Practical Anonymous Subscriptions

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Anonymous subscriptions

Provide registered/paid u ability to *log in* and *acc*

Music/video streaming
reading news articles
transit pass

…while remaining **anonymous**…

…yet still allowing the server to enforce **admission control**

I.e., users cannot share their login with friends

System model

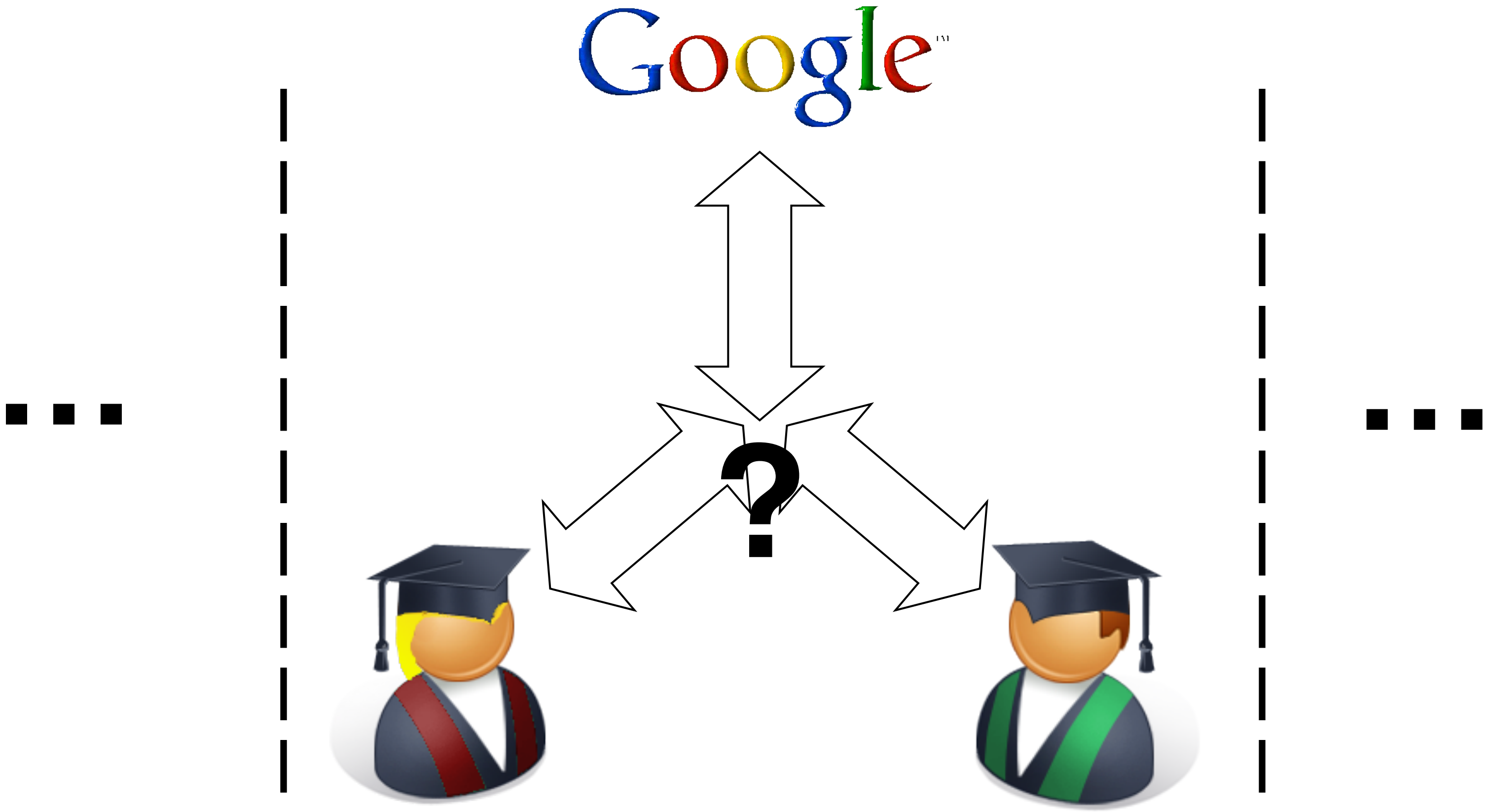
Time broken into a series of well-defined *epochs*

Anonymity/unlinkability

- Cannot link a **user login** to a **user registration**

- Cannot link **logins by the same user** (in different epochs) to each other

Anonymity/unlinkability



Admission ctr’l (“soundness”)

- Each registered user can only have **one** active login per epoch
  - I.e., a user cannot freely share their login information with their friends
  - (Formal definition later)

Soundness

sk_1 sk_1

How long is an epoch?

