How to *truly* improve the Internet's transport layer, part 2

(the technical details)

CAIA, Swinburne University, Melbourne, 10. 2. 2011

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Setting the stage... a reminder

- I have already told you that
  - the Internet's transport layer is as flexible as a rock
  - New, useful protocols like SCTP and DCCP remain unused

- A more flexible design would use abstraction
  - applications don't specify protocol, just service (still best effort model) ➔ "transport system" could make the best possible choice out of what is available
    - Can gradually evolve without changing applications, via OS upgrades and growing protocol support by ISPs

How to get there?

- Build the system
  - benefit from protocol features without application involvement
  - API design
  - try to use a new protocol with TCP as a fall-back
- Get protocols deployed so that the system makes sense: ensure that they are attractive (SCTP implementation, DCCP service issues)
- Measure protocol availability, provide tools

You've seen proof-of-concept results

Today

API Design

[Stefan Jörer: A Protocol-Independent Internet Transport API, MSc. thesis, University of Innsbruck, December 2010]

[Michael Welzl, Stefan Jörer, Stein Gjessing: "Towards a Protocol-Independent Internet Transport API", FutureNet IV workshop, ICC 2011, June 2011, Kyoto Japan]

Two approaches

- Top-down: start with application needs ("QoS-view")
  - + flexible, good for future use of new protocols
  - – loss of service granularity: some protocol features may never be used
  - – been there, done that, achieved nothing...
- Bottom-up: unified view of services of all existing Internet transport protocols
  - + No loss of granularity, all services preserved
  - + Totally new approach, concrete design space
  - – May need to be updated in the future

Our chosen design method

- Bottom-up: use TCP, UDP, SCTP, DCCP, UDP-Lite
  - start with lists from key references

- Step 1: from list of protocol features, carefully identify application-relevant services
  - features that would not be exposed in APIs of the individual protocols are protocol internals
  - e.g. ECN, selective ACK

Result of step 1

transport protocol	connection oriented	flow control	congestion control	app. PDU bundling	error detection	reliability	delivery type	delivery order	multi streaming	multi homing
TCP	x	x	x	0/1	x	t	s	o		
UDP					x		m	u		
UDP-Lite					x/p1		m	u		
DCCP	x	x	2/3/4		x/p1		m	u		
SCTP	x	x	x	0/1	x	t/p2	m	o/u	0/1	0/1

- x = always on, empty = never on; 0/1 = can be turned on or off
- 2/3/4 = choice between CCIDs 2, 3, 4
- P1 = partial error detection; t = total reliability, p2 = partial reliability
- s = stream, m = message; o = ordered, u = unordered

Expansion

- A line for every possible combination of features
  - 43 lines: 32 SCTP, 3 TCP/UDP
- List shows reduction possibilities (step 2)
  - e.g. flow control coupled with congestion control
  - duplicates, subsets

service no.	transport protocol	connection-oriented	flow control	congestion control	app. PDU bundling	error detection	reliability	delivery type	delivery order	multi streaming	multi homing
1	TCP	x	x	x		x	t	s	o		
2	TCP	x	x	x	x	x	t	s	o		
3	UDP					x		m	u		
4	UDP-Lite					x		m	u		
5	UDP-Lite					p1		m	u		
6	DCCP	x	x	CC 2		x		m	u		
7	DCCP	x	x	CC 2		p1		m	u		
8	DCCP	x	x	CC 3		x		m	u		
9	DCCP	x	x	CC 3		p1		m	u		
10	DCCP	x	x	CC 4		x		m	u		
11	DCCP	x	x	CC 4		p1		m	u		
12	SCTP	x	x	x		x	t	m	o		
13	SCTP	x	x	x		x	t	m	o		x
14	SCTP	x	x	x		x	t	m	o	x	
15	SCTP	x	x	x		x	t	m	o	x	x
16	SCTP	x	x	x		x	t	m	u		
17	SCTP	x	x	x		x	t	m	u		x
18	SCTP	x	x	x		x	t	m	u	x	
19	SCTP	x	x	x		x	t	m	u	x	x
20	SCTP	x	x	x		x	p2	m	o		
21	SCTP	x	x	x		x	p2	m	o		x
22	SCTP	x	x	x		x	p2	m	o	x	
23	SCTP	x	x	x		x	p2	m	o	x	x
24	SCTP	x	x	x		x	p2	m	u		
25	SCTP	x	x	x		x	p2	m	u		x
26	SCTP	x	x	x		x	p2	m	u	x	
27	SCTP	x	x	x		x	p2	m	u	x	x
28	SCTP	x	x	x	x	x	t	m	o		
29	SCTP	x	x	x	x	x	t	m	o		x
30	SCTP	x	x	x	x	x	t	m	o	x	
31	SCTP	x	x	x	x	x	t	m	o	x	x
32	SCTP	x	x	x	x	x	t	m	u		
33	SCTP	x	x	x	x	x	t	m	u		x
34	SCTP	x	x	x	x	x	t	m	u	x	
35	SCTP	x	x	x	x	x	t	m	u	x	x
36	SCTP	x	x	x	x	x	p2	m	o		
37	SCTP	x	x	x	x	x	p2	m	o		x
38	SCTP	x	x	x	x	x	p2	m	o	x	
39	SCTP	x	x	x	x	x	p2	m	o	x	x
40	SCTP	x	x	x	x	x	p2	m	u		
41	SCTP	x	x	x	x	x	p2	m	u		x
42	SCTP	x	x	x	x	x	p2	m	u	x	
43	SCTP	x	x	x	x	x	p2	m	u	x	x

