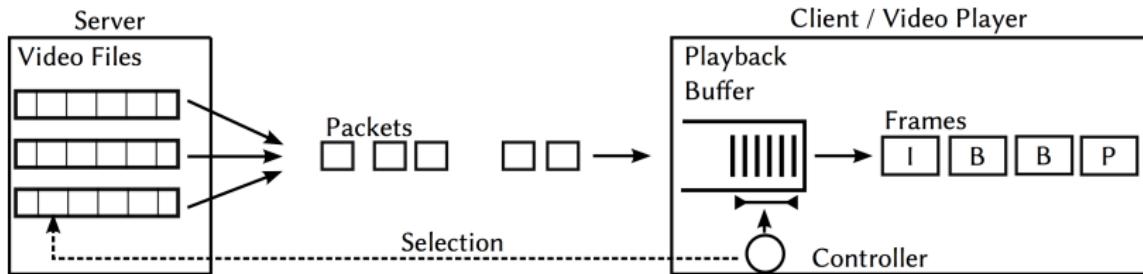
“Reliable” Video Streaming?

- Uses TCP+HTTP instead of “classic” UDP+RTP
- Offers different properties to RTP
 - Reliability, pull-based control, explicit quality adaptation
- No standardized approach, difficult to compare



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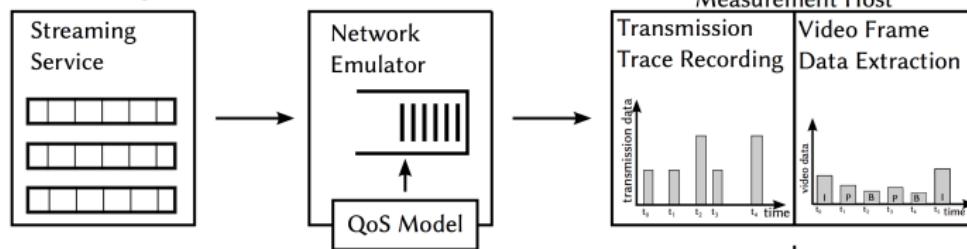
Measurement Approach

- Transmission process has no influence on the image quality (reliability)
- Evaluate streaming solely on the basis of buffering behavior
- Number and duration of stalls as metric for non-adaptive streaming

Progressive Streaming Measurement Model

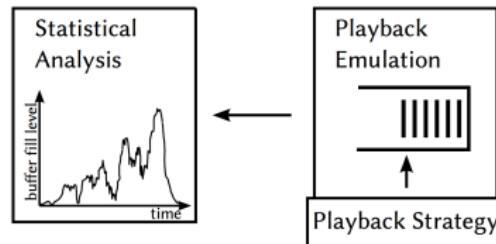
Pass 1 - Measurement:

Data Recording

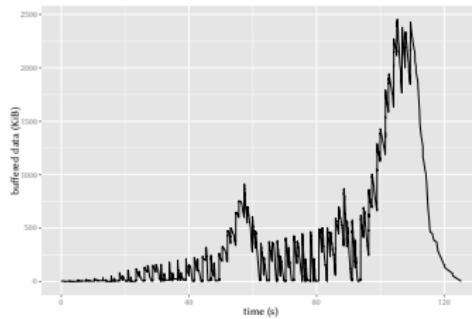


Pass 2 - Emulation:

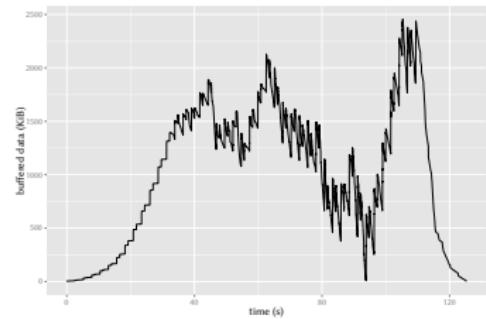
Model Based Data Evaluation



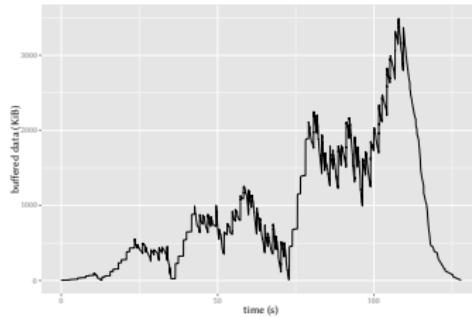
Non-adaptive Playback Strategies



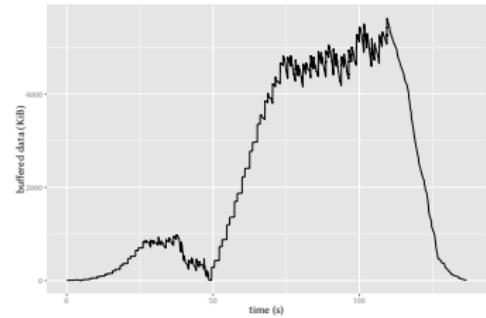
Null Strategy



Delayed Playback



YouTube Flash

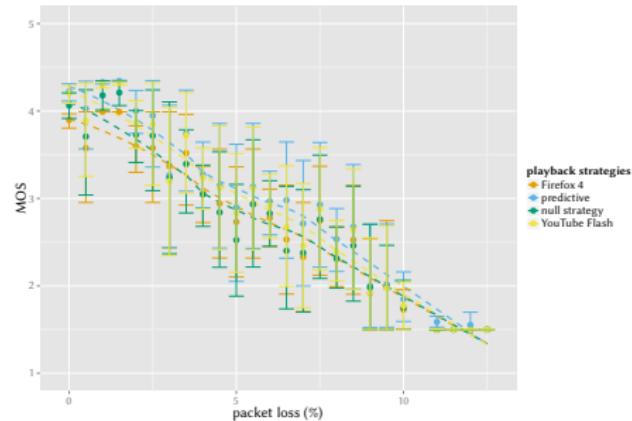
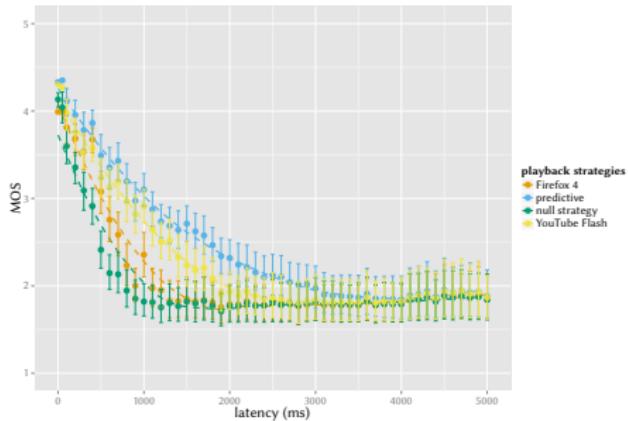


Firefox 4 HTML5

Testing the Model

YouTube Measurement Campaign

- Subjecting the playback strategies to YouTube transmission traces under different network QoS (latency, loss)
- Calculate MOS according to [Hoß+13]



- If network QoS is insufficient, no strategy can ensure QoE
- TCP interacts unpredictably with loss, strategies have little influence
- QoE optimization potential for increased latency

Section 5

Reliable Streaming in Mobile Networks

Reliable Streaming in Mobile Networks

Interactions and Influences

- Reliable streaming often designed for wired conditions
- Complex mobile signaling interacts with streaming
- Possible sources on every layer, need to be understood
 - But exploitable through cross-layer information exchange (not shown)
 - e.g. GTP tunnels and signaling with streaming transmission patterns

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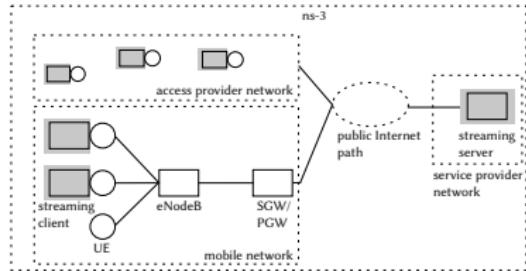
Provide two more angles to conduct measurements

- Enhancing active measurements with mobile-specific metadata
 - Privacy-aware sensor crowdsourcing app for large scale mobile measurement campaigns (Sensorium, not shown here)
- Simulating streaming in mobile networks using the introduced streaming measurement model
 - Selected the ns-3 LTE model as a basis after a survey of various mobile network simulators
 - Limitations due to the absence and accuracy of most control plane procedures

Mobile Streaming Simulation

with ns-3

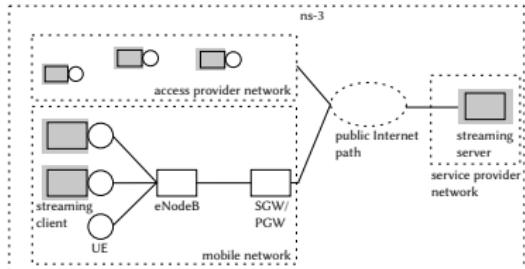
- Port the reliable streaming model to ns-3's LTE model
- Create an extensible reliable streaming mobile network scenario



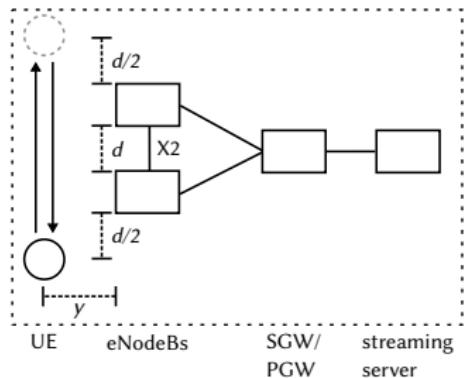
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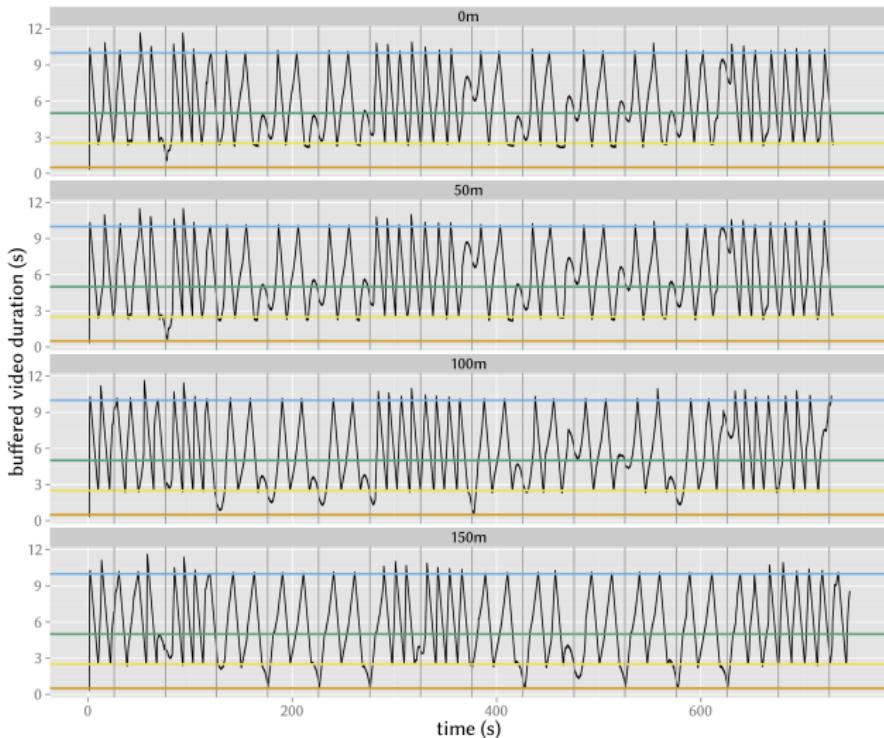


- Simple dual eNodeB scenario
- Moving back and forth between them, induce handovers



Simulation Evaluation

Mobility Scenario with Progressive Streaming



Future Work

■ Mobile Control Plane

- Compare to signaling in LTE/EPC networks
- Look at other potential signaling hotspots, e.g. MME/HLR or PCEF/PCRF
- Investigate specific signaling influence sources, esp. user traffic aspects
- Reduce statefulness in future 3GPP networks for improved scaling and efficiency

■ Reliable Streaming

- Investigate influences of different transport and application layer protocols, e.g. QUIC, TLS, HTTP/2, TCP variants
- QoE optimization of playback strategies for current context factors
- Streaming centric mobile measurements and simulations with focus on the interaction of adaptivity with mobility and other context factors

Section 6

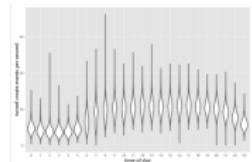
Conclusions

Summary and Contributions

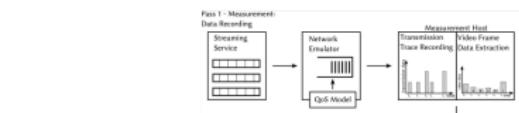
- Investigated interworkings and influences of reliable streaming and mobile networks
- Provided angles to wholly evaluate streaming and in particular mobile reliable streaming
 - Two phase streaming measurement model
 - Mobile active measurement and simulation approaches
 - Impact of mobility on streaming
- Streaming design guidelines for service providers can be derived
- Better understanding of mobile control plane for future architectures
 - Operation and impact of GTP tunnels and signaling
 - Control plane signaling depends on traffic patterns not volume
- Tools for better network dimensioning, planning, and traffic management for operators
 - GGSN Model, Queuing Simulation (, and virtualized GGSN)
- Models published in several papers, open sourced tools and frameworks

Thanks!

