# Ring Signatures for Deniable AKEM: Gandalf's Fellowship

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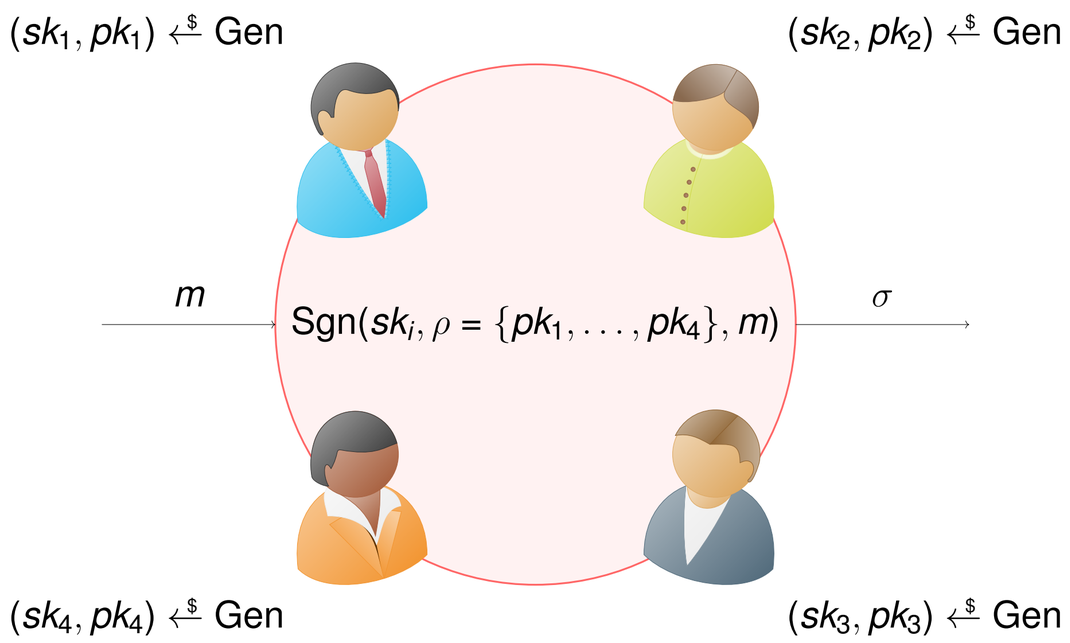
## Ring Signature Scheme [RST01]

RSig = (Gen, Sgn, Ver)

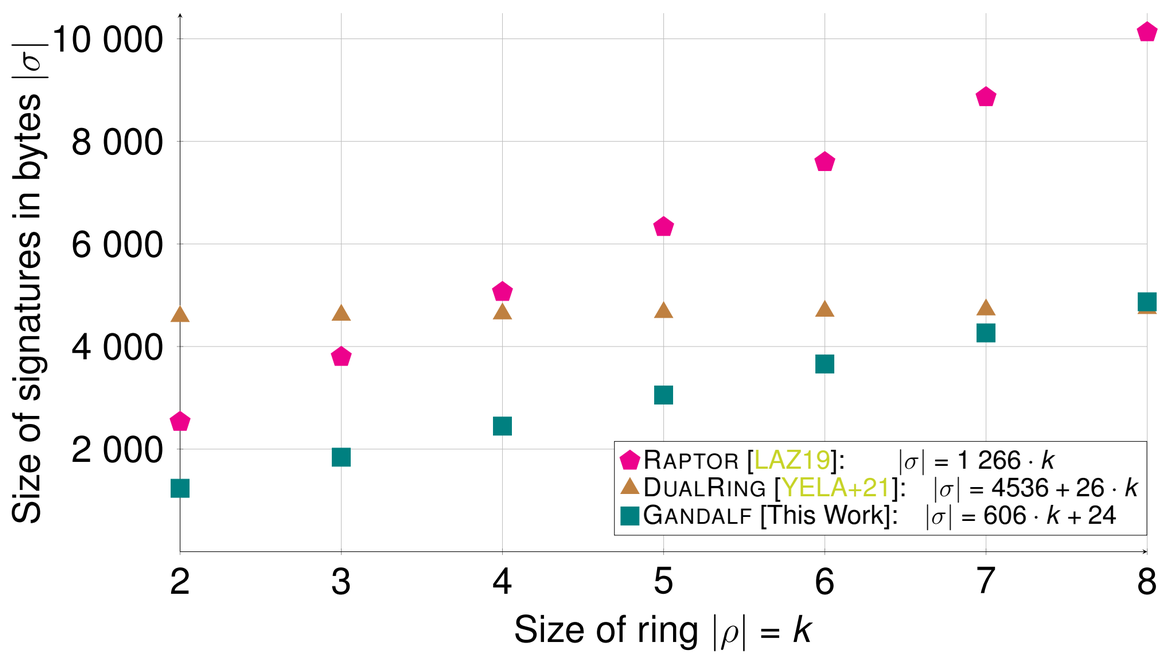



- Ring signatures [RST01] allow users to sign messages on behalf of dynamically formed user groups, and are publicly verifiable while preserving the signer's anonymity within the group (signing ring $\rho$).
- Ring signatures are widely adopted in blockchains and voting systems.
- Recent works achieve asymptotic signature size $\mathcal{O}(\log(|\rho|))$ using proof systems. However, for applications involving small rings, linear schemes are preferable.
- We construct a ring signature scheme, GANDALF, specifically for small rings, providing 50% reduction in signature sizes over the state of the art.