Reduction method for step 2

- Remove services that seem unnecessary as a result of step 1 expansion
- Apply common sense to go beyond purely mechanical result of step 1
  - Question: would an application have a reason to say “no” to this service under certain circumstances?
  - Features that are just performance improvements if they are used correctly (i.e. depending on environment, not app) are <u>not</u> services

Step 2

- Connection orientation
  - Removing it does not affect service diversity
  - User view: API is always connection oriented
  - on the wire, non-congestion-controlled service will always use UDP or UDP-Lite
  - static distinction, clear by documentation

- Delivery type
  - easy for API to provide streams on top of message transport
  - no need to expose this as a service

Step 2, contd.

- Multi-streaming
  - Performance improvement, depending on environment conditions / congestion control behavior, not an application service
- Congestion control renamed ➔ "flow characteristic"
- Multi-homing kept although not an app. service
  - this is part of a different discussion
  - could be removed above our API

Result of Step 2

service no.	*supported by transport protocol(s)*	flow characteristic	app. PDU bundling	error detection	reliability	delivery order	multi-homing
1	*TCP/SCTP*	TCP-like		x	t	o	
2	*TCP/SCTP*	TCP-like	x	x	t	o	
3	*UDP/-Lite*			x		u	
4	*UDP-Lite*			pl		u	
5	*DCCP/SCTP*	TCP-like		x	[p2]	u	
6	*DCCP*	TCP-like		pl		u	
7	*DCCP*	Smooth		x		u	
8	*DCCP*	Smooth		pl		u	
9	*DCCP*	Smooth-SP		x		u	
10	*DCCP*	Smooth-SP		pl		u	
11	*SCTP*	TCP-like		x	t	o	x
12	*SCTP*	TCP-like		x	t	u	
13	*SCTP*	TCP-like		x	t	u	x
14	*SCTP*	TCP-like		x	p2	o	
15	*SCTP*	TCP-like		x	p2	o	x
16	*SCTP*	TCP-like		x	p2	u	x
17	*SCTP*	TCP-like	x	x	t	o	x
18	*SCTP*	TCP-like	x	x	t	u	
19	*SCTP*	TCP-like	x	x	t	u	x
20	*SCTP*	TCP-like	x	x	p2	o	
21	*SCTP*	TCP-like	x	x	p2	o	x
22	*SCTP*	TCP-like	x	x	p2	u	
23	*SCTP*	TCP-like	x	x	p2	u	x