Shorter epochs ⇒ better anonymity

Longer epochs ⇒ less computation

How long is an epoch?

- Here: **conditional linkability**
  - Logged in user can choose to “re-up” his login for the next epoch
    - Re-up is cheaper than a login
  - Allows server to link user across epochs
    - User decides when this is acceptable
    - User can do a full login if unlinkability is desired

Related (but different)

- Anonymous credentials, DAA, group signatures
  - Anonymity, but no admisison control
- Anonymous blacklisting systems
  - Anonymity, revocation, but no notion of per-epoch admission control
- E-cash
  - Anonymity, double spending detected, but no notion of unlimited re-use

Related work

- Unclonable authentication [Damgård, Dupont, Østergaard]
- n-time anonymous authentication [Camenisch et al.]
  - Uses prior ideas from e-cash [Camenisch, Hohenberger, Lysyanskaya]
  - Different model – multiple verifiers, traceability after the fact

Our contributions

- **More efficient, simpler** construction
  - "Weaker" cryptographic assumptions
  - Cleaner definitions
- **Conditional linkability** for improved efficiency
- **Implementation** and system evaluation

What we do *not* prevent

- Users sharing login information to use at **different** times
- **Other ways** of breaking anonymity
  - Traffic analysis, IP addresses
  - User behavior
  - History of accessed content

  - Address using complementary techniques

Functional definition I

- **Setup** – server generates public/private keys; initializes state including **cur/next**
- **Registration** – user/server interact; user obtains secret key sk (or error)

Functional definition II

- **Login** – Using sk and the current epoch number, user logs in to server
    - Server increments **cur**

- **Link** (“re-up”) – User currently logged in during epoch *t* can log in for epoch *t +1*
    - Server increments **next**

Functional definition III

- **EndEpoch** – server refreshes state; updates **cur/next**
  - **cur** = **next**; **next** = 0

Security definitions

- (Honest) user is **logged in** at some pont in time if (1) that user previously ran Login in that epoch, or (2) at some point in previous epoch, user was logged in and ran Link

- (Honest) user *i* is **linked** at some point in time if at some previous point during that epoch, user was logged and ran Link

Soundness (informal)

- Attacker registers any number N of users; honest users also register
- Attacker interacts with server abritrarily
- Honest users login/link (so affect server state), but attacker cannot observe
- Attacker controls when epochs end

Attacker **succeeds** if, at any point in time, **cur** > N + #honest users logged in

Anonymity (informal)

- Phase 0
  - Attacker outputs arbitrary public key
  - Two honest users register (and get secret keys)
- Phase I
  - Attacker induces honest users to Login/Link
- Phase II – neither user logged in
  - Users either permuted or not
  - Attacker induces honest users to Login/Link

Attacker **succeeds** if it can guess whether users were permuted in Phase II (with significantly better than ½ probability)

Construction (intuition)

- **Registration**: user gets “anonymous credential” C (i.e., a re-randomizable blind signature) on PRF key k
- **Login** in epoch t: user sends C’ + $F_k(t)$ + ZK proof of correctness
    - Server verifies signature and proof; checks that $F_k(t)$ not in table; stores $F_k(t)$ in table
- **Link** in epoch t: user sends $F_k(t)$ + $F_k(t+1)$ + ZK proof of correctness
    - Look up $F_k(t)$ in table; verify proof; add $F_k(t+1)$

