SPHINCS+C

Compressing SPHINCS+ With (Almost) No Cost

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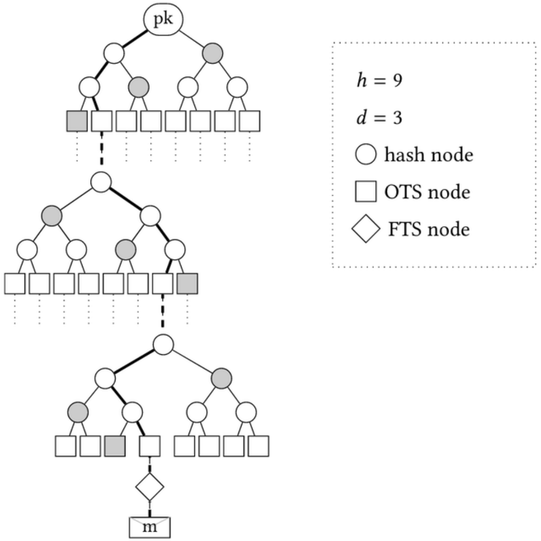
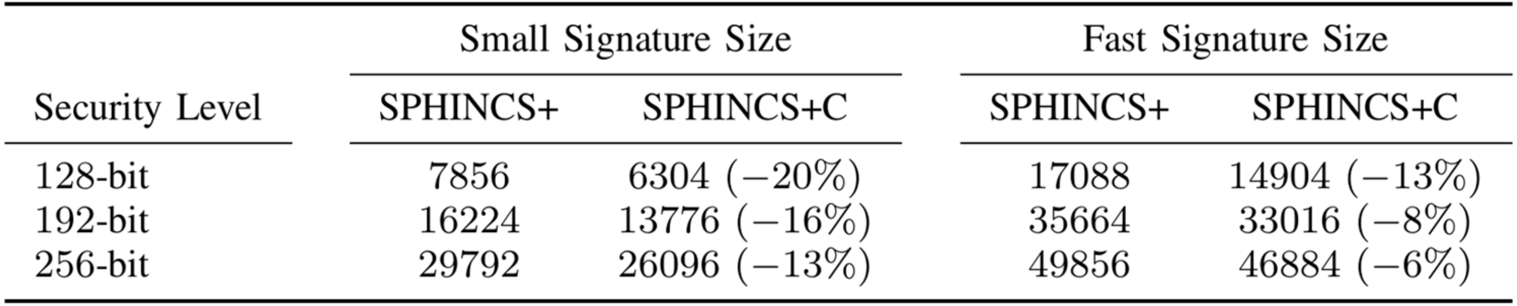
SPHINCS+

- A hash-based signature scheme
- One of the selected NIST PQ digital schemes
  - One of the most secure and robust schemes
- Has a “small” and “fast” variant (for each security level)
- Actually allows a wide range of tradeoffs between:
  - Sig-Size, Sig-Gen-Time, Sig-Ver-Time
  - In general: faster Sig-Gen-Time and Sig-Ver-Time -> larger Sig-Size



SPHINCS+C

- Same structure with new more efficient primitives: WOTS+C, FORS+C
- Minor code changes compared to SPHINCS+
- Allows a new realm of better tradeoffs than SPHINCS+:
    - E.g., smaller Sig-Size with same Sig-Gen-Time

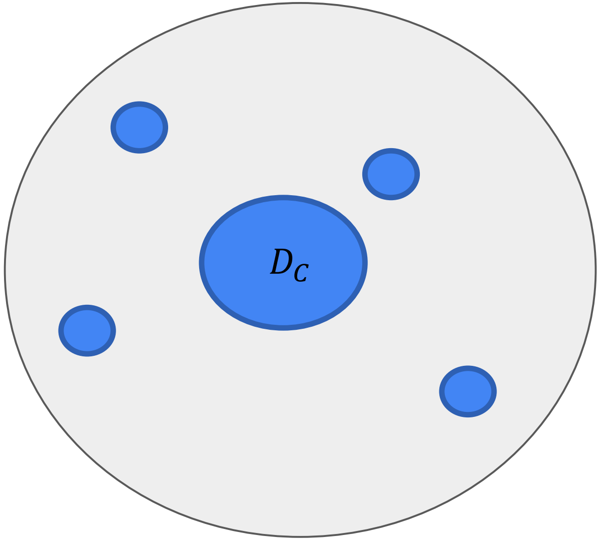


	Small Signature Size		Fast Signature Size	
Security Level	SPHINCS+	SPHINCS+C	SPHINCS+	SPHINCS+C
128-bit	7856	6304 (−20%)	17088	14904 (−13%)
192-bit	16224	13776 (−16%)	35664	33016 (−8%)
256-bit	29792	26096 (−13%)	49856	46884 (−6%)