API Design

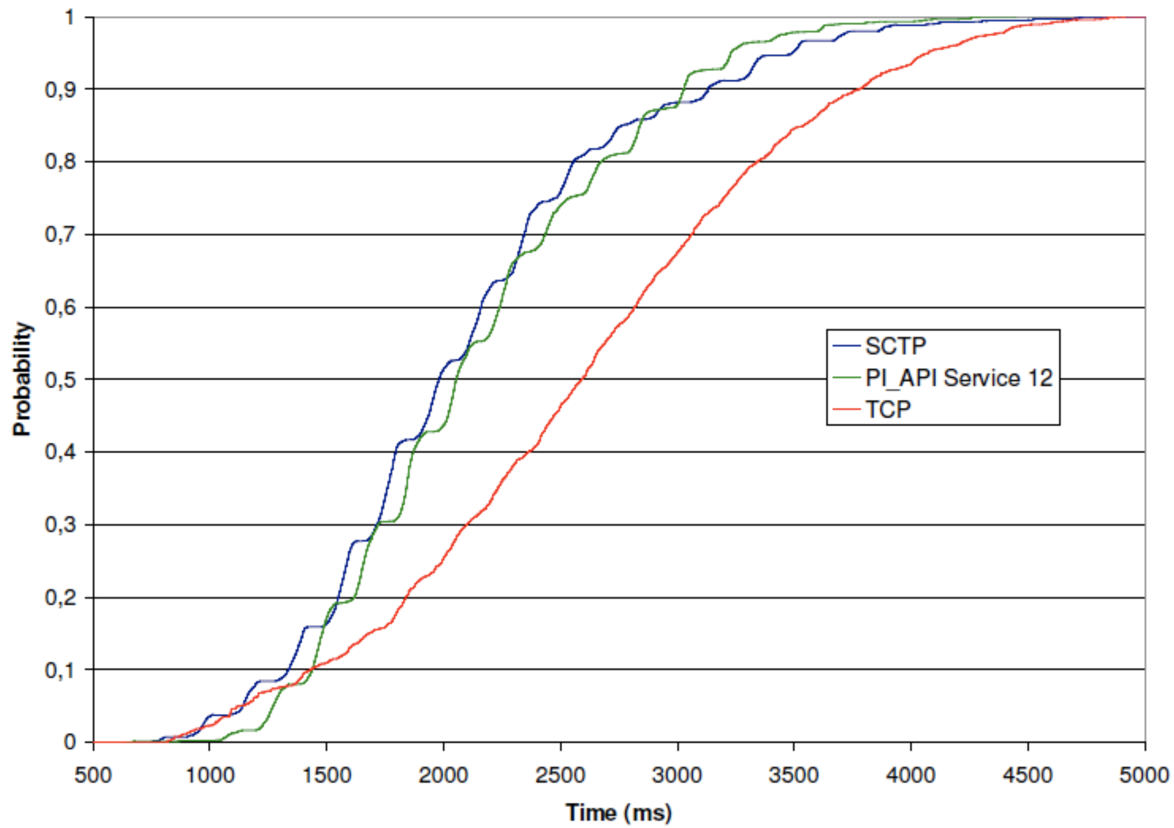
- Goal: make usage attractive = easy
  - stick with what programmers already know: deviate as little as possible from socket interface
- Most services chosen upon socket creation
  - `int socket(int domain, int service)`
  - service number identifies line number in table
  - understandable aliases: e.g. `PI_TCPLIKE_NODELAY`, `PI_TCPLIKE`, `PI_NO_CC_UNRELIABLE` for lines 1-3
- Sending / receiving: provide sendmsg, recvmsg; for services 1,2,11,17: send, recv

API Design /2

- We classified features as
  - static: only chosen upon socket creation
    - flow characteristic
  - configurable: chosen upon socket creation + adjusted later with setsockopt
    - error detection, reliability, multi-homing
  - dynamic: no need to specify in advance
    - application PDU bundling (Nagle in TCP)
    - delivery order: socket option or flags field

Implementation example

- Unordered reliable message delivery with SCTP
  - removes head-of-line (HOL) blocking delay



- Local testbed, 2 Linux PCs

How is this achieved?

- Based on draft- ietf- tsvwg- sctpsocket-23
- Could not make this work in our testbed (suspect: bug in SCTP socket API)

```
struct sctp_sndrcvinfo *si;
struct cmsghdr *cmsg;
char cbuf[sizeof (*cmsg) + sizeof (*si)];
size_t cmsglen = sizeof (*cmsg) + sizeof (*si);

cmsg = (struct cmsghdr *)cbuf;
cmsg->cmsg_level=IPPROTO_SCTP;
cmsg->cmsg_type= SCTP_SNDRCV;
si = (struct sctp_sndrcvinfo *)(cmsg + 1);
si->sinfo_stream = 1;
si->sinfo_flags = SCTP_UNORDERED;

msg.msg_control = cbuf;
msg.msg_controllen = cmsglen;

sendmsg(sockfd, &msg, 0);
```