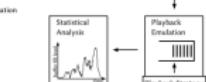
Measurement Data



GTP tunnels

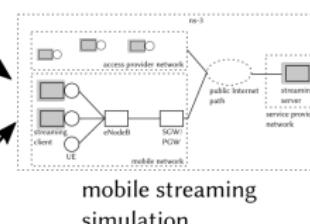
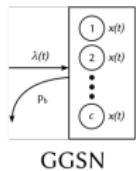


YouTube
streaming

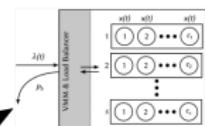


streaming
measurement

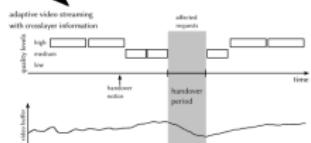
Models



Optimization Potential



virtualized GGSN



cross-layer
context factors

Questions!

Publications I



A. Biernacki, **F. Metzger**, and K. Tutschku. “On the Influence of Network Impairments on YouTube Video Streaming”.
In: *Journal of Telecommunications and Information Technology (JTIT) 2012.03* (2012).



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“Analysis of web-based video delivery”.
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F. Metzger, A. Rafetseder, P. Romirer, S. Gebert, K. Salzlechner, and K. Tutschku. “Research Report On Signaling Load and Tunnel Management in a 3G Core Network”.
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Publications II



F. Metzger, A. Rafetseder, P. Romirer-Maierhofer, and K. Tutschku. "Exploratory Analysis of a GGSN's PDP Context Signaling Load". In: *Journal of Computer Networks and Communications* (Feb. 2014).



F. Metzger, A. Rafetseder, and K. Tutschku. "A performance evaluation framework for video streaming". In: *Packet Video Workshop (PV), 2012 19th International*. 2012, pp. 19–24.



F. Metzger, C. Schwartz, and T. Hoßfeld. "GTP-based Load Model and Virtualization Gain for a Mobile Network's GGSN". In: *Communications and Electronics (ICCE), 2014 IEEE Fifth International Conference on*. July 2014, pp. 206–211.

Publications III



F. Metzger, C. Steindl, and T. Hoßfeld.

“A Simulation Framework for Evaluating the QoS and QoE of TCP-based Streaming in an LTE Network”. In: *27th International Teletraffic Congress (ITC 27)* (2015). submitted, under review.



A. Rafetseder, F. Metzger, D. Stezenbach, and K. Tutschku.

“Exploring YouTube’s Content Distribution Network Through Distributed Application-layer Measurements: A First View”.

In: *Cnet 2011 : International Workshop on MODELING, ANALYSIS, AND CONTROL OF COMPLEX NETWORKS*. Cnet ’11. San Francisco, California: International Teletraffic Congress, 2011, pp. 31–36. ISBN: 978-0-9836283-1-6.

Publications IV



A. Rafetseder, **F. Metzger**, D. Stezenbach, and K. Tutschku.
“Network Federation as a Provider Concept: From Today’s Measurement to Tomorrow’s Architecture”.

In: *12th Würzburg Workshop on IP: ITG Workshop ”Visions of Future Generation Networks” (EuroView2012)*. July 2012.



A. Rafetseder, **F. Metzger**, and L. Pühringer.
“Sensorium – A Generic Sensor Framework”.

In: *PIK - Praxis der Informationsverarbeitung und Kommunikation* 36.1 (Feb. 2013), p. 46.

Source Code

Thesis, this presentation, and associated scripts

<https://github.com/fmetzger/thesis>

Video Streaming Emulation & Evaluation

<https://github.com/fmetzger/videostreaming-bufferemulation>

GGSN Queuing Simulation

<https://github.com/fmetzger/ggsn-simulation>

Sensorium

<https://github.com/fmetzger/android-sensorium>

Mobile Streaming Simulation

<https://github.com/Steindi01/lteNS3>

References I

A complete list of references can be found in the written thesis.



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M. Allman, K. Avrachenkov, U. Ayesta, J. Blanton, and P. Hurtig.
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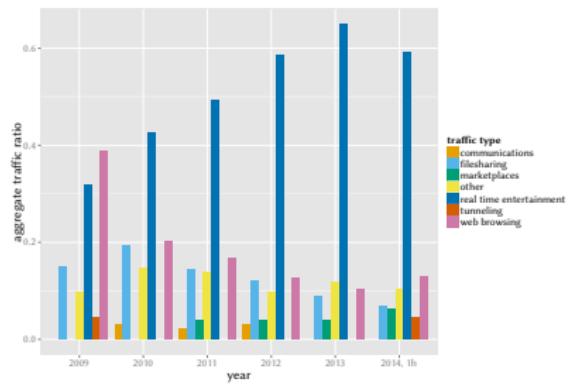


Figure: Traffic composition of North American peak fixed access aggregate traffic (data source: [San14]).

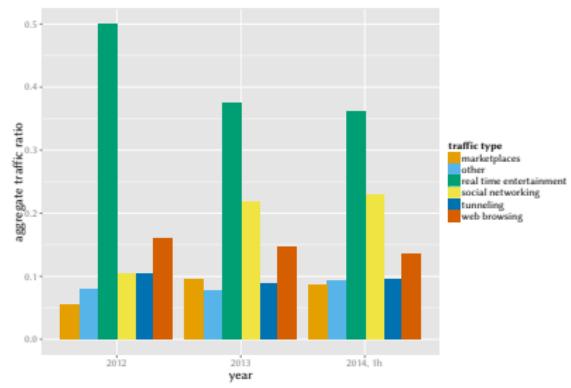


Figure: Traffic composition of North American peak mobile access aggregate traffic (data source: [San14]).

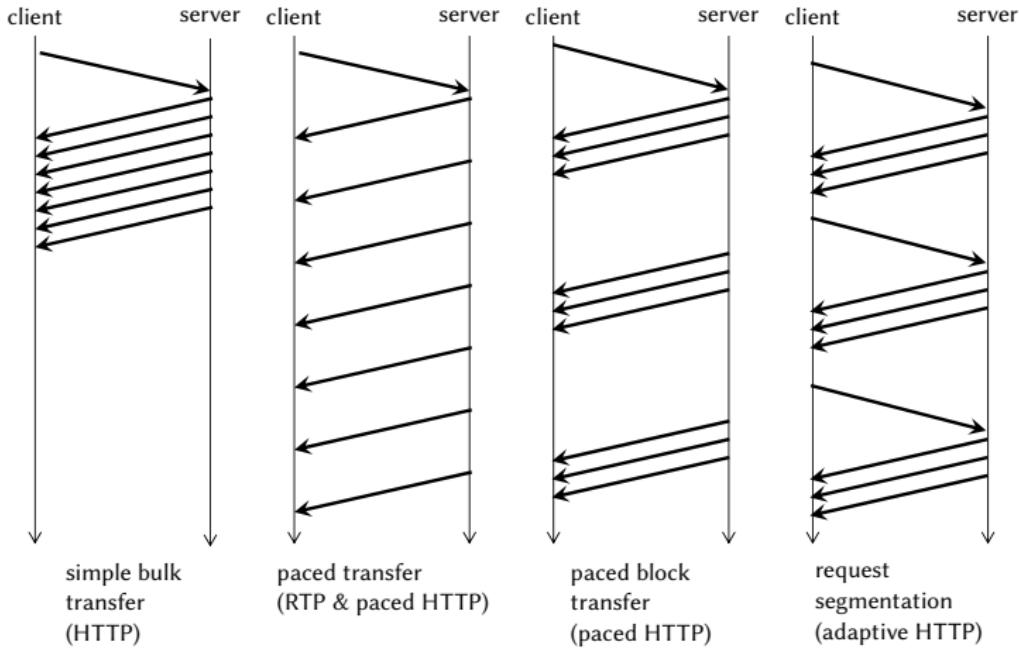


Figure: Comparison of several possible streaming transmission modes depicting the timing of the sent packets (source: [Ma+11]).

Protocol Classification Matrix

Protocol	Vertical Location of Control	Horizontal Location of Control	Reliable Transport	Video Type	Adaptivity	Multi-cast
RTP	out-of-band, application layer protocol	server-side and limited intermediary (translators and mixers)	unreliable (UDP)	low delay streaming	de-live	server-side adaptation (transcoding)
simple HTTP	in-band, streaming application	client-side	reliable (TCP)	stored, not live	none	emulated through CDN
adaptive HTTP (e.g. DASH)	in-band, streaming application	client-side	reliable (TCP)	stored and near-live	client-side with file segmentation	emulated through CDN

Further Playback Strategies

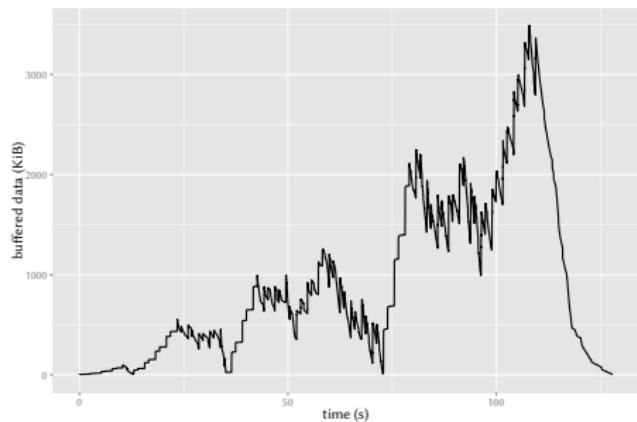


Figure: Sample buffer fill level for a 5 s buffered video duration threshold strategy with an additional 2 s initial threshold; 34 s total stalling.

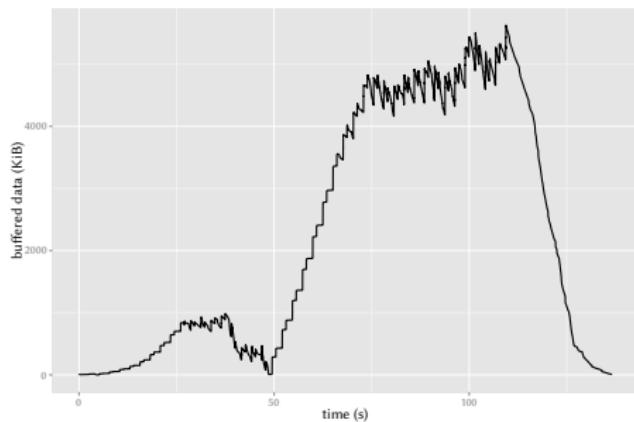


Figure: Sample buffer fill level for the Firefox 4 strategy, 44 s total stalling.

Firefox 4 Playback Strategy

```
if  $s_{MA} > v_{MA}$  then  
   $c \leftarrow (b_b = 20s \vee b_T = 20s)$   
else  
   $c \leftarrow (b_b = 30s \vee b_T = 30s)$   
end if
```

To estimate the current and future rates, the moving average of the transmission rate s_{MA} and the video bitrate v_{MA} are calculated. The condition c Firefox uses to start and resume the playback process is given in the algorithm, with the buffered video duration b_b , and the duration spent buffering b_T .

Latency Measurement Series

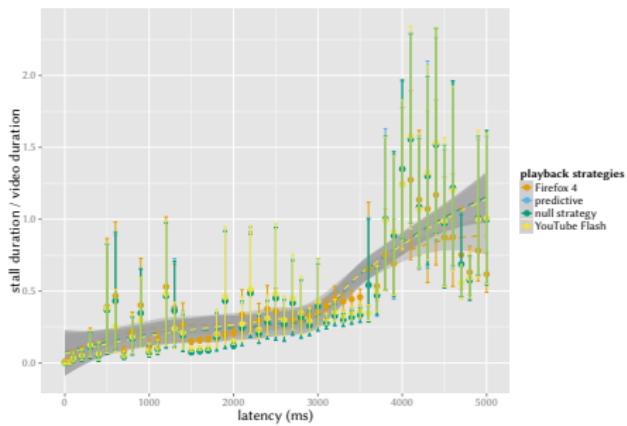


Figure: Stalling duration in relation to transmission latency with a local polynomial least-squares fit.

