The Architecture of the GNUnet: 45 Subsystems in 45 Minutes

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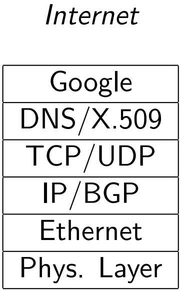
10.12.2015

"Never doubt your ability to change the world." –Glenn Greenwald

The Internet is Broken

- Network generally learns too much
- Insecure defaults and high system complexity
- Centralized Internet infrastructure requires administation:
  - Number resources (IANA)
  - Domain Name System (Root zone)
  - X.509 CAs (HTTPS certificates)
- Administrators have power, and power attracts attackers
- Self-organizing systems aka P2P systems offer a way forward!

Our Vision (Simplified)



Internet

Google

DNS/X.509

TCP/UDP

IP/BGP

Ethernet

Phys. Layer

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Google	Applications
DNS/X.509	GNU Name System
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Today: 45 things to do with GNUnet

- A fast tour-de-force through GNUnet's features
- Features for users, developers and researchers
- What you can do, **not** how it is done

C library

- Safer C: `GNUNET_malloc(), GNUNET_asprintf(), ...`
- Containers: multi hash map, Bloom filter, heap, ...
- Networking: event loop, socket abstraction (client, server)
- Initialization: find paths, parse configuration, parse options
- Disk: buffered and unbuffered IO, endianess conversion, logging

Cryptographic primitives

- RNG, permutation
- AES, Twofish
- SHA-512, SHA-256, SCRYPT, HKDF, CRC32, CRC16
- Curve25519 point addition, Curve25519 point multiplication, small-scalar Curve25519-DLOG
- EdDSA, ECDHE
- Paillier (homomorphic addition)
- RSA blind signatures

The Automated Restart Manager (ARM)

- Starts services on-demand (like systemd)
- Automatically restarts crashed services (like ARM on OS/360)
- Can provide performance data per service
- `gnunet-arm -e` only terminates after peer is fully down
- Simple API: `GNUNET_ARM_request_service_start()`, `GNUNET_ARM_request_service_stop()`, etc.

Transport

- Unreliable, out-of-order packet delivery semantics
- Over TCP, UDP, IPv4/IPv6, HTTP/HTTPS, WLAN or BT (pluggable)
- Enforces bandwidth quotas
- Enforces connection restrictions (F2F)
- Supports NAT traversal
- Supports bootstrap via broadcast/multicast
- Measures network latency
- UDP/WLAN/BT: Fragments large messages (including ACKs and selective retransmission)

Distance-Vector Routing (WiP)

- Transport plugin
- Bounded (i.e. ≤ 3 hops) distance-vector routing
- Provides "illusion" of direct connections

Automated Transport Selection (ATS)

- Decides which connections to establish
- Selects "best" transport plugin to use
- Allocates bandwidth to peers by network technology (LO, LAN, WAN, WLAN)
- Allows other subsystems to specify preferences:
  - Which peers?
  - Minimize latency?
  - Maximize bandwidth?

CORE

- Off-the-record link encryption between peers
- Multiplexes inbound messages by type to higher-level subsystems
- Hides connections from/to peers that do not speak same higher-level protocol

HOSTLIST

- Allows download of known peer addresses for bootstrapping
- HTTP client and HTTP server provided
- URLs from configuration or learned via gossip among peers

The Network Size Estimate (NSE)

- Gives estimate of $\log n$ where n is number of active peers (with reasonable lifetime)
- All peers converge to the same network size estimate
- Extremely cheap (bandwidth, storage & amortized CPU cost)
- Byzantine fault-tolerant
- Malicious attacker can only slightly increase size estimate
- Trivial API: `GNUNET_NSE_connect()`

Distributed Hash Table (DHT)

- Store key-value pairs in overlay network
- Replication in the network
- Multiple values per key possible
- Duplicate/known replies not transmitted repeatedly
- Tolerates small-world underlay topology
- Can optionally track path key-values took in the network
- $O(\sqrt{n} \log n)$ lookup complexity, $O(\log n)$ hops
- Plugins provide custom logic to verify integrity of key-value pairs in DHT
- Simple API: `GNUNET_DHT_get()`, `GNUNET_DHT_put()`, `GNUNET_DHT_monitor_start()`

Confidential Ad-Hoc Decentralised End-to-End Transport

- AXOLOTL-encrypted end-to-end communication
- Reliable or unreliable
- In-order or out-of-order
- Low-latency or buffered
- Multiple streams duplexed over one authenticated encrypted channel
- Encrypted channel multiplexed over multiple, redundant paths
- Easy API: `GNUNET_CADET_connect()`, `GNUNET_CADET_channel_create()`, `GNUNET_CADET_notify_transmit_ready()`

Identity (management)

- Public key pairs as “egos” to identify users
- Each user can have many alter-egos (or pseudonyms)
- Separate from peer identities (network addresses)

The GNU Name System (GNS)