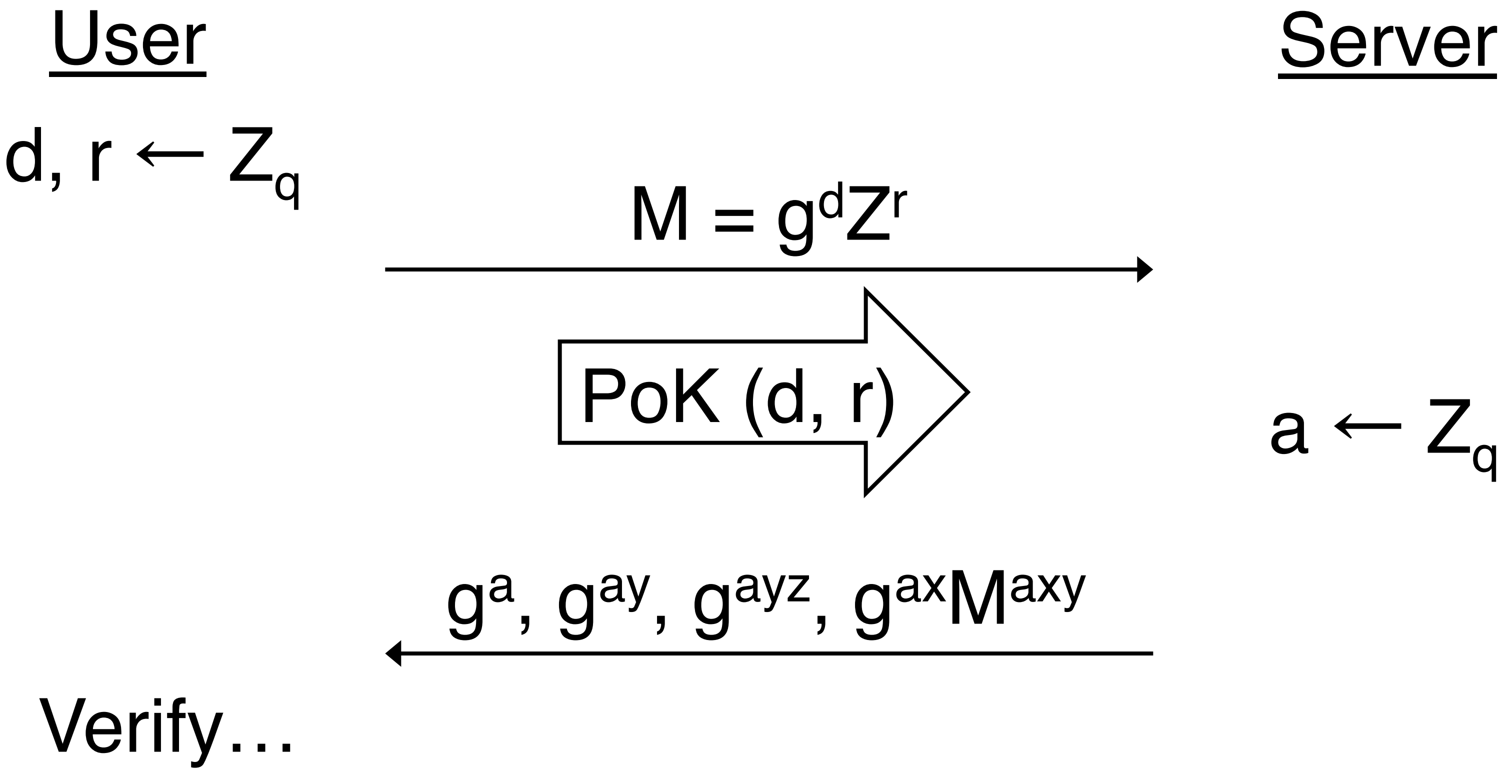
Construction (further detail)

- Anonymous credential is based on variant of **Camenisch-Lysyanskaya signatures**
  - Public key = (g^x, g^y, g^z)
  - Signature on (d, r) is $(g^a, g^{ay}, g^{ayz}, g^{ax}(g^d Z^r)^{axy})$
  - Re-randomizable, blindable, efficient ZK proofs

- **Dodis-Yampolskiy PRF**
  - $F_k(t) = g^{1/(k+t)}$
  - Compatible with various efficient ZK proofs

Construction (further detail)

