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How to *truly* improve the Internet's transport layer, part 2
(the technical details)

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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

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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 ³

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

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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

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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

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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

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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

seq. 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	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	x
14	SCTP	x	x	x		x	t	m	o	x	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	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	x
23	SCTP	x	x	x		x	p2	m	u		
24	SCTP	x	x	x		x	p2	m	u		x
25	SCTP	x	x	x		x	p2	m	u		x
26	SCTP	x	x	x		x	p2	m	u	x	x
27	SCTP	x	x	x		x	p2	m	u	x	x
28	SCTP	x	x	x		x	t	m	o		
29	SCTP	x	x	x		x	t	m	o		x
30	SCTP	x	x	x		x	t	m	o	x	x
31	SCTP	x	x	x		x	t	m	o	x	x
32	SCTP	x	x	x		x	t	m	u		
33	SCTP	x	x	x		x	t	m	u		x
34	SCTP	x	x	x		x	t	m	u	x	x
35	SCTP	x	x	x		x	t	m	u	x	x
36	SCTP	x	x	x		x	p2	m	o		
37	SCTP	x	x	x		x	p2	m	o		x
38	SCTP	x	x	x		x	p2	m	o	x	x
39	SCTP	x	x	x		x	p2	m	o	x	x
40	SCTP	x	x	x		x	p2	m	u		
41	SCTP	x	x	x		x	p2	m	u		x
42	SCTP	x	x	x		x	p2	m	u	x	x
43	SCTP	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 not services

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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

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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

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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			p1		u	
5	DCCP/SCTP	TCP-like		x	[p2]	u	
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	
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

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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`

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API Design /2

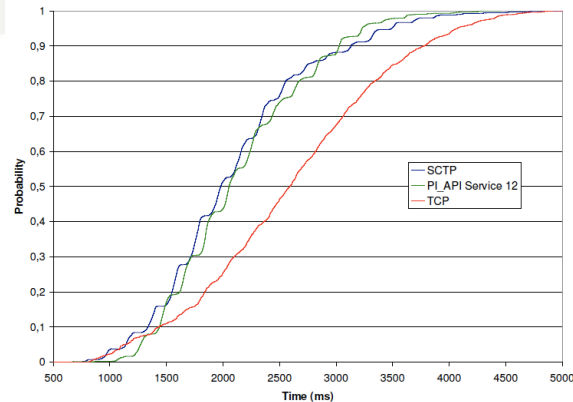
- We classified features as
 - static: only chosen upon socket creation
 - flow characteristic
 - configurable: chosen upon socket creation + adjusted later with `setsockopt`
 - error detection, reliability, multi-homing
 - dynamic: no need to specify in advance
 - application PDU bundling (Nagle in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

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Implementation example

- Unordered reliable message delivery with SCTP
 - removes head-of-line (HOL) blocking delay
- Local testbed, 2 Linux PCs



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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);`

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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]

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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-transport-08)
 - out-of-band (e.g. DNS server) [Iyengar presentation at Hiroshima IETF]¹⁹



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

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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