Intuition for WOTS+C and FORS+C

- Hash and Sign
    - $d = HASH(r||m),\ m \in \{0,1\}^*,\ d \in \{0,1\}^n,\ r \leftarrow \$$
    - $\sigma = SIGN(d)$
- SIGN accepts any value of d
    - SIGN may be “compressed” (size, run time) for some sub-domains
- Basic idea
    - Find “good” sub-domain D_C and compress SIGN/VER for it
    - For signing, we add an incrementing counter to the hash
    - Search for cnt value such that $\mathrm{d}_\mathrm{C} = HASH(r||cnt||m) \in D_C$
    - $\sigma_c = SIGN_C(d_c)$||cnt
    - Verifier checks that $HASH(r||cnt||m) \in D_C$ and $VER_C(d, \sigma) = 1$

Domain of SIGN

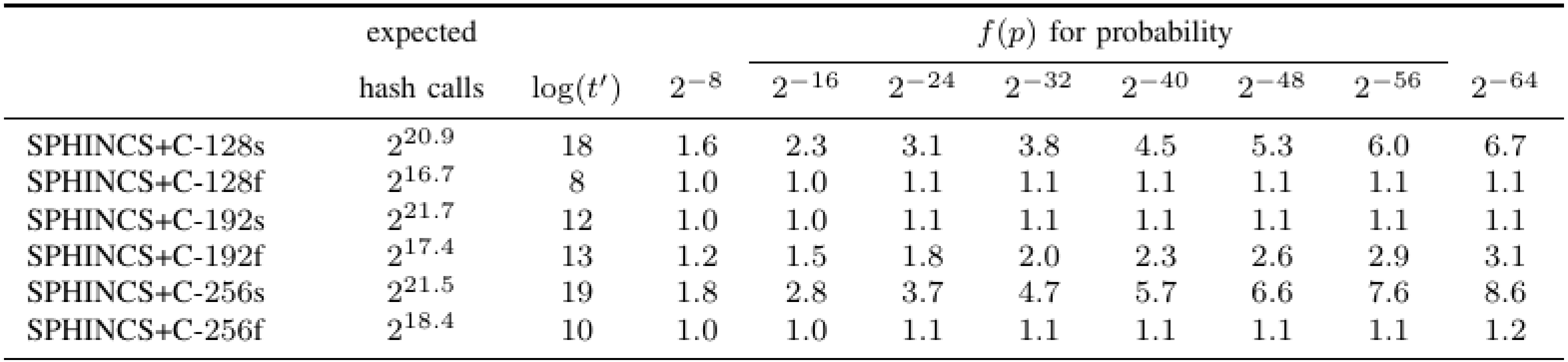


Intuition for WOTS+C and FORS+C

- Wait a minute, the Sig-Gen running time is not constant!
  - Yes, but this is actually OK
- Is this secure against side-channel attacks?
  - Yes, if original SPHINCS+ is “Constant time” crypto then so is SPHINCS+C
  - “Constant time” means independence of running time and secret inputs
  - Our run time variance only depends on the message and public values
  - Variance is independent from any secret values and doesn't leak any information about them

Intuition for WOTS+C and FORS+C

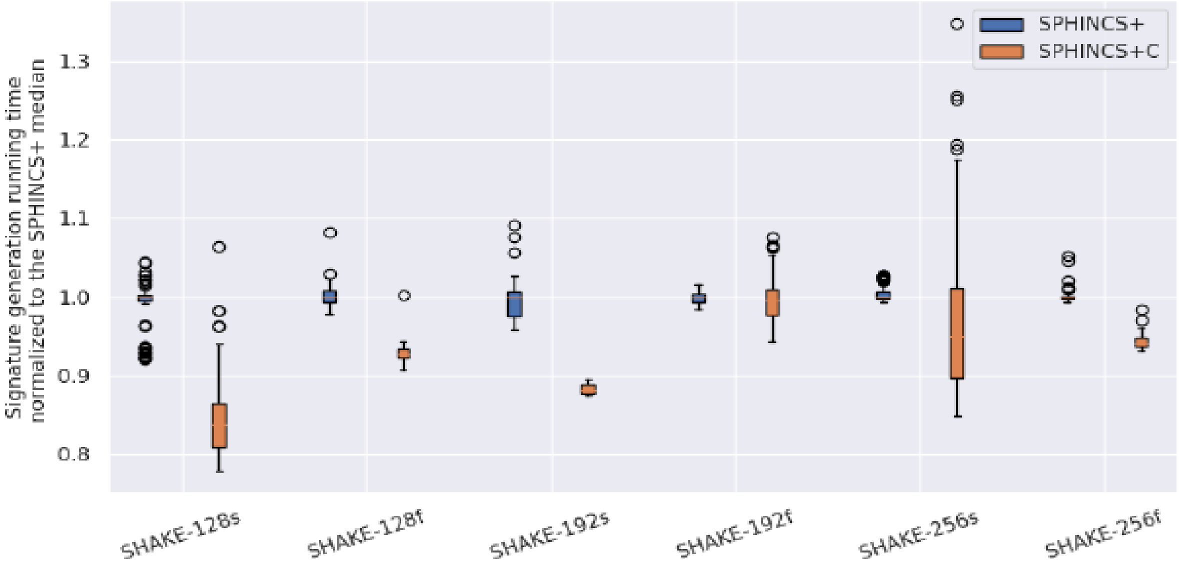
- Won’t some signatures take a really long time?
  - We bound the probability p for s signature will run more than $f(p)$ time the expected time
  - E.g., $f(2^{-16}) < 3$, $f(2^{-32}) < 5$ and $f(2^{-64}) < 9$
  - Can optimize for parameter sets with lower variance.
    - E.g., for SPHINCS+C-256f $f(2^{-64}) < 1.2$