- Decentralized name system with secure memorable names
- Delegation used to achieve transitivity
- Also supports globally unique, secure identifiers
- Achieves query and response privacy
- Provides alternative public key infrastructure
- Interoperable with DNS
- Trivial API: `GNUNET_GNS_connect()`, `GNUNET_GNS_lookup()`

(Key) revocation

- Instant revocation at all peers that the network allowed to receive it
- Highly efficient protocol
- Revocation messages can be prepared and stored off-line if desired
- Trivial API: `GNUNET_REVOCATION_revoke()`, `GNUNET_REVOCATION_query()`

Set

- Compute set union or set intersection
- Surprisingly low bandwidth required
- Few round trips, but non-deterministic

Scalarproduct (SMC)

- Given private maps $a : A \to \mathbb{Z}$ and $b : B \to \mathbb{Z}$, calculates scalar product

$$\prod_{e \in A \cap B} a(e)b(e) \tag{1}$$

- Bandwidth-efficient at ≈ 100 bytes/element
- CPU-efficient with runtime in milliseconds/element
- Only leaks information derivable from final result and prior knowledge
- Result only disclosed to one party
- Assumes honest-but-curious adversary model
- Trivial API: `GNUNET_SCALARPRODUCT_start_computation()`, `GNUNET_SCALARPRODUCT_accept_computation()`

Random Peer Sampling (WiP)

- Selects a random peer, or sequence of random peers
- Fully decentralised
- Byzantine fault-tolerant

Multicast (WiP)

- Source controls membership in multicast group
- End-to-end encrypted
- Source does not have to KX with each group member
- Members that left really can no longer read messages

PSYC2

- Extensible messaging format: syntax and semantics
- Stateful protocol with state updates using deltas
- Efficient encoding and decoding (in bandwidth and CPU)
- Runs on top of Multicast

Social (Network Applications)

- Combines PSYC2 and GNS to build social networking applications
- Key concepts:

nym	pseudonym of another user in the network
place	where social interactions happen
host	owner of a place
guest	visitor of a place

- API then offers vocabulary: `enter`, `leave`, `host eject`, `host entry decision`, `host announce`, `guest talk`, `place history replay`, `place look at`

SecuShare (WiP)

- Social networking application using SOCIAL API
- GUI written with Qt

Statistics

- Collects numeric run-time information from a peer
- Used for primarily for diagnostic monitoring and performance evaluation
- Trivial API: `GNUNET_STATISTICS_set()`, `GNUNET_STATISTICS_update()`, `GNUNET_STATISTICS_get()`

The Testbed

- Run controlled experiments
- Detect available ports, generate configurations
- Share services across peers for higher efficiency (i.e. DNS resolver)
- Connect peers into custom network topologies
- Run peers with non-uniform configurations
- Run multiple peers on one host
- Run testbed across multiple hosts
- Control large-scale execution with hierarchy of testbed controllers
- Launch thousands of peers per second

Conversation

- GNU Name System PKI:
  - Address book ≡ GNS zone
  - make calls to `phone.alice.bob.gnu`
- OPUS-encoded voice streams
- CADET end-to-end encryption
- Clean API, command-line and GTK user interfaces
- put calls on hold, etc.
- still lacks ringtones!

File-"Sharing"

- Anonymous, pseudonymous and non-anonymous *publishing*
- Files broken up into blocks (Merkle tree)
- Peers caching blocks cannot view contents (encrypted queries and replies)
- Multi-source download
- Contributing peers rewarded with better performance
- Keyword search
- File meta-data available as part of search result
- Can share directories, can mount shared directories via FUSE
- API, command-line and GTK GUIs

Search by REgular EXpression

- Service publisher advertises regular expression (!)
- Client *searches* using string
- Services where the RegEx matches string are returned
- Fully decentralised, uses R^5N DHT
- Trivial API: `GNUNET_REGEX_announce()`, `GNUNET_REGEX_search()`
- Warning: non-trivial theory. Read up about RegEx prefixes before using.

DNS Integration

Intercept DNS queries using `iptables` to:

- Observe DNS activity
- Drop DNS queries
- Supply “alternative” DNS replies
- Can be used to support GNS instead of NSS, proxies or GNS-specific resolution APIs

IP-over-GNUnet

- Open TUN interface to receive inbound IP traffic ("VPN")
- Open TUN interface to forward IP traffic to Internet ("EXIT")
- Translate between IPv4 and IPv6 as needed and implement NAT-PT for DNS ("PT")
- Also allows routing IP traffic to a particular GNUnet peer
- Integrates with the GNU Name System

Byzantine Fault-tolerant Consensus

- Given a set of *n* peers with at most *k* malicious participants
- And a deadline (synchronous protocol!) and enough bandwidth for honest participants
- Compute the global *union* over a set of initial elements distributed across the $n - k$ honest participants
- Malicious participants may add additional (well-formed) elements
- All honest participants end up with exactl the same set
- Final set is super-set of union of initial elements at honest peers