- GANDALF, is based on the NTRU pre-image sampleable trapdoor function $f_h$ [GPV08] over the NTRU ring.
- Concretely, $f_h$ inputs two ring elements of small norm and is defined as $f_h(u, v) = h * u + v$. A valid ring signature on message $m$ for the ring $\rho = \{h_1, \ldots, h_k\}$ consists of a vector $(u_1, \ldots, u_k) \in \mathcal{R}^k$ such that

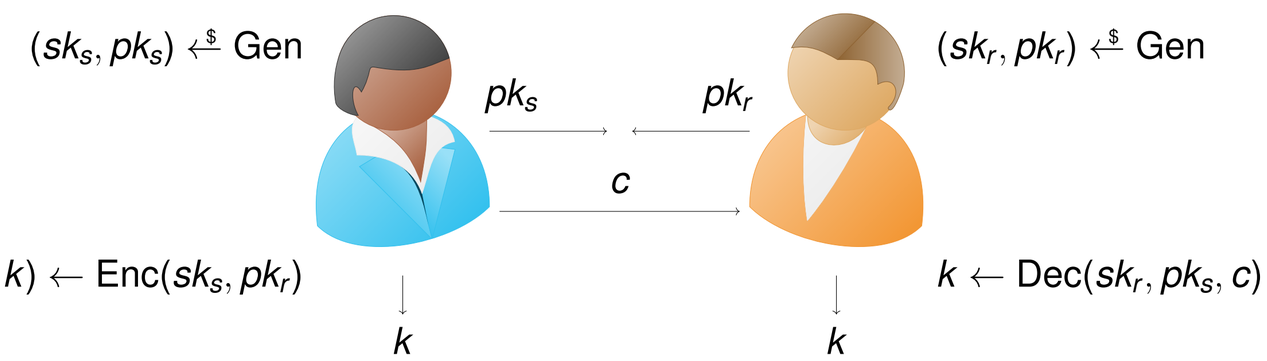
$$\left\| \left( u_1, \ldots, u_k, v = \mathsf{H}(m, \rho) - \sum_{i=1}^{k} h_i * u_i \right) \right\|_2 \leq \beta.$$

- The ring signature essentially consists of $k$ "unseeded FALCON signatures" [PFHK+22] and ring element $v$ is implicitly reconstructed in the verification equation.




## Deniable Authenticated Key Exchange Mechanisms (AKEM) [ABHK+21]

AKEM = (Gen, Enc, Dec)




- An AKEM can be thought of the KEM analogue of signcryption and was first formalised in [ABHK+21]. It is the primitive behind the recent HPKE [BBLW22] standard used in MLS and TLS.
- Our work introduces and formalises deniability for the AKEM primitive.
- Furthermore, we show a black box construction of a deniable AKEM using our ring signature scheme.

| | | Honest Receiver | | Dishonest Receiver | |
|---|---|---|---|---|---|
| | | $sk_r$ does not leak | $sk_r$ leaks | $sk_r$ does not leak | $sk_r$ leaks |
| Honest Sender | $sk_s$ does not leak | $\mathrm{Sim}(\emptyset), \mathcal{A}(\emptyset)$ | $\mathrm{Sim}(\emptyset), \mathcal{A}(sk_r)$ | $\mathrm{Sim}(sk_r), \mathcal{A}(\emptyset)$ | $\mathrm{Sim}(sk_r), \mathcal{A}(sk_r)$ |
| | $sk_s$ leaks | $\mathrm{Sim}(\emptyset), \mathcal{A}(sk_s)$ | $\mathrm{Sim}(\emptyset), \mathcal{A}(sk_s, sk_r)$ | $\mathrm{Sim}(sk_r), \mathcal{A}(sk_s)$ | $\mathrm{Sim}(sk_r), \mathcal{A}(sk_s, sk_r)$ |

| Primitive | Scheme (variant) | Security | Model | Size (in bytes) | | |
|---|---|---|---|---|---|---|
| | | | | $\sigma$ | $c$ | $pk$ |
| RSig | GANDALF [this work] | **UF**, **Ano** | ROM | 1 244 | — | 896 |
| KEM | NTRU-A [DHKL+23] | **IND-CCA** | QROM | — | 768 | 768 |
| AKEM | AKEM [this work] | **Ins-Aut**, **Ins-CCA** **HR-Den**, **DR-Den** | Standard | — | 2 012 | 1 664 |

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