How is this achieved? /2

- SCTP, version 2 (this worked)
  - `socket(PF_INET, SOCK_STREAM, IPPROTO_SCTP)`
  - set `SCTP_NODELAY` with `setsockopt`
  - followed by (10 parameters!):
    `sctp_sendmsg(sockfd, textMsg, msgLength, NULL, 0, 0, SCTP_UNORDERED, 1, 0, 0);`
- PI_API version
  - `pi_socket(PF_INET, 12);`
  - `pi_sendmsg(sockfd, &msg, 0);`

Trying to use a new protocol with TCP as a fall-back

[Bryan Ford, Janardhan Iyengar: “Efficient Cross-Layer Negotiation”, HotNets 2009]

[D. Wing, A. Yourtchenko, P. Natarajan: “Happy Eyeballs: Trending Towards Success with SCTP”, Internet-draft draft-wing-tsvwg-happy-eyeballs-sctp-02, October 2010]

[Discussions with Bryan Ford, Jana Iyengar, Michael Tüxen, Joe Touch]

The larger problem

- Simply trying protocol x instead of y may not be good enough in the long run
  - Scalability concerns when we try: SIP/TLS/DCCP/IPv6 vs. SIP/UDP/IPv4 vs. ....
- In fact, hosts should be able to *negotiate* the protocol combination; proposals exist
  - separate protocol describing preference graphs (HotNets Ford / Iyengar)
  - signaling over HTTP (draft-wood-tae-specifying-uri-transports-08)
  - out-of-band (e.g. DNS server) [Iyengar presentation at Hiroshima IETF]

The immediate problem

- Hosts A and B can agree on whatever they wish, but then that may just not work
  - no way to bypass trying
- Proposed negotiation methods must be used, then tested ➔ no point in doing this *initially*
- So let's look at the "just try it" approach

Happy Eyeballs

- Originally proposed as a method to solve the IPv6 / IPv4 setup problem and SCTP / TCP
  - Then split into two drafts
  - We focus on SCTP / TCP (and keep DCCP in mind)

- Algorithm:
  - Send a TCP SYN + SCTP INIT; use what comes back first
  - Optional: delay TCP processing a bit in case TCP SYN/ACK arrives before SCTP INIT-ACK