- **Registration**



User

Server

$d, r \leftarrow Z_q$

$M = g^d Z^r$

PoK (d, r)

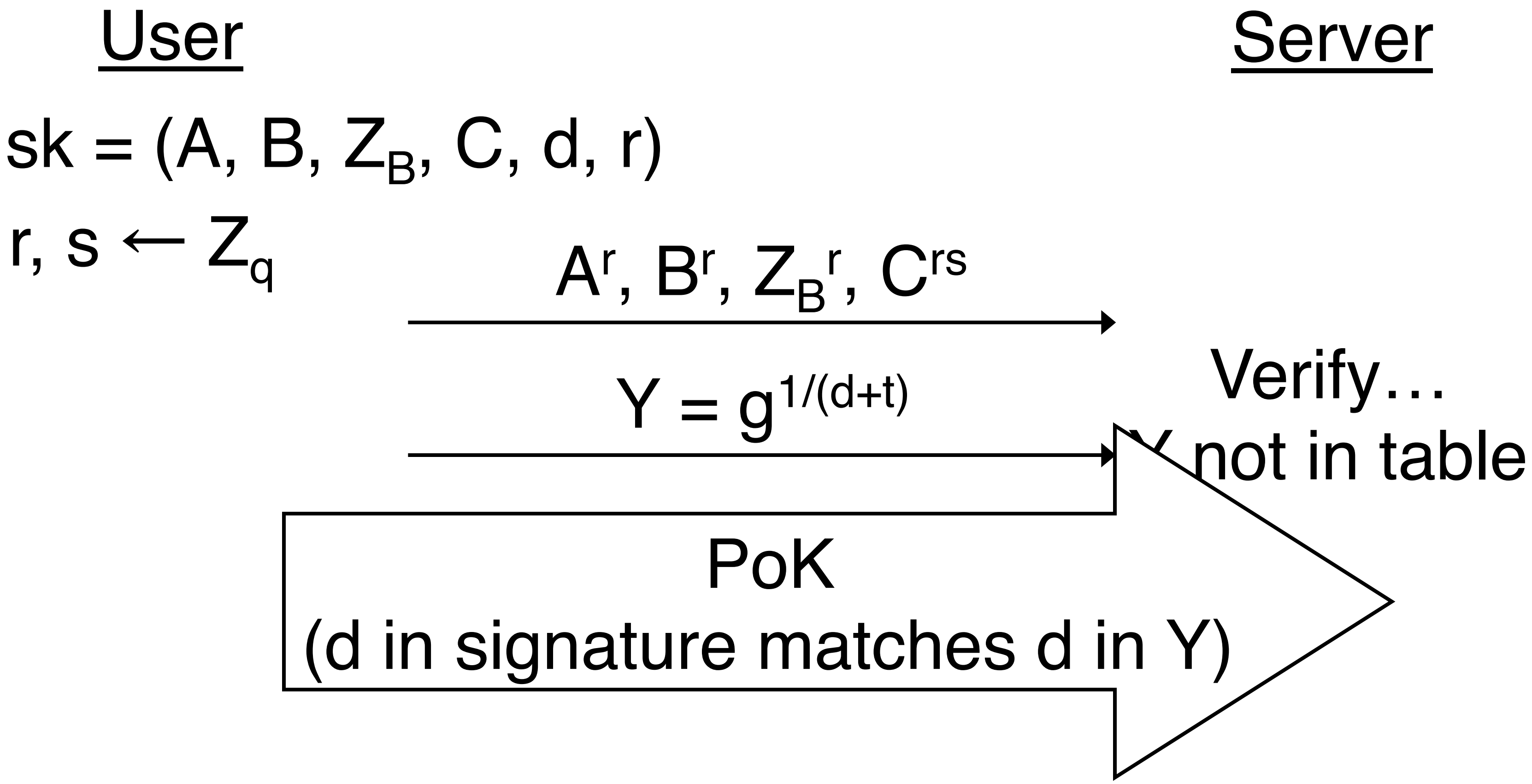
$a \leftarrow Z_q$

$g^a, g^{ay}, g^{ayz}, g^{ax}M^{axy}$

Verify…

Construction (further detail)