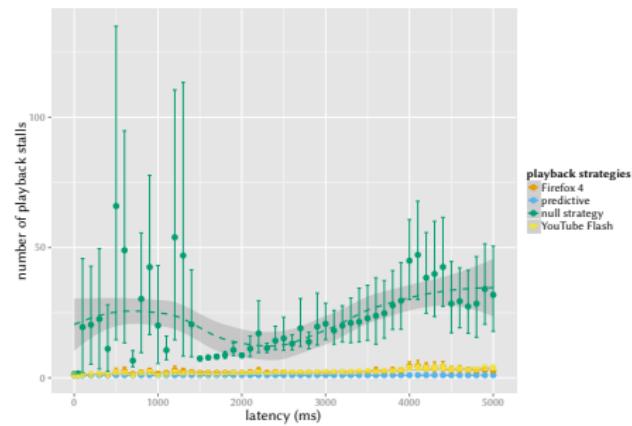


Figure: Number of stalls in relation to transmission latency with a local polynomial least-squares fit.

Loss Measurement Series

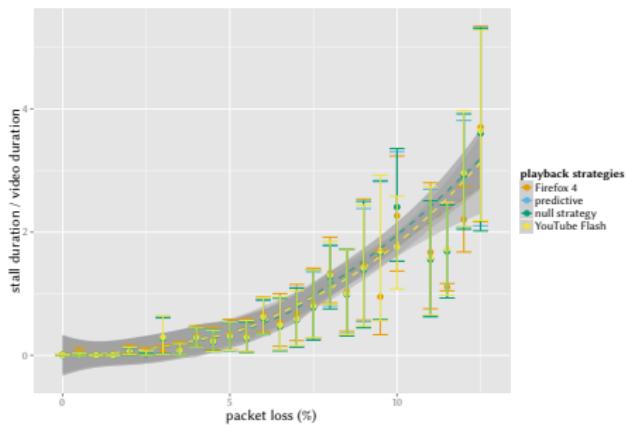


Figure: Stalling duration in relation to the packet loss with a local polynomial least-squares fit.

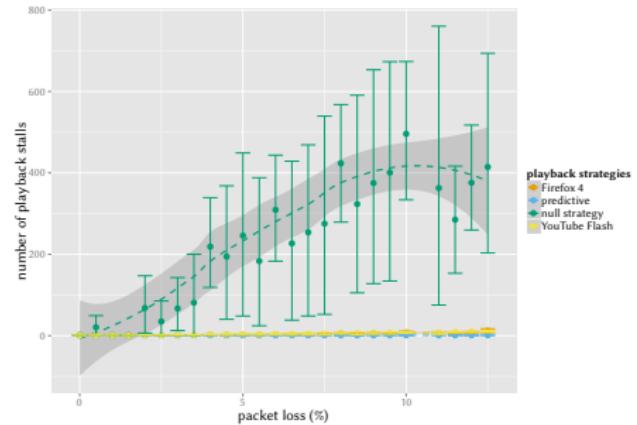


Figure: Number of playback stalls in relation to packet loss with local polynomial least-squares fit.

Loss Measurement Series QoE

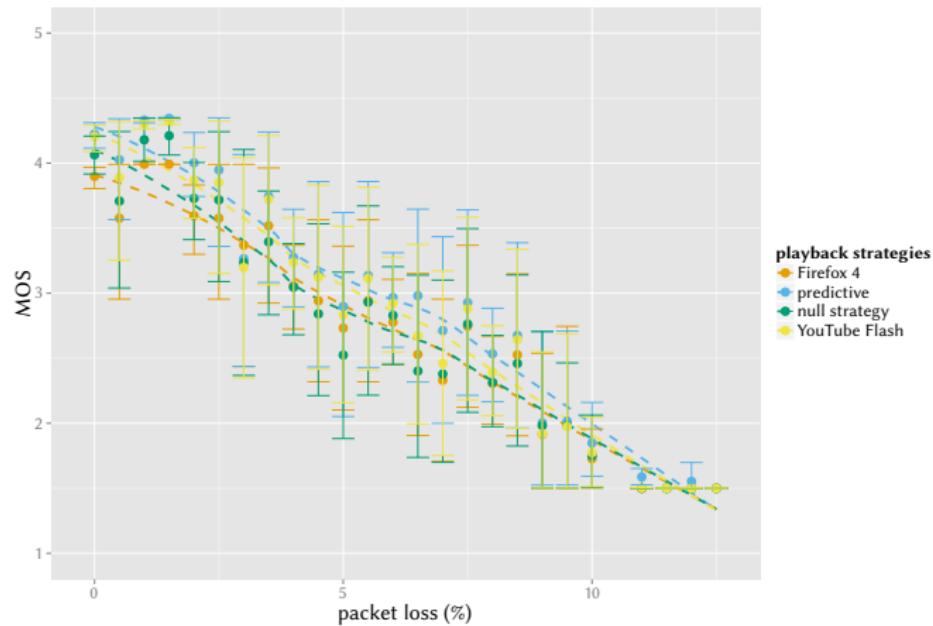


Figure: Calculated MOS for the loss measurement series.

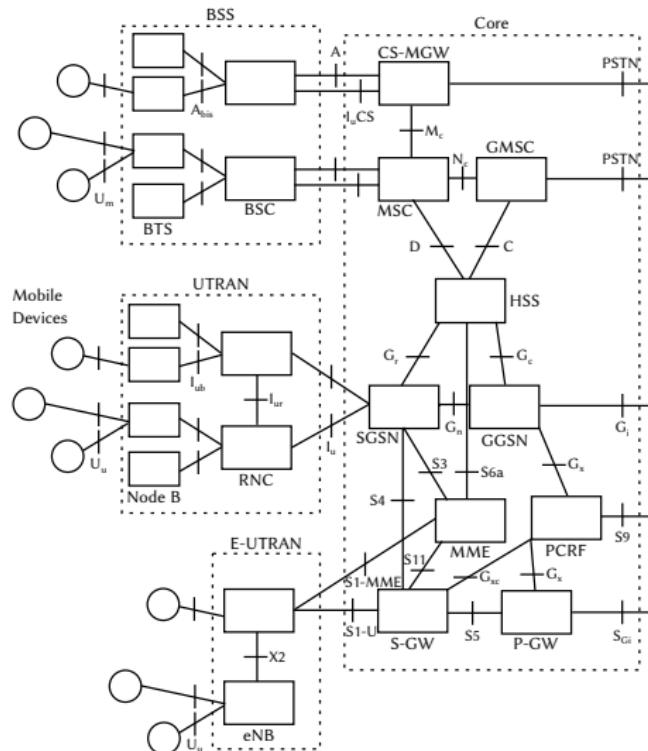


Figure: Overview of a combined CS/PS GSM/UMTS/LTE architecture.

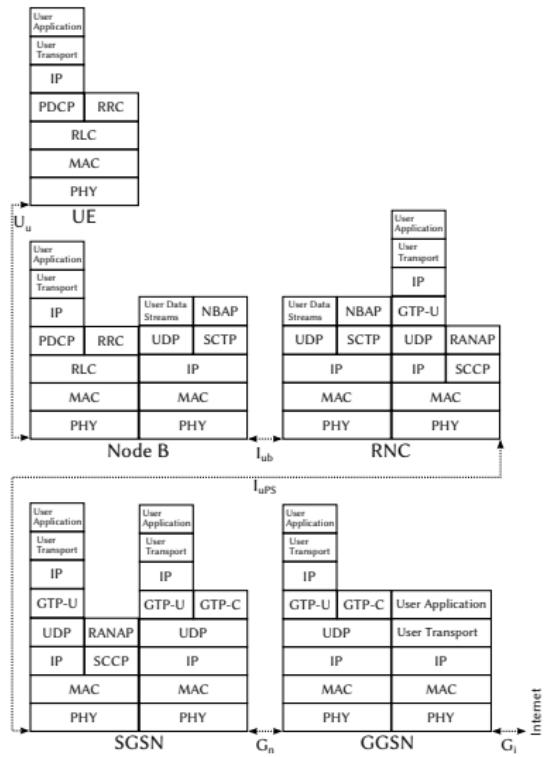


Figure: Simplified control plane and user plane IP-based protocol stacks on the user traffic path through the mobile network.

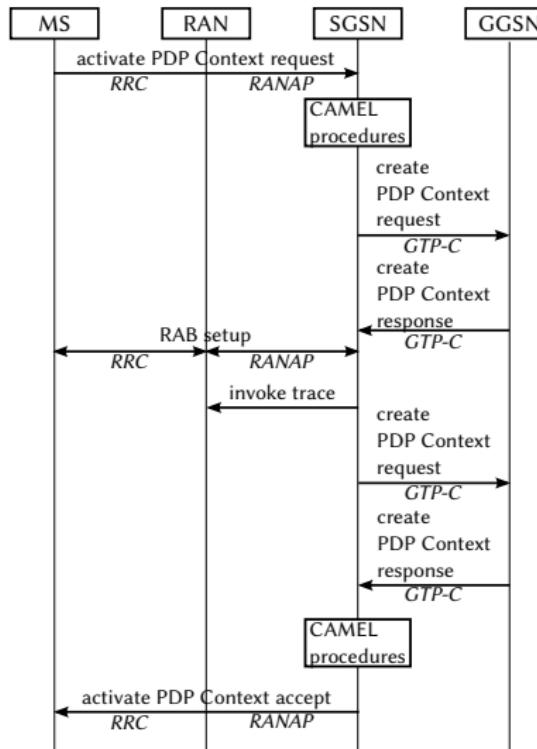


Figure: PDP Context activation procedure signaling interaction diagram for UMTS, including involved signaling protocols.

Octets	Bits							
	8	7	6	5	4	3	2	1
1	Version			1	0	E	S	PN
2	Message Type							
3	Length							
4								
5								
6	Tunnel Endpoint Identifier							
7								
8								
9	Sequence Number							
10								
11	N-PDU							
12	Next Extension Header Type							

Figure: General 12 B GTP header format.

Table: All IE in a Create PDP Context request and size thereof for IPv4 network and user traffic only. The denoted sizes exclude the first message type byte.

IE	Presence	Size	IE	Presence	Size
IMSI	cond.	8B	TFT	cond.	max
RAI	opt.	6B			257B
Recovery	opt.	1B	Trigger Id	opt.	var.
Selection mode	cond.	1B	OMC Identity	opt.	var.
TEID Data I	mand.	4B	Common Flags	opt.	3B
TEID Control Plane	cond.	4B	APN Restriction	opt.	3B
NSAPI	mand.	1B	RAT	opt.	3B
Linked NSAPI	cond.	1B	User Location Information	opt.	10B
Charging Characteristics	cond.	2B	MS Time Zone	opt.	4B
Trace Reference	opt.	2B	IMEI (SV)	cond.	10B
Trace Type	opt.	2B	CAMEL Charging Information	opt.	var.
End User Address	cond.	8B	Container		
APN	cond.	max	Additional Trace Info	opt.	11B
PCO	opt.	102B	Correlation-ID	opt.	3B
		255B	Evolved Allocation Retention	opt.	3B
SGSN signaling address	mand.	6B	Priority I		
SGSN user traffic address	mand.	6B	Extended Common Flags	opt.	3B
MSISDN	cond.	max	User CSG Information	opt.	10B
		17B	APN-AMBR	opt.	11B
QoS Profile	mand.	max	Signaling Priority Indication	opt.	3B
		257B	Private Extension	opt.	var.

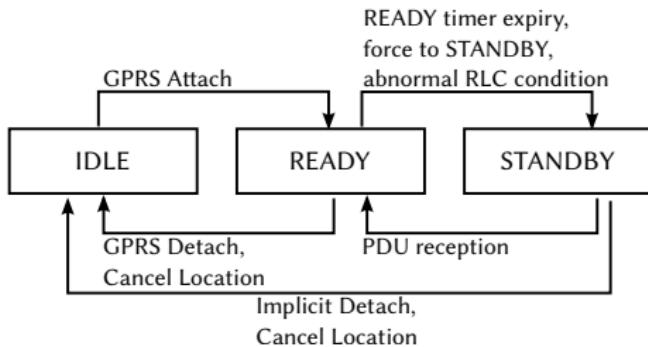


Figure: SGSN MM state machines for 2G radio access as defined in [3GP13, Section 6.1].

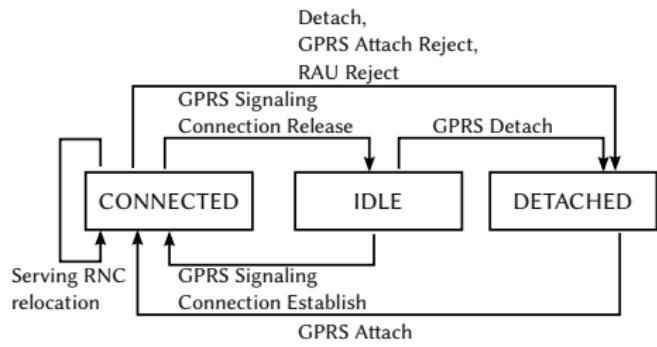


Figure: SGSN MM state machines for 3G radio access as defined in [3GP13, Section 6.1].