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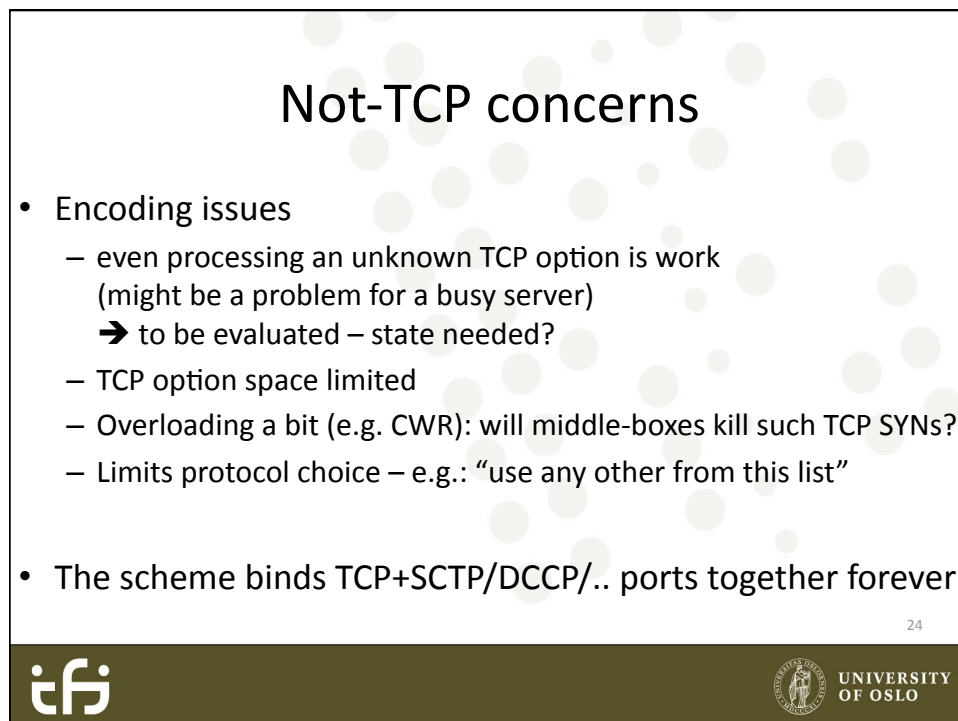
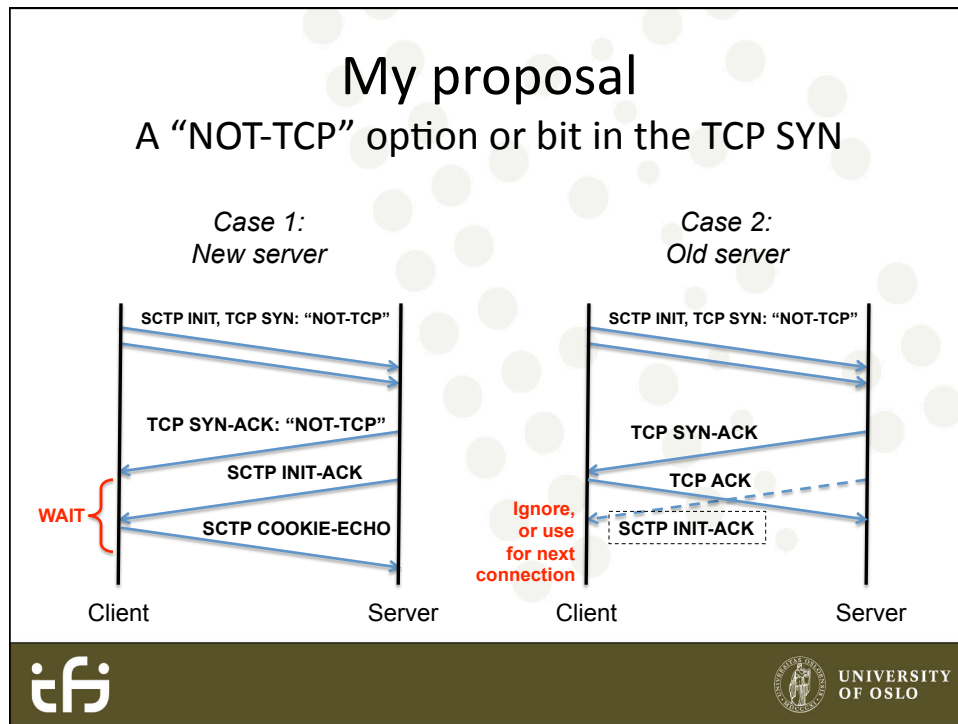


The early-TCP-SYN-ACK-problem

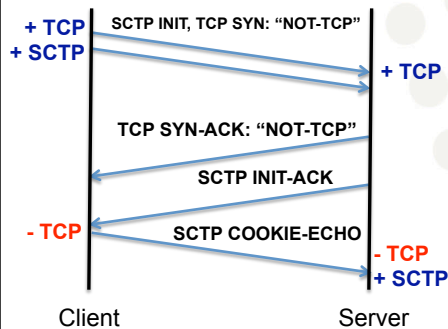
- When Florian started his thesis, he tried this, and he told me that TCP always returned first
 - Obvious: more efficient processing in server
 - Likely to stay the same for a while
- How to cope with this?
 - Ignore late SCTP INIT-ACK: SCTP often not used
 - Switch to SCTP on-the-fly: does not seem feasible
 - Delay TCP processing: always affects TCP connections
 - Use SCTP for later connections: delayed effect of SCTP, must know that there will be later connections

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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: "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
- 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)

Small on-going project

Asking for money

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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

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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 @ PFIDNeT10₉



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/rcv 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?)

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DCCP

6	<i>DCCP</i>	TCP-like		p1		u	
7	<i>DCCP</i>	Smooth		x		u	
8	<i>DCCP</i>	Smooth		p1		u	
9	<i>DCCP</i>	Smooth-SP		x		u	
10	<i>DCCP</i>	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?

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MuITFRC

- 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 MuITFRC

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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 $bw \cdot delay$ link)
 - no need to stripe data across multiple connections
 - less overhead (also only one setup/teardown)
- $N \in \mathbb{R}^+$ - can also be $0 < N < 1$
 - useful for less important traffic and multi-path (cf. MPTCP)
- can give a knob to users

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

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Conclusion

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

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Thank you

Questions?

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