- **Login** (epoch t)



User

Server

sk = (A, B, Z_B, C, d, r)

r, s ← Z_q

$A^r, B^r, {Z_B}^r, C^{rs}$

$Y = g^{1/(d+t)}$

Verify…

Y not in table

PoK

(d in signature matches d in Y)

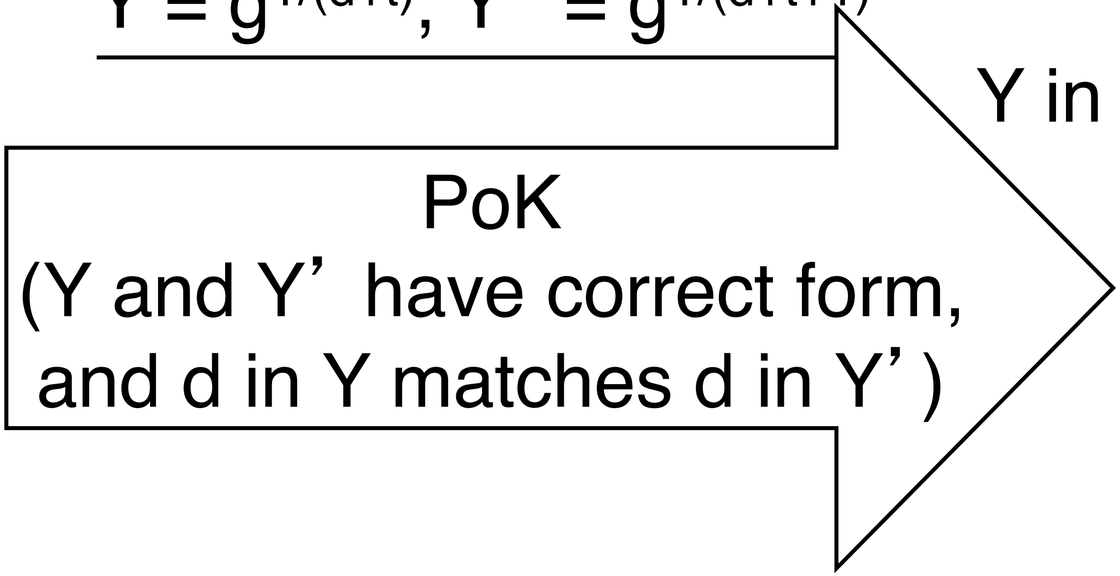
Construction (further detail)

- **Link** (epoch t)

User

Server

sk = (A, B, Z_B, C, d, r)



$Y = g^{1/(d+t)}$, $Y' = g^{1/(d+t+1)}$

Y in table?

PoK
(Y and Y' have correct form,
and d in Y matches d in Y')