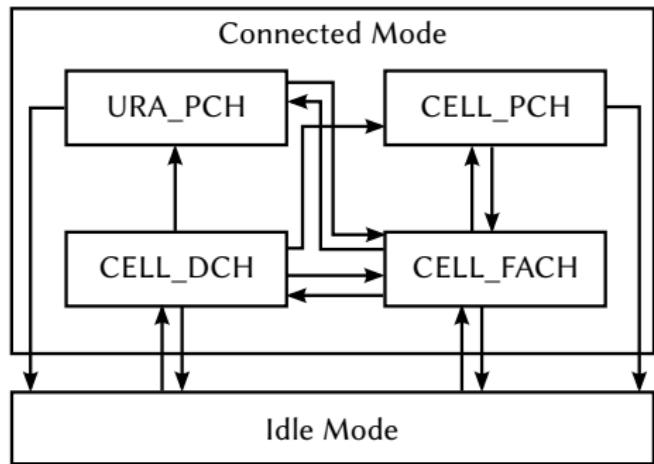


Figure: RRC State Model as per [3GP12, Section 7.1].

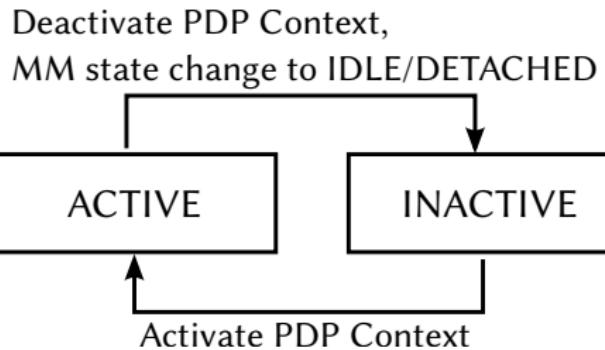


Figure: PDP State Model defined in [3GP13, Section 9].

Table: Relative TAC statistics.

Type	Relative number of devices with an entry in the TAC dataset
Total number of flows	99.72 %
Ratio of total traffic	99.97 %
Total number of tunnels	87.57 %
Total number of GTP signaling messages	90.95 %
Number of distinct UEs	80.93 %

Table: Relative device-discriminated traffic statistics extracted from the dataset.

	Flows	Traffic	Tunnels	GTP message pairs	Devices
By device type					
Smartphones	20.58%	12.81%	60.31%	75.99%	37.97%
Regular phones	0.26%	0.37%	5.40%	0.94%	9.25%
3G dongles	66.55%	75.12%	12.71%	9.53%	25.10%
By OS					
Android	10.82%	6.48%	14.33%	43.33%	14.01%
iOS	7.22%	4.47%	18.91%	20.35%	7.94%
Symbian	1.02%	1.09%	21.17%	4.51%	12.97%
Blackberry OS	0.07%	0.10%	2.17%	2.60%	1.48%

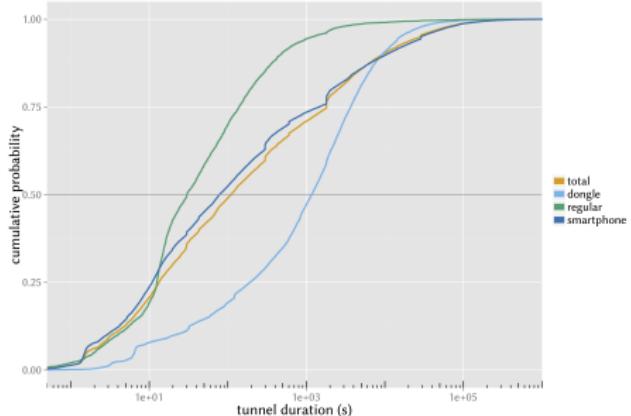


Figure: Tunnel duration distribution, separated for 3G dongles, smartphones and regular phones with medians at 115 s (total), 31 s (regular), 82 s (smartphone), and 1207 s (dongle).

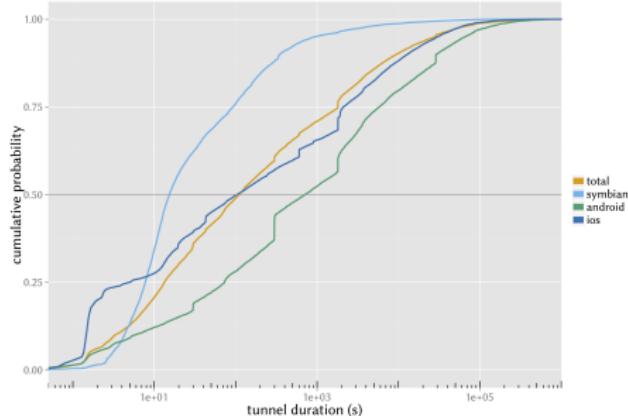


Figure: Tunnel duration CDF, separated for select OSs; Medians at 115 s (total), 15.5 s (symbian), 104 s (iOS), and 765 s (android).

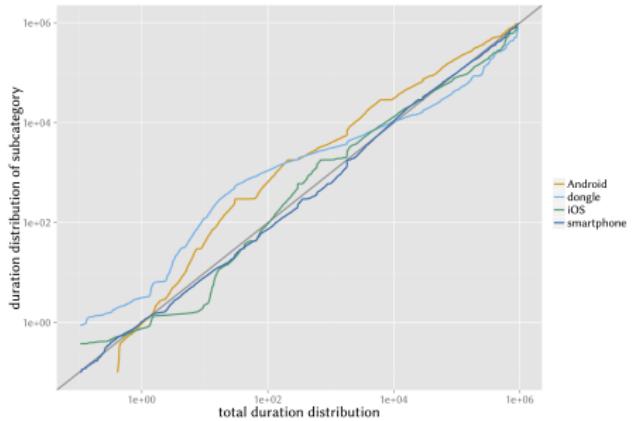


Figure: Q-Q Plots of the tunnel duration distributions in comparison to device classification categories.

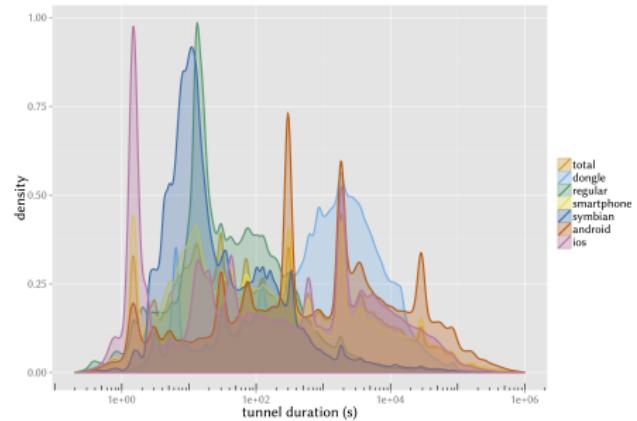


Figure: Logscaled density plot of the tunnel duration with all classifications.

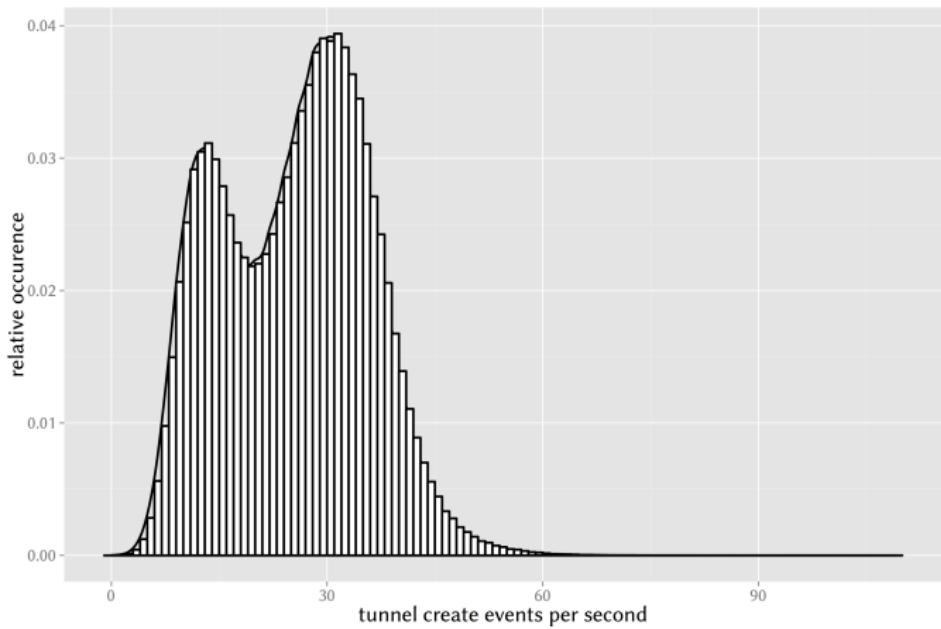


Figure: Density plot of tunnel arrival rate.

ECDF of the tunnel IAT in seconds by time of day

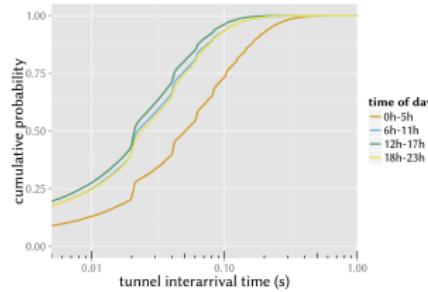


Figure: All tunnel requests.

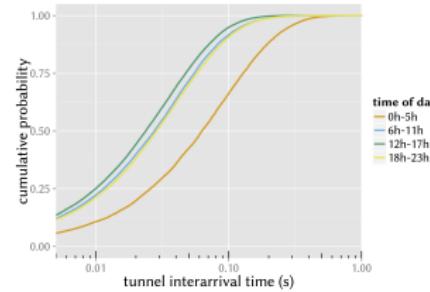


Figure: Only tunnels with data flows.

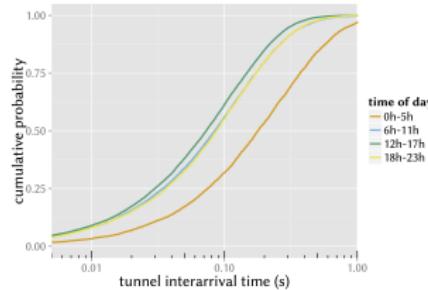


Figure: Tunnels with GPRS data flows.

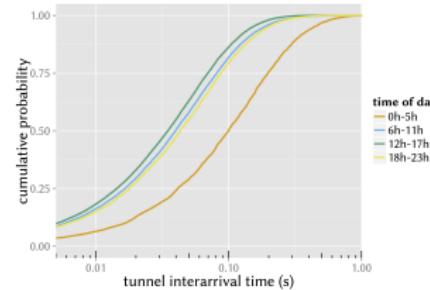


Figure: Tunnels with UMTS data flows.

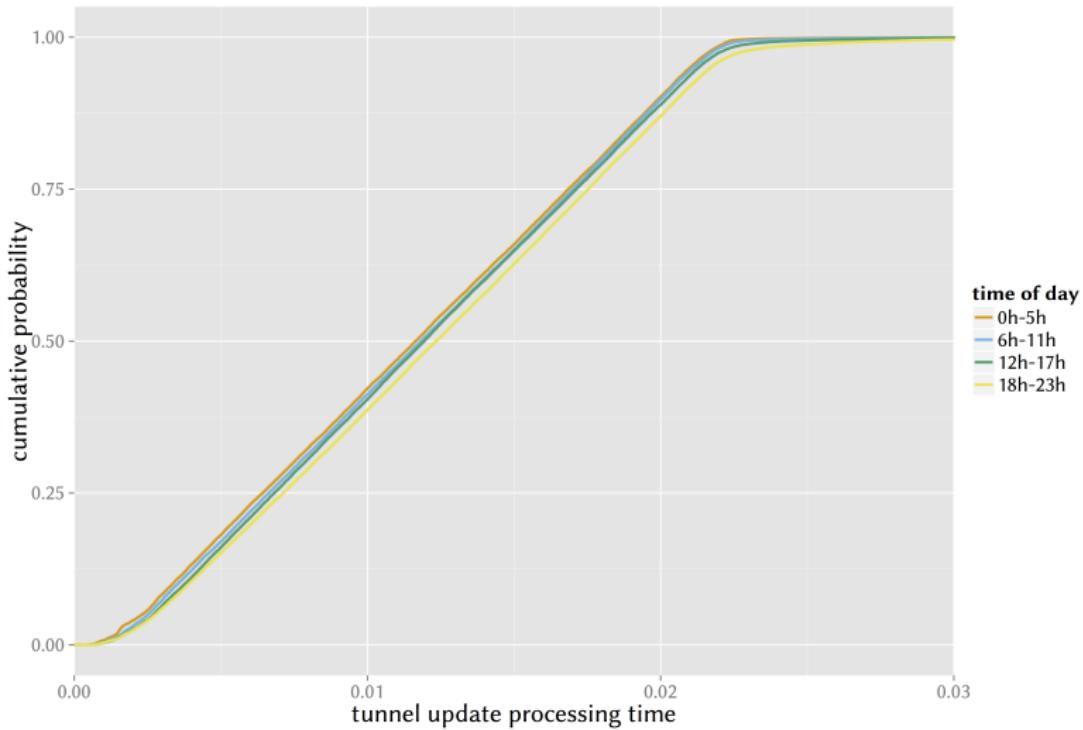


Figure: ECDFs of the time in seconds it takes a GGSN to process a GTP update event, separately plotted for four time slots each day.