Electronic Voting (SMC)[1]

- Implements Cramer'97-style electronic voting:

  correctness votes are counted correctly, one vote per voter

  secrecy voter's votes remain secret

  indi. verif. each voter can verify

  univ. verfi. third parties can verify

  fairness will not leak partial outcomes

  robustness a threshold faction of officials may be corrupt

  ~~coercion res.~~ **Not** offered! Adversary could verify that voter complied with his demands

- Three types of participants:

  supervisor affirms list of eligible voters, selects authorities

  authorities collect & verify ballots, tally results, provide audit data

  voter registers to vote, votes, submits ballot

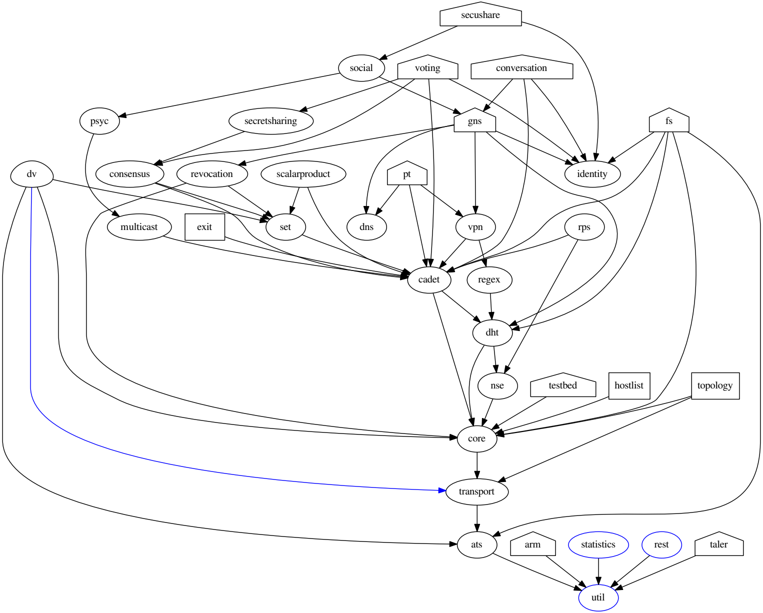
[1] Implemented in `gnunet-java`

RESTful APIs (WiP)

- Access GNUnet services via HTTP
- Plugin architecture
- Data encoded using JSON
- Used to buile Web service with JS for identity management

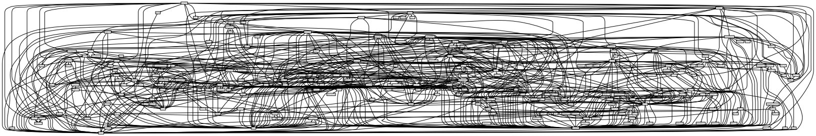
Taxable Anonymous Libre Electronic Reserves

- Payment system, not a new currency
- Client-server architecture, not peer-to-peer
- HTTP RESTful protocol (JSON over HTTP/HTTPS)
- Supposed to be used initially over Tor for anonymity
- Payer remains anonymous
- Payee easily identifiable by the government ("taxable")
- Affero GPL server, GPL wallet, LGPL merchant logic
- Cheap transactions, can give change, supports refunds

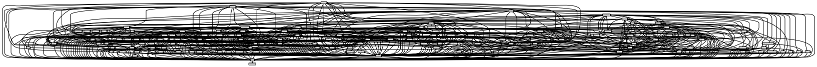

secushare
social
voting
conversation
psyc
secretsharing
gns
fs
dv
consensus
revocation
scalarproduct
pt
identity
multicast
exit
set
dns
vpn
rps
cadet
regex
dht
nse
testbed
hostlist
topology
core
transport
ats
arm
statistics
rest
taler
util

GNUnet dependencies (generated by GNU Guix)

Compile time:



Runtime:



Close inspection shows: Guix didn't build *all* of it.

Future Work

- Improve all of the above, in particular the WiPs
- Onion routing
- Asynchronous messaging
- Secure auctions
- News distribution / timeline construction
- Collaborative editing
- Multiparty linear programming

Conclusion

- GNUnet provides foundations for an alternative network stack
- More work needs to be done: SMTP 2.0, Web 3.0, Tor 2.0, ...
- If what you need is not there, help us add it!

Do you have any questions?

References:

- Nathan Evans and Christian Grothoff. *R^5N. Randomized Recursive Routing for Restricted-Route Networks*. **5th International Conference on Network and System Security**, 2011.
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- Christian Grothoff, Bart Polot and Carlo von Loesch. *The Internet is broken: Idealistic Ideas for Building a GNU Network*. **W3C/IAB Workshop on Strengthening the Internet Against Pervasive Monitoring (STRINT)**, 2014.
- Matthias Wachs, Martin Schanzenbach and Christian Grothoff. *A Censorship-Resistant, Privacy-Enhancing and Fully Decentralized Name System*. **13th International Conference on Cryptology and Network Security**, 2014.