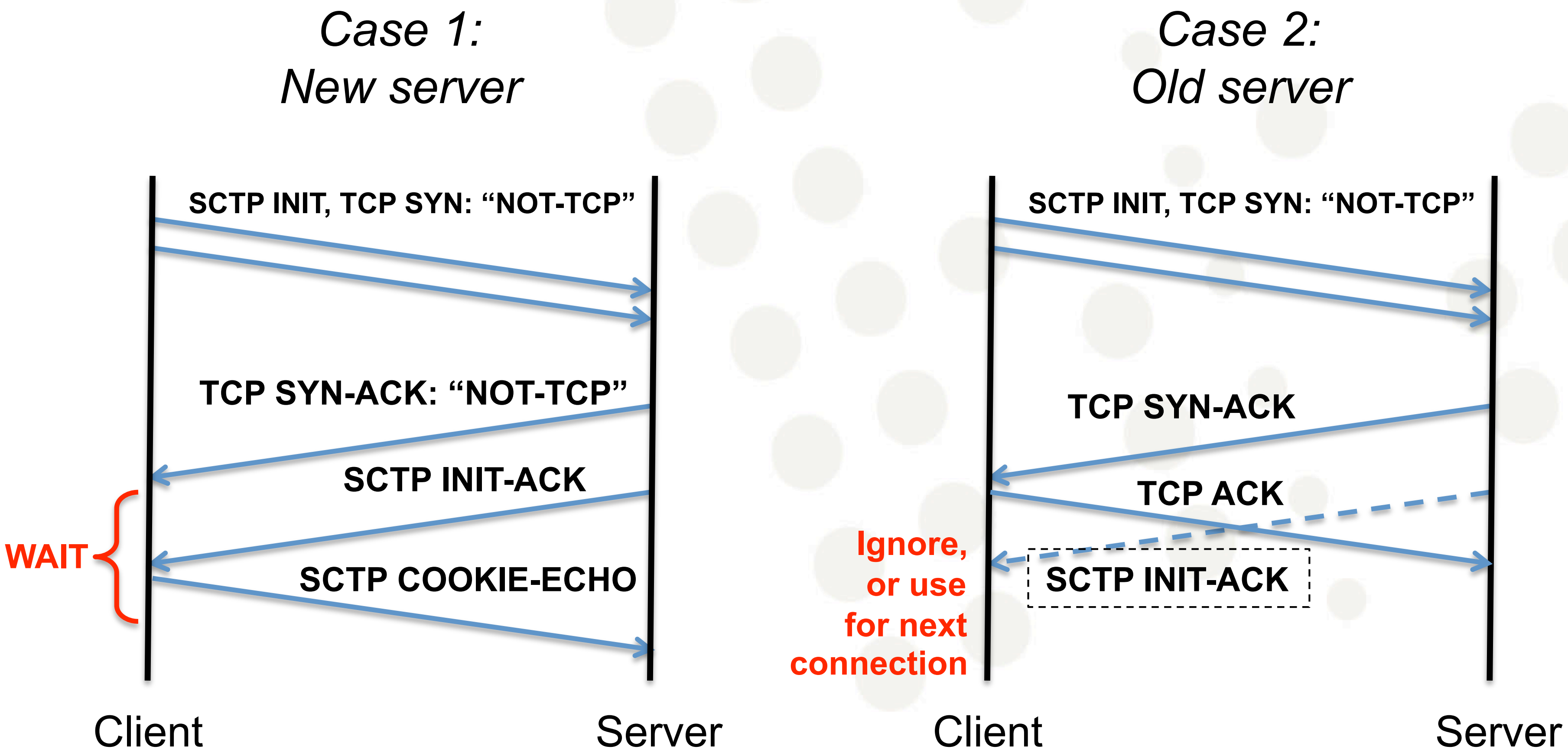
The early-TCP-SYN-ACK-problem

- When Florian started his thesis, he tried this, and he told me that TCP <u>always</u> returned first
  - Obvious: more efficient processing in server
  - Likely to stay the same for a while

- How to cope with this?
  - Ignore late SCTP INIT-ACK: SCTP often not used
  - Switch to SCTP on-the-fly: does not seem feasible
  - Delay TCP processing: <u>always</u> affects TCP connections
  - Use SCTP for later connections: delayed effect of SCTP, must know that there will be later connections

My proposal

A “NOT-TCP” option or bit in the TCP SYN

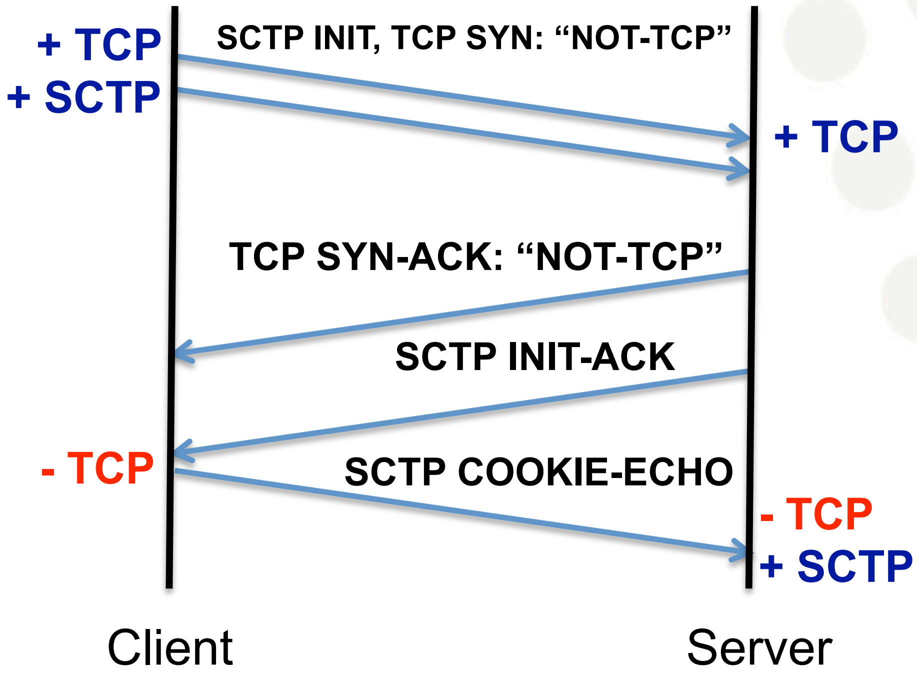


Not-TCP concerns

- Encoding issues
  - even processing an unknown TCP option is work (might be a problem for a busy server)
    ➔ to be evaluated – state needed?
  - TCP option space limited
  - Overloading a bit (e.g. CWR): will middle-boxes kill such TCP SYNs?
  - Limits protocol choice – e.g.: “use any other from this list”