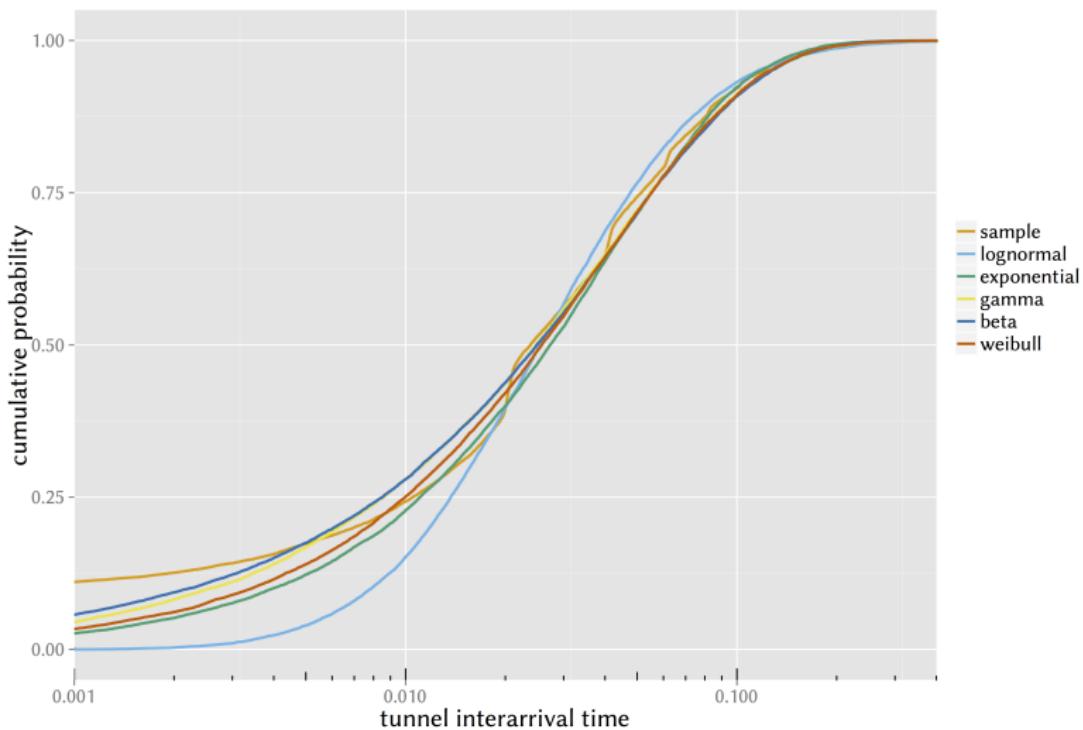
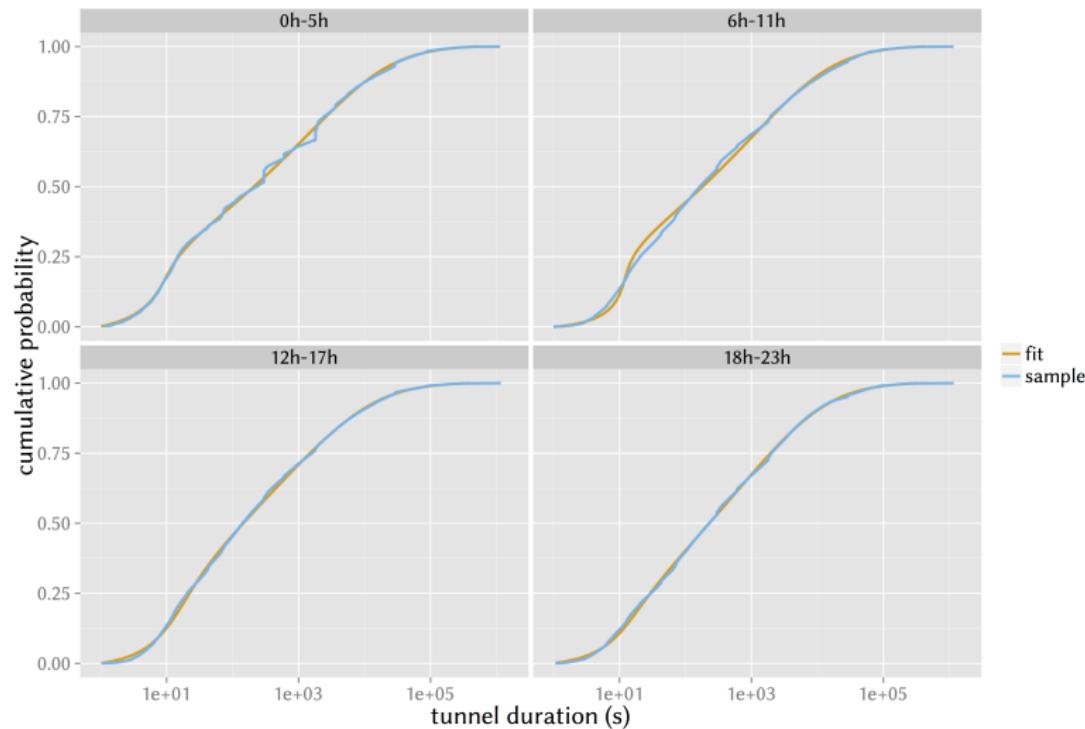


Figure: Sampled inter-arrival time CDF and fitted theoretical distributions.

Exponential Arrival Process Fits



Serving Time Rational Functions Fit

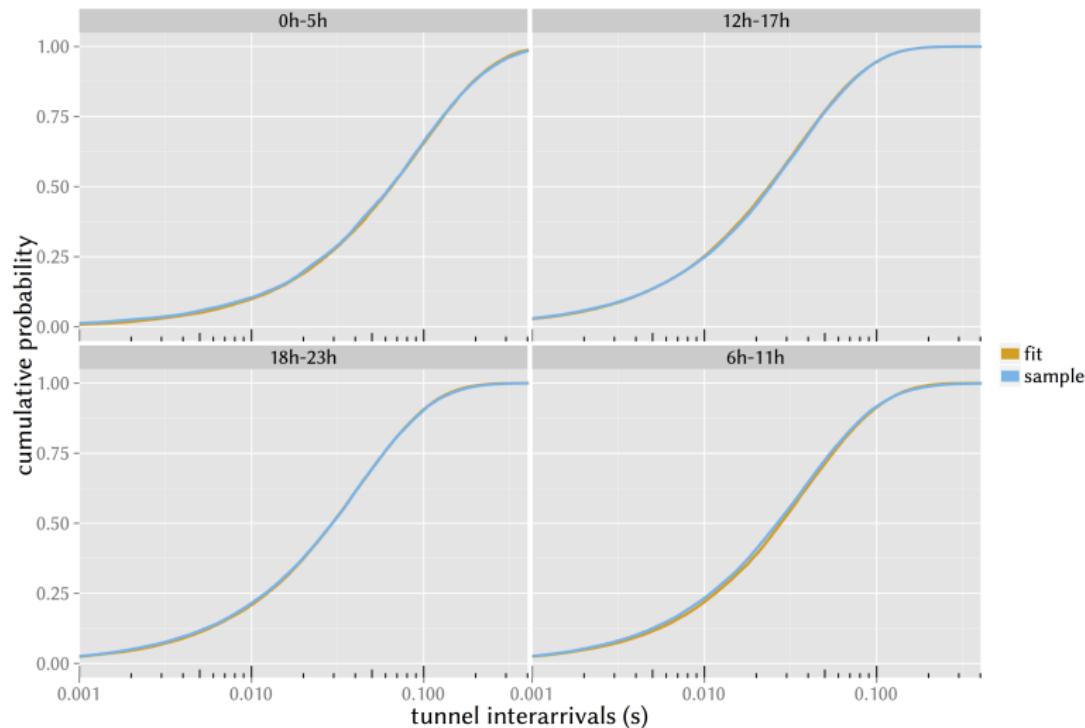


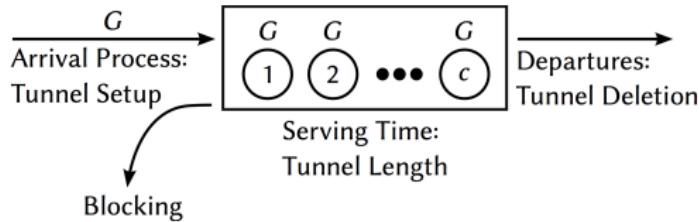
Table: Parameters for the exponentially distributed inter-arrival times and corresponding Pearson correlation coefficients.

Time of Day	λ	$R_{arrival}$
0h-5h	10.67477	0.995
6h-11h	24.53298	0.992
12h-17h	29.2504	0.993
18h-23h	23.49983	0.986

Table: Inverse rational functions fitted to the ECDFs of the tunnel duration by time of day and correlation coefficients of the fit.

Time of Day	Inverse Serving Time CDF Representation	R_{dur}
0h-5h	$0.919208 - 60.6136y - 3498.78y^3 - \frac{110.707y+2289.94y^3}{y-1.00469}$	0.999
6h-11h	$1 + 117.484y - 368.643y^2 - \frac{1720.13y^4}{y-1.0041}$	0.999
12h-17h	$0.952566 + 69.4907y + \frac{81146.1y^3+1.08572\times 10^6y^5}{805-802.01y}$	0.999
18h-23h	$0.911924 + 82.0562y - \frac{2936.93y^4}{1.94468y-1.9532}$	0.999

Queuing Models



Described by Kendall's Notation $A/S/c/q$

- Distribution of the arrival process A
- Distribution of the serving time S
- Number of Servers c
- Queue Length q
 - $q = \infty$ no loss will occur
 - 0 loss/blocking system, no queue
- Evaluate
 - Average queue length and server occupation
 - Blocking probability

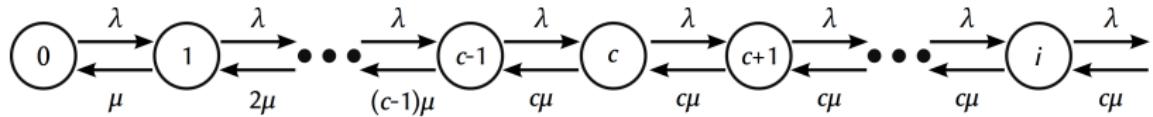
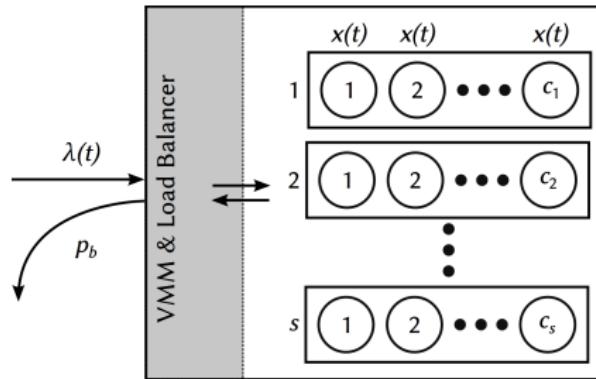


Figure: $M/M/c/\infty$ Markov chain model.

Expanding the Model

Virtualized GGSN Queuing Model



- Suggestion for a virtual GGSN architecture for 3G networks
 - Same arrival and serving time process, no queue
 - Load balancing strategies for VM management and tunnel placement
 - Could incur additional blocking (virtualization overhead)
 - Additional dimension for scaling compared to monolithic model
- $M(t)/G(t)/\|\vec{c}\|_1/0$ ($\|\vec{c}\|_1$: total tunnel capacity of all s VMs)

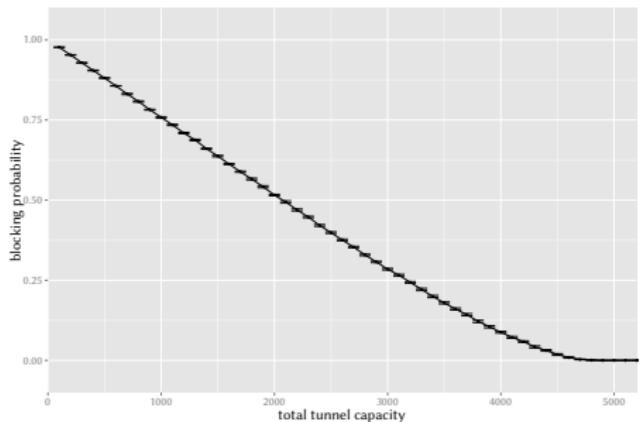


Figure: Impact of the number of supported parallel tunnels on the blocking probability for the traditional GGSN model.