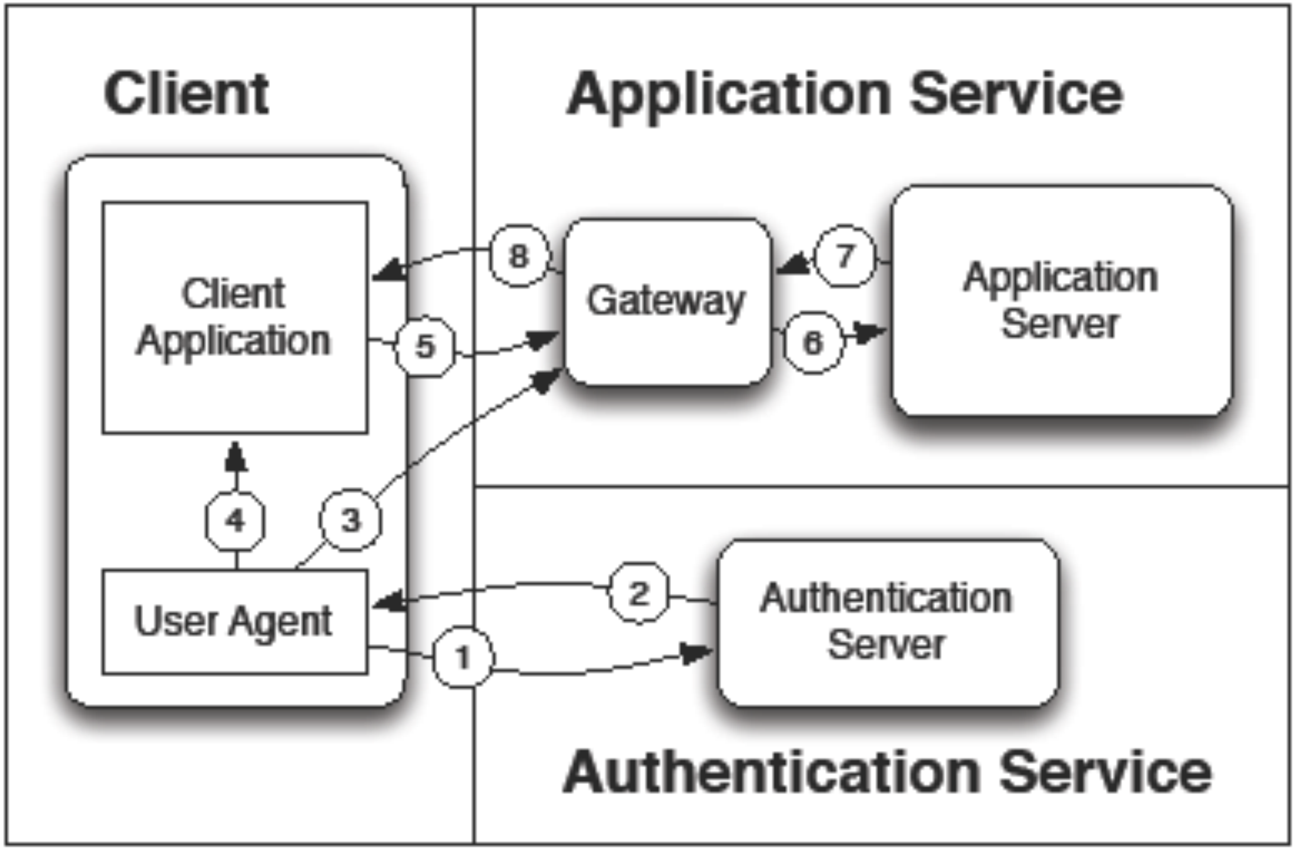
Construction (further detail)

- ZK proofs (of knowledge) fairly standard
  - Made non-interactive using Fiat-Shamir

Security guarantees

- Soundness holds under **LRSW assumption** (essentially, unforgeability of CL signatures)
- Anonymity holds under **DDHI assumption**
  - $g^{1/x}$ “looks random” even given g^x, …, g^{x^n}
- Note: in our security proofs, we assume extraction from all ZKPoKs is possible
  - Can be enforced if interactive proofs are used and sequentiality is enforced
  - Heuristic security if Fiat-Shamir proofs are used

System architecture



Notes

- Only loose synchronization needed
  - Server sends timestamp when connection is established
  - User caches previous timestamp to prevent rollback attacks on anonymity

- Login + (multiple) link(s) are done more efficiently than running Login, Link, …

Implementation

- Using PBC library [Lynn] and PolarSSL
  - Symmetric pairing; 160-bit elliptic-curve group over 512-bit field
- 1400 loc
- Pre-processing used when possible

Raw performance

	User	**Server**
Login	13.5 ms	7.9 ms
Link	1.3 ms	0.72 ms

(quad-core 2.66 GHz Intel Core 2 CPU, 8GB RAM)

Evaluation I

- Integrated our system into a streaming-music service
  - 7500 users
  - Epoch length = 15 seconds
  - Acceptable performance in terms of playback delay/latency; details in paper

Evaluation II

- Anonymous public-transit passes
  - Epoch length = 5 minutes
  - Estimate <10 servers could handle BART peak-traffic volumes

- Implemented user agent as Android app
  - Login message displayed as QR code for physical scanner to read
  - No network connectivity required
  - Login time: 220 ms (HTC Evo 3D)

Conclusions

- Design, implementation, and evaluation of a system providing **anonymous subscriptions**
- Formal definitions, cryptographic proofs
- Performance acceptable for practical applications