- The scheme binds TCP+SCTP/DCCP/.. ports together forever

Not-TCP and state



- Both sides can immediately tear down all TCP state after exchanging "Not-TCP" and an SCTP packet
- (Only?) advantage over TCP SYN Cookies: no need for teardown (FIN / FIN/ACK)

Ensure that SCTP and DCCP are attractive

[Florian Niederbacher:” Florian Niederbacher: “Beneficial gradual deployment of SCTP”, MSc. thesis, University of Innsbruck, February 2010]

[Dragana Damjanovic: "Parallel TCP Data Transfers: A Practical Model and its Application", Ph.D. thesis, University of Innsbruck, February 2010]

[Dragana Damjanovic, Michael Welzl: "MulTFRC: Providing Weighted Fairness for Multimedia Applications (and others too!)", CCR 39(3), July 2009.]

[Dragana Damjanovic, Michael Welzl: “An Extension of the TCP Steady-State Throughput Equation for Parallel Flows and its Application in MulTFRC”, to appear in IEEE/ACM ToN. (accepted with minor changes)]

SCTP

- Essentially, SCTP = TCP++
  - what's the point if it performs worse than TCP?
  - so that should never happen

Small on-going project

- Two sides to this
  - Implementation issues: FreeBSD is well maintained, but Linux has many problems
  - Specification issues: One SCTP association with N streams should never perform worse than N TCP connections (and sometimes better)

Asking for money

Linux SCTP implementation

- Florian Niederbacher detected problems
  - mainly: lack of auto-buffer tuning and pluggable congestion control

- Auto-buffer tuning now available: http://tinyurl.com/4bhxt74 and patch submitted: http://tinyurl.com/45ng5d6

- Pluggable congestion control is ongoing work; probably not going to be finished in this project

More (smaller) issues

- Missing sender-dry-event (functional shortcoming, necessary for DTLS over SCTP)
  - Linux only; pointed out by Michael Tüxen

- Sending too little data in Slow-Start
  - Linux only; detected by Florian, probably wrong implementation of ABC or side-effect from burst mitigation

- Wrong calculation of header overhead
  - General problem, presented by Michael Tüxen @ PFlDNeT10

More (smaller) issues /2

- Message size > MTU needed for efficient operation in small-RTT environments
  - Linux only; detected by Florian, confirmed by Stefan Jörer, probably caused by overhead of send/recv system calls
- Flow control might be buggy
  - Pointed out by Michael Tüxen; not confirmed yet
- Making implementation more up-to-date: “improving robustness against non-congestion events”, Andreas Petlund’s thin stream work, spurious loss event detection (simplified Eifel possible?)

DCCP

6	*DCCP*	TCP-like		p1		u		
7	*DCCP*	Smooth		x		u		
8	*DCCP*	Smooth		p1		u		
9	*DCCP*	Smooth-SP		x		u		
10	*DCCP*	Smooth-SP		p1		u		

- TCP-like, Smooth, and Smooth-SP flow characteristic, each with unordered delivery and either partial or full error protection
  - Smooth-SP is not a "feature" (!), it's a necessity
  - partial error correction is rather experimental
- So, "smooth" (TCP-friendly) behavior is the only real news here
  - TFRC congestion control; is this enough as a selling argument?

MulTFRC

- TFRC in a nutshell
  - smooth (➔ less jitter) yet TCP-friendly sending rate
  - receiver ACKs, sender gets measurements
  - sender constantly calculates TCP steady-state throughput equation, sends at calculated rate

- We derived an extension of this equation which yields the rate of N flows
  - plug that into TFRC, and it becomes MulTFRC

Who cares?

- Bottleneck saturation of N TCPs (w/o queues): 100-100/(1+3N) %
  [Altman, E., Barman, D., Tuffin, B., and M. Vojnovic, "Parallel TCP Sockets: Simple Model, Throughput and Validation", Infocom 2006]
  - 1: 75%. 2: 85.7% ... 6: 95% ➔ MulTFRC with N=6 nicely saturates your bottleneck (except high bw*delay link)
  - no need to stripe data across multiple connections
  - less overhead (also only one setup/teardown)

Future work?
e.g. Mul-CUBIC-FRC?

- N ε R^+ - can also be 0 < N < 1
  - useful for less important traffic and multi-path (cf. MPTCP)
- can give a knob to users

Conclusion

- There's a chance to get a more flexible Internet transport layer
  - A lot of useful, fun work to be done

- Join me! ☺

Thank you

Questions?