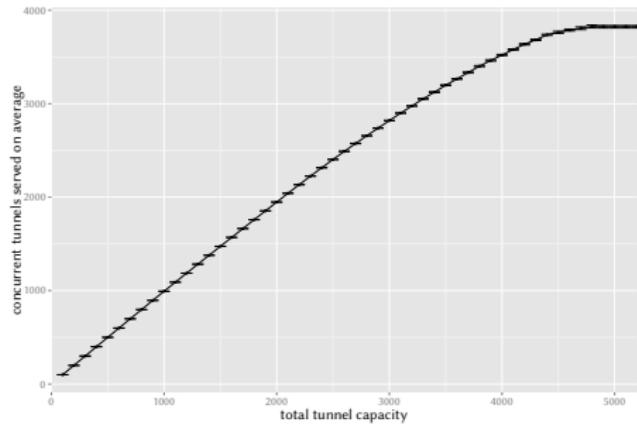


Figure: Mean number of tunnels concurrently served by the GGSN for incrementally increasing capacity.

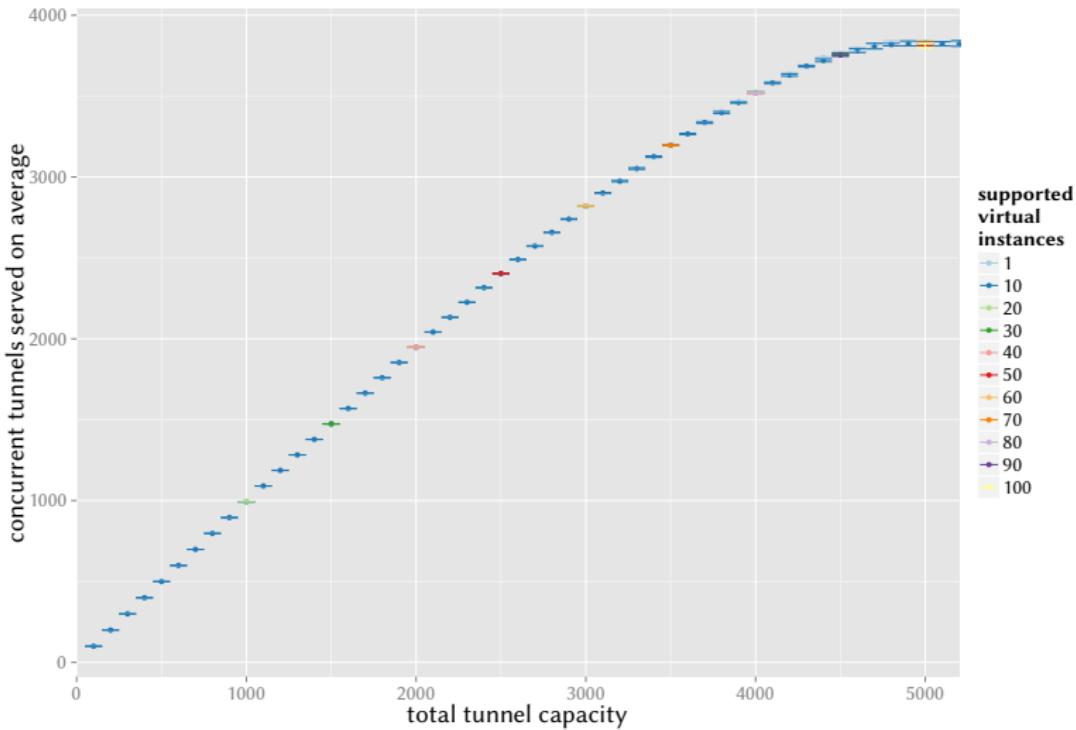


Figure: Comparison of the mean tunnel capacity usage of the individual virtual instance configurations.

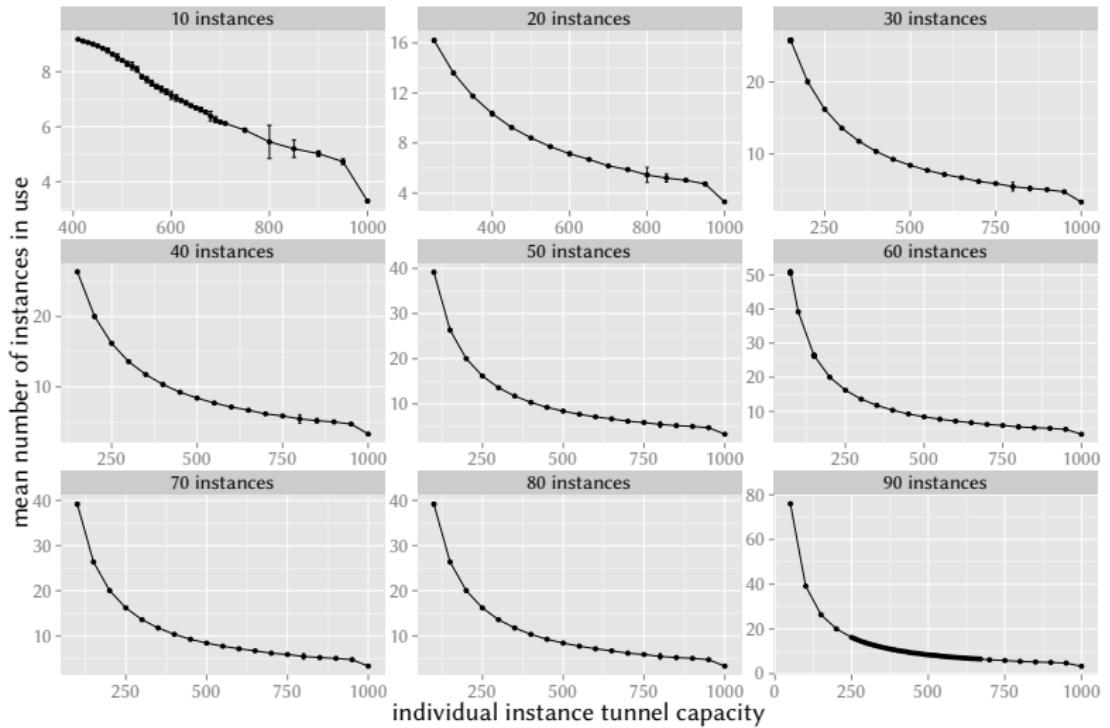


Figure: Mean instance usage of various virtualization configurations. A higher number of total instances results in a finer granularity of scaling and energy efficiency as more instances can be kept shut down.

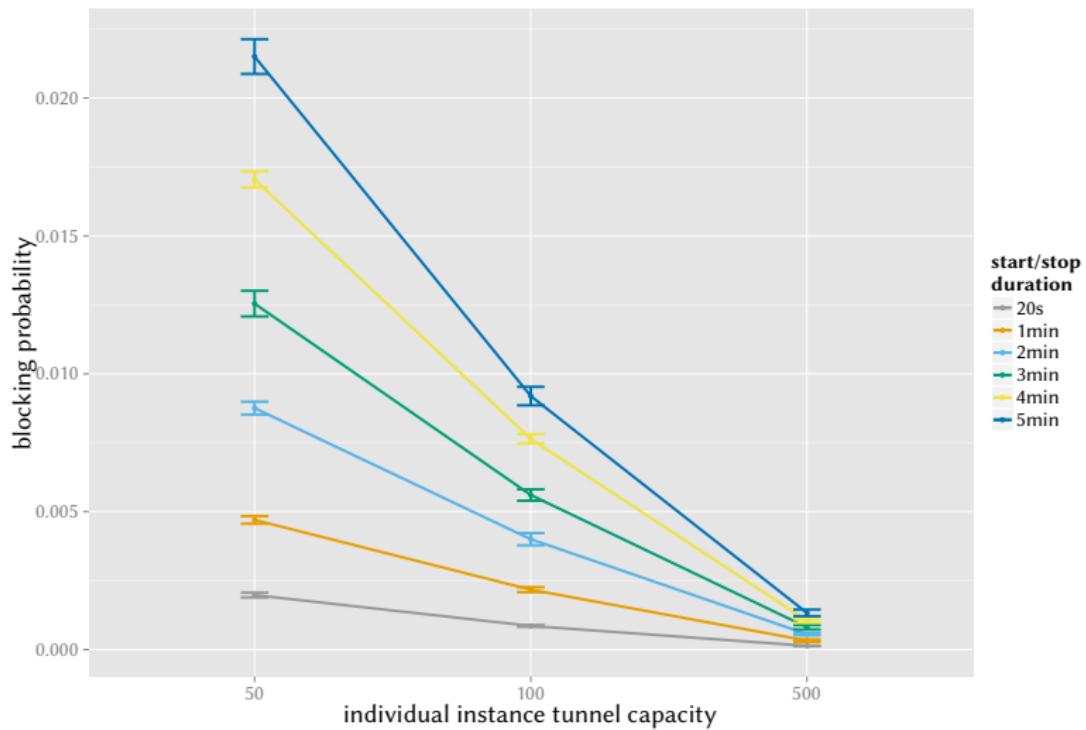


Figure: Influence of start up and shut down time on blocking probability with regard to different numbers of instances.

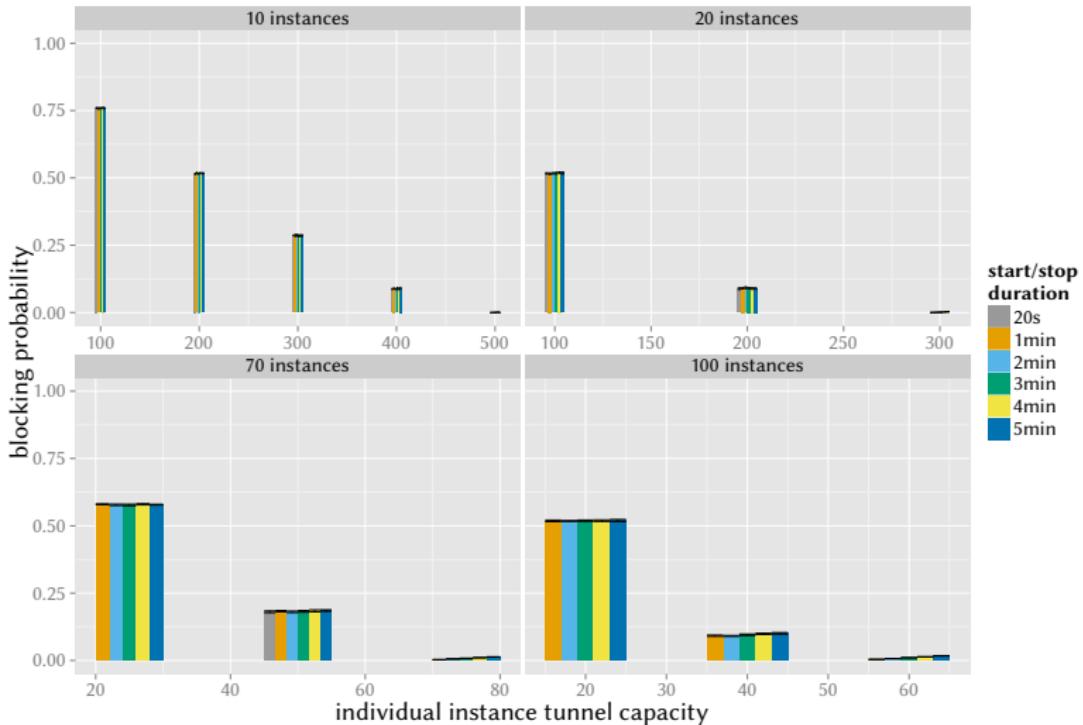
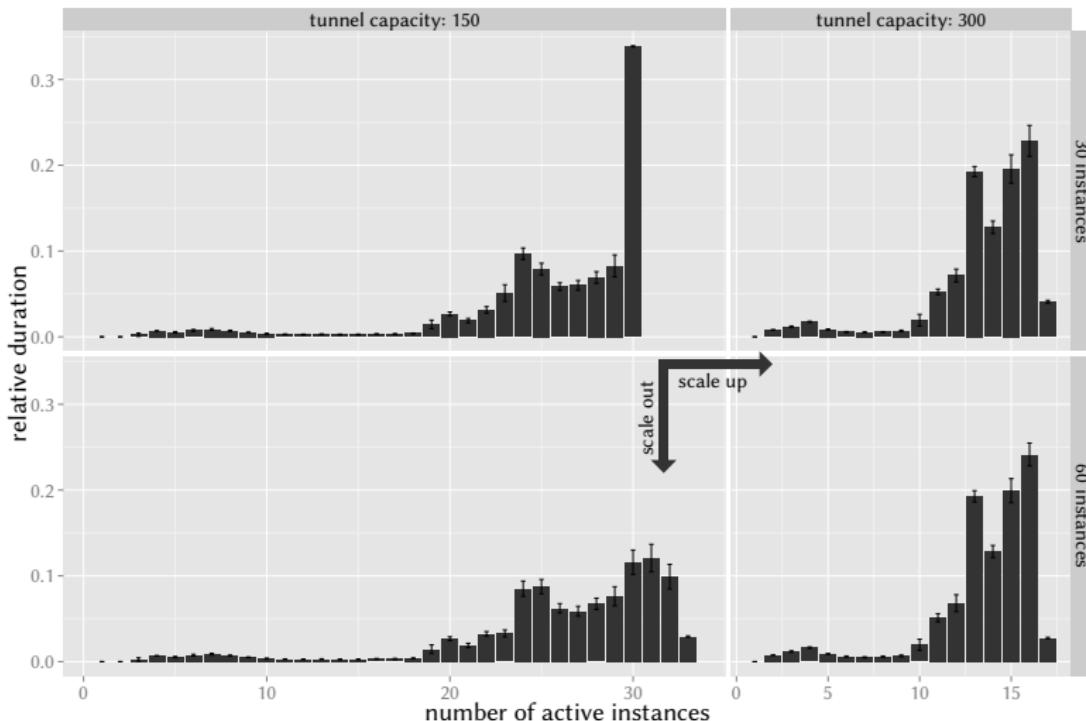


Figure: Influence of the boot and shutdown time on the blocking probability.

Scaling Up or Out with a Virtualized GGSN



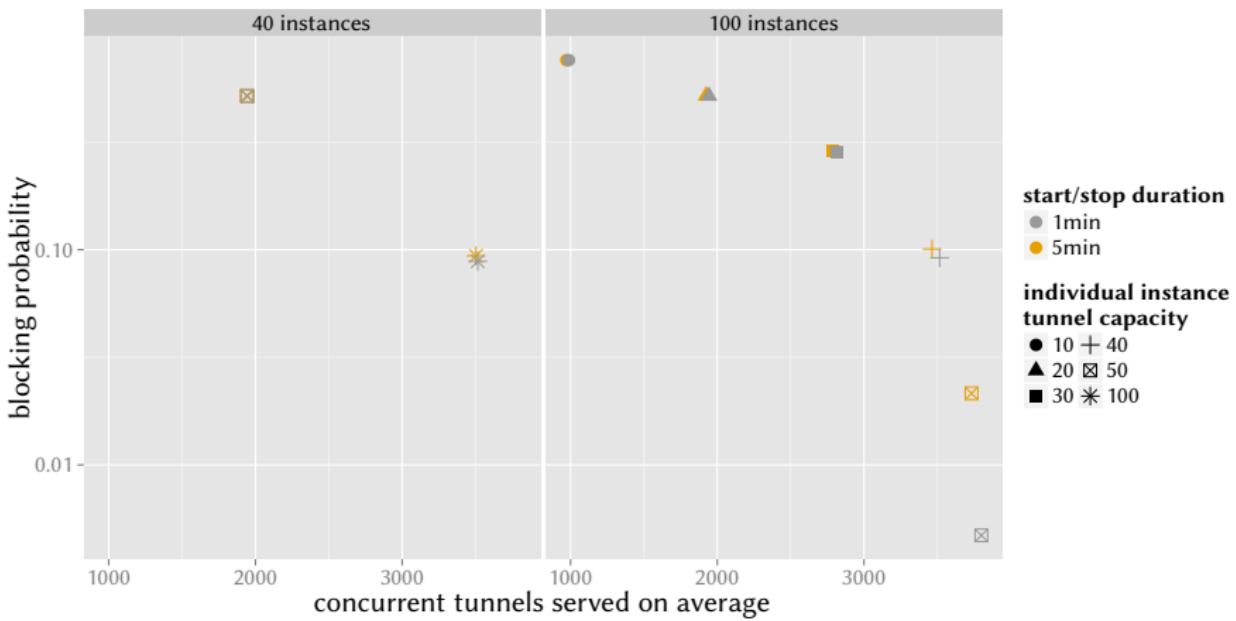
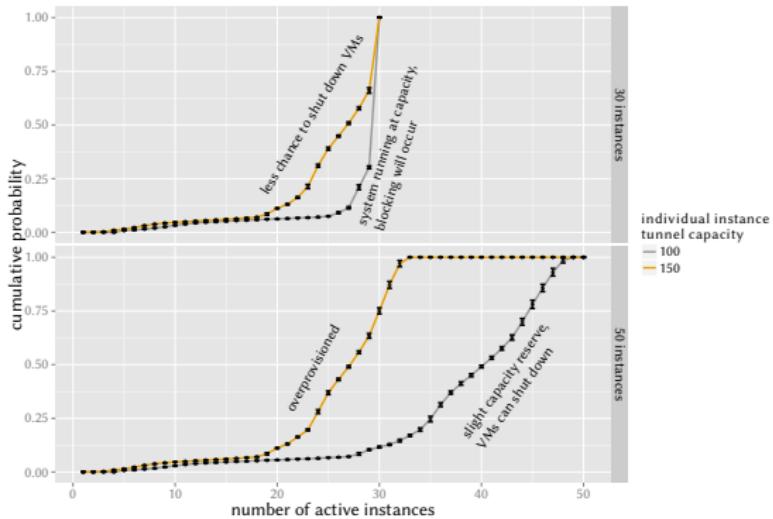


Figure: Trade-off between blocking probability and mean resource utilization with regard to maximum number of instances, instance tunnel capacity, and start and stop time.

Virtualized GGSN Impact



- Monolithic and virtualized GGSN scale equally with supported tunnels
- Scaling VM model by VM count instead of size has minimal impact on p_B
- Unused instances can be shut down for increased energy efficiency compared to monolithic model

Table: Effect sizes of the simulation parameters based on a one-way ANOVA.

	<i>F – ratio</i>	<i>p – value</i>	η^2	ω^2
Blocking probability				
Individual instance tunnel capacity	104	< 0.001	0.468	0.463
Number of instances	9.29	< 0.001	0.056	0.050
Start/stop duration	0.21	0.931	< 0.001	0.002
Total tunnel capacity	317257	< 0.001	0.999	0.999
Mean number of tunnels				
Individual instance tunnel capacity	105.7	< 0.001	0.472	0.467
Number of instances	9.39	< 0.001	0.056	0.050
Start/stop duration	0.25	0.912	< 0.001	0.002
Total tunnel capacity	365753	< 0.001	0.999	0.999

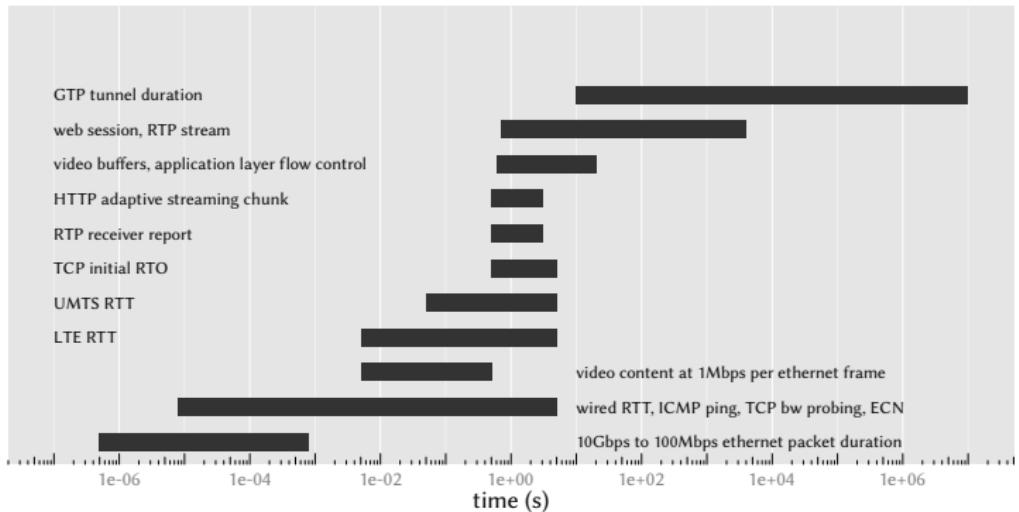


Figure: Approximate discernible time scales the networking stack protocols operate on in each layer.

Mobile Streaming Interactions

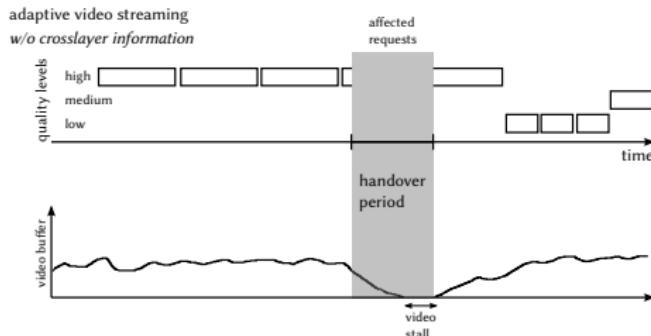
Use Case: Leveraging Crosslayer Information

- Make streaming apps aware of mobile net state to deal with influences
- Crosslayer information exchange model to pass baseband info to applications and include info in their decision making
- Predict future events through other context information sources, e.g. handover events through GPS data and neighboring cells

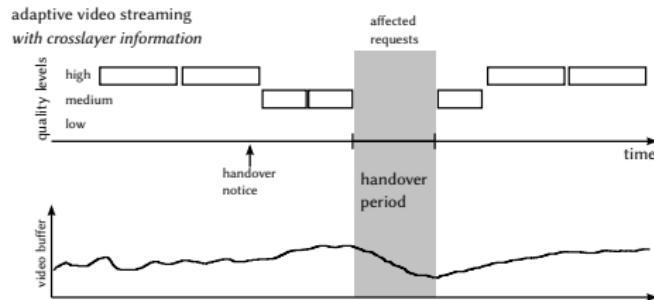
Mobile Streaming Interactions

Use Case: Leveraging Crosslayer Information

- Make streaming apps aware of mobile net state to deal with influences
- Crosslayer information exchange model to pass baseband info to applications and include info in their decision making
- Predict future events through other context information sources, e.g. handover events through GPS data and neighboring cells



Stalling occurs without handover
hinting



Stalling can be prevented by
proactively filling the playback buffer

TCP Changes in the Linux Kernel

Change	Related Work	Kernel	Date
BIC as default congestion avoidance algorithm (from Reno)		2.6.8	August 2004
CUBIC as default congestion avoidance algorithm	[HRX08]	2.6.19	November 2006
New TCP Slow Start: HyStart	[HR11]	2.6.29	March 2009
Multipath TCP	[RFC6824]	external	2011
TCP User Timeout	[RFC5482]	2.6.37	January 2011
Initial Receive Window 10 MSS	[RFC6982]	2.6.38	March 2011
Initial Congestion Window 10 MSS	[RFC6982]	2.6.39	May 2011
1 s initial RTO (from 3 s)	[RFC6298]	3.1	October 2011
Changes to sstresh and CWND behavior	[RFC5681]	3.1	October 2011
TCP Proportional Rate Reduction	[RFC6937]	3.2	January 2012
Byte queue limits and TCP buffer limits		3.3	March 2012
CoDel AQM	[NJ14]	3.5	July 2012
TCP Early Retransmit	[RFC5827]	3.5	July 2012
TCP small queues		3.6	September 2012
TCP Fast Open (client side)	[Che+14]	3.6	September 2012
TCP Fast Open (server side)		3.7	December 2012
TCP tail loss probe		3.10	June 2013
TCP Forward RTO-Recovery	[RFC5682]	3.10	June 2013
Low latency network polling		3.11	September 2013
Improved RTO calculation and handling of reordering		3.12	November 2013
TCP Fast Open enabled by default		3.13	January 2014
TCP auto corking		3.14	March 2014
PIE AQM		3.14	March 2014
TCP Fast Open over IPv6		3.16	2014
LISP	[RFC6830]	3.16	2014

Leveraging Cross-Layer Information

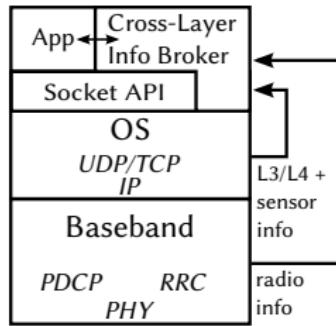
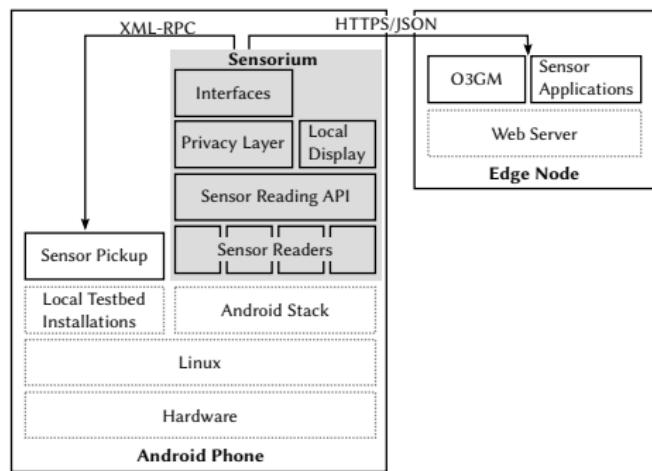


Figure: Model and architecture of the proposed cross-layer information exchange.

Active Measurement Testbed with Metadata

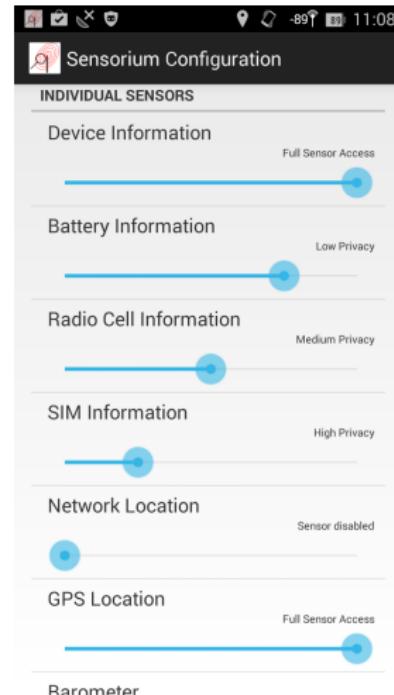
Using Sensorium

- Difficulty to conduct realistic mobile measurement campaigns
- Importance of additional metadata in mobile measurements (location, connectivity, baseband state)
- Privacy issues, let the user control data access and granularity
- Provide sensor-reading and collection framework for smartphones to conduct ones own campaign on “foreign” devices



- Demo campaign **Open 3G Map:** Collected 3G coverage data and aggregate to map overlay

Sensorium



Open3G Map

● GSM ● GPRS ● EDGE ● 2G/3G ● UMTS ● HSPA ● HSDPA ● HSPA+

controls features links

Feature Information

click on a feature

Capture TS Jan. 21, 2013,
1:55 p.m.

Network type UMTS

Cell ID 3016406

Lac ID 27

Tac ID 353160

Operator 232-1

IP 93.111.65.199

RSSI -101

GPS accuracy 10.00

GPS altitude 228.90

GPS longitude 16.3399889

GPS latitude 48.06208901

Vendor ZTE

Model Blade

Battery 63

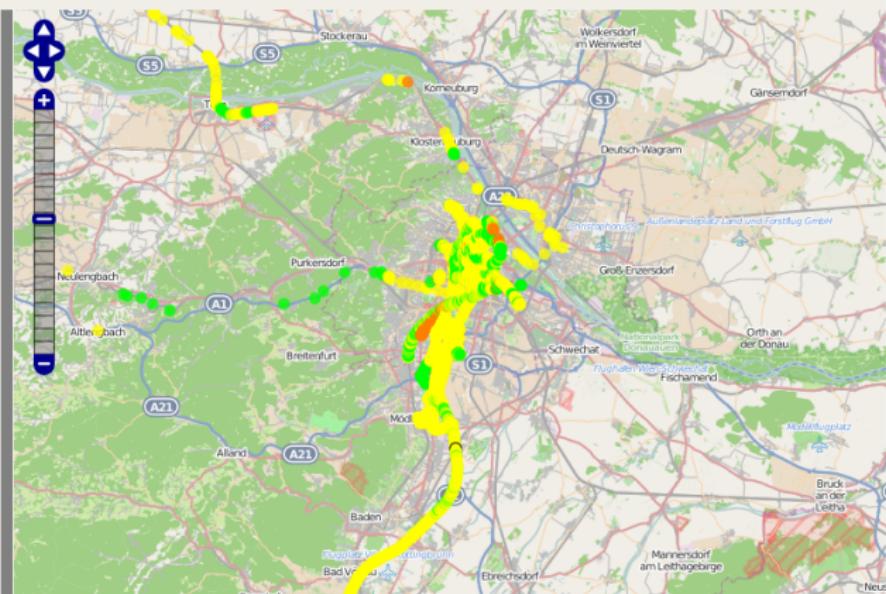


Figure: The O3GM web page, displaying a 3G coverage measurements layer with data collected by Sensorium on top of the OpenStreetMap base layer.

Reliable Streaming

Categorization and Measuring

Streaming categorization criteria

- Video source (Live, VOD)
- Adaptivity, e.g.
 - Implicit through unreliable transmission (RTP)
 - Explicit through multiple quality levels (adaptive streaming, e.g. DASH)
- Location of streaming control
 - Server-side: push-based (RTP)
 - Client-side: pull-based (HTTP)
- Transport/application protocol and transmission pattern

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Measurement Approach

- Transmission process has no influence on the image quality (reliability)
- Evaluate streaming solely on the basis of buffering behavior
- Number and duration of stalls as metric for non-adaptive streaming

Mobile Streaming Simulation

Simulator Survey

- Much easier to conduct than active measurements, but often with limited fidelity
- Conducted survey for the suitability of existing mobile streaming simulators
 - Most only concerned with radio interface simulation, not core or signaling
 - Needs to have a fully functioning up-to-date network stack
 - None freely available and up-to-date for 3G
 - Candidates for LTE: Omnet++ and ns-3
 - Both provide rudimentary core and tunneling but no control plane
 - Attributable to specification complexity, control plane in particular
- ns-3 chosen as basis for simulation framework, with limitations in mind
- Can be additionally used as a network emulator

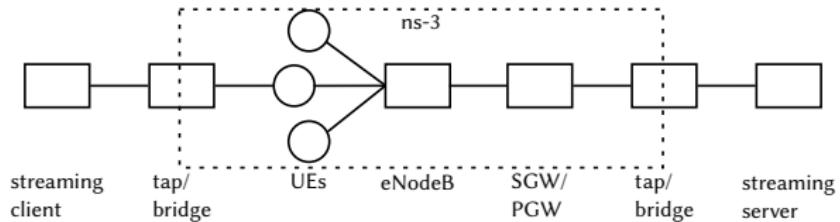
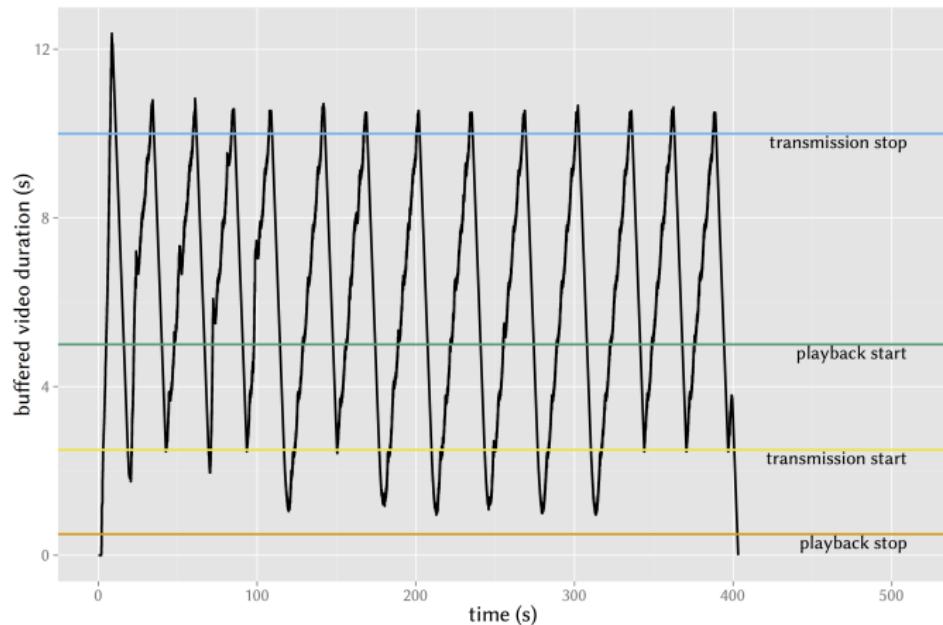


Figure: Future testbed iteration: hybrid of ns-3 LTE simulation and actual or emulated streaming client and server bridged to it.

Mobile Streaming Strategies

Example Four Threshold Strategy



Limits for playback start/stop, transmission start/stop

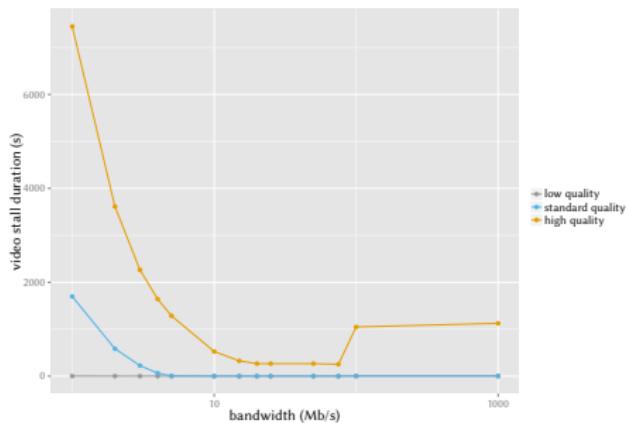


Figure: Relative stalling duration of the simulated reliable streaming player under limited Internet bandwidth.

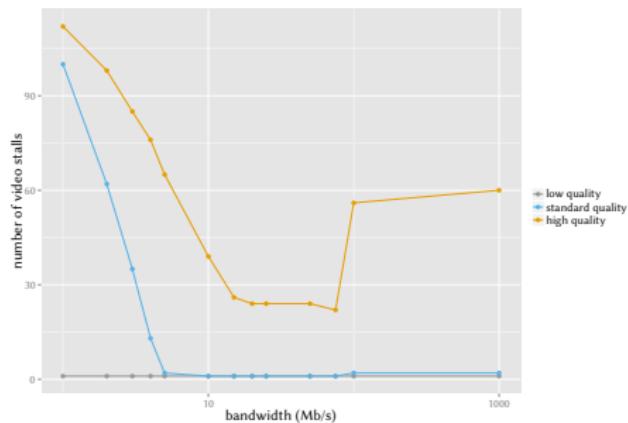


Figure: Number of stalling events of the simulated reliable streaming player under limited Internet bandwidth.

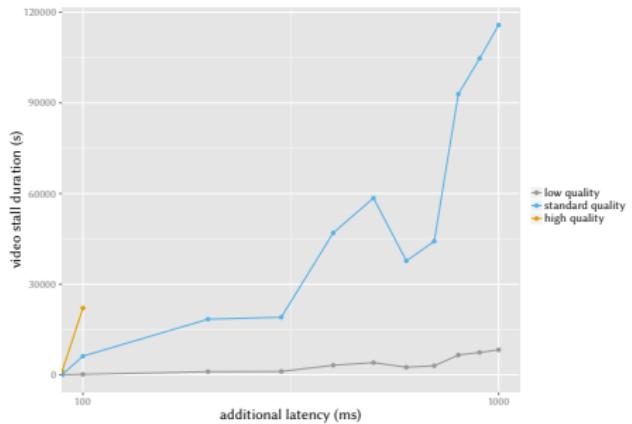


Figure: Relative stalling duration of the simulated reliable streaming player under increased Internet latency.

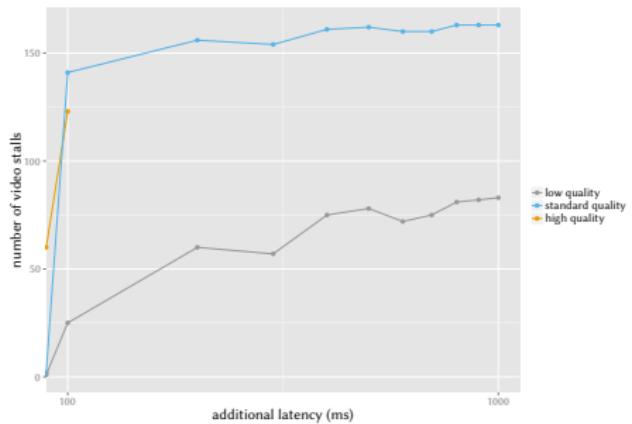


Figure: Number of stalling events of the simulated reliable streaming player under increased Internet latency.