	expected		$f(p)$ for probability							
	hash calls	$\log(t')$	2^{-8}	2^{-16}	2^{-24}	2^{-32}	2^{-40}	2^{-48}	2^{-56}	2^{-64}
SPHINCS+C-128s	$2^{20.9}$	18	1.6	2.3	3.1	3.8	4.5	5.3	6.0	6.7
SPHINCS+C-128f	$2^{16.7}$	8	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1
SPHINCS+C-192s	$2^{21.7}$	12	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1
SPHINCS+C-192f	$2^{17.4}$	13	1.2	1.5	1.8	2.0	2.3	2.6	2.9	3.1
SPHINCS+C-256s	$2^{21.5}$	19	1.8	2.8	3.7	4.7	5.7	6.6	7.6	8.6
SPHINCS+C-256f	$2^{18.4}$	10	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.2

Intuition for WOTS+C and FORS+C

- Won’t some signatures take a really long time?
  - We also run experiments to compare variability in SIG-GEN time with SPHINCS+



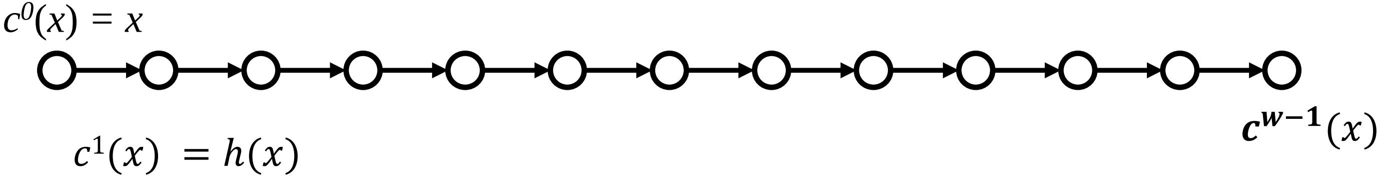
From WOTS+ and FORS to WOTS+C and FORS+C

Function chains in WOTS*

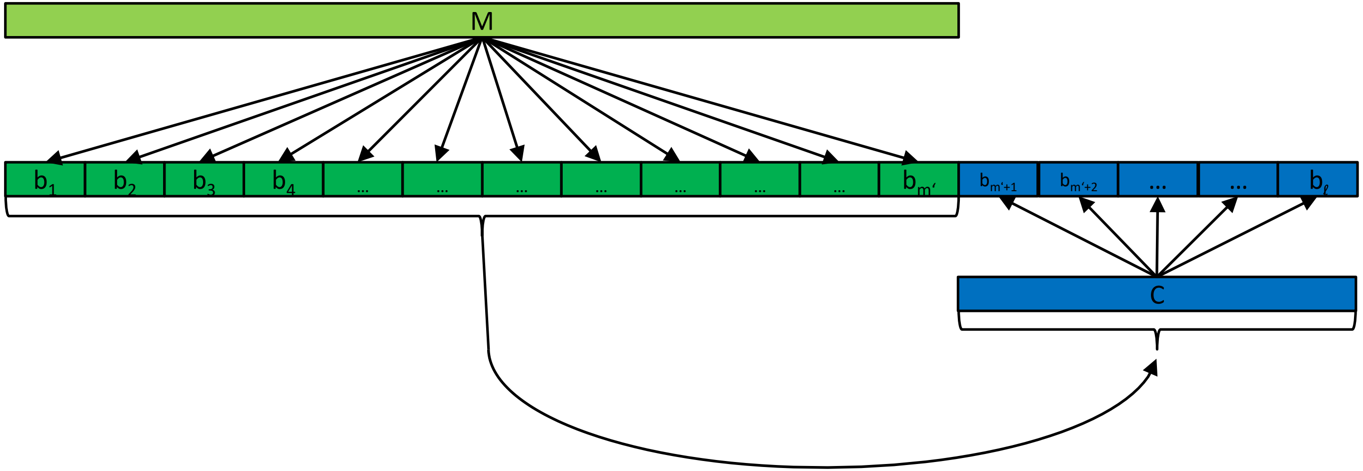
Hash function $h : \{0,1\}^n \rightarrow \{0,1\}^n$

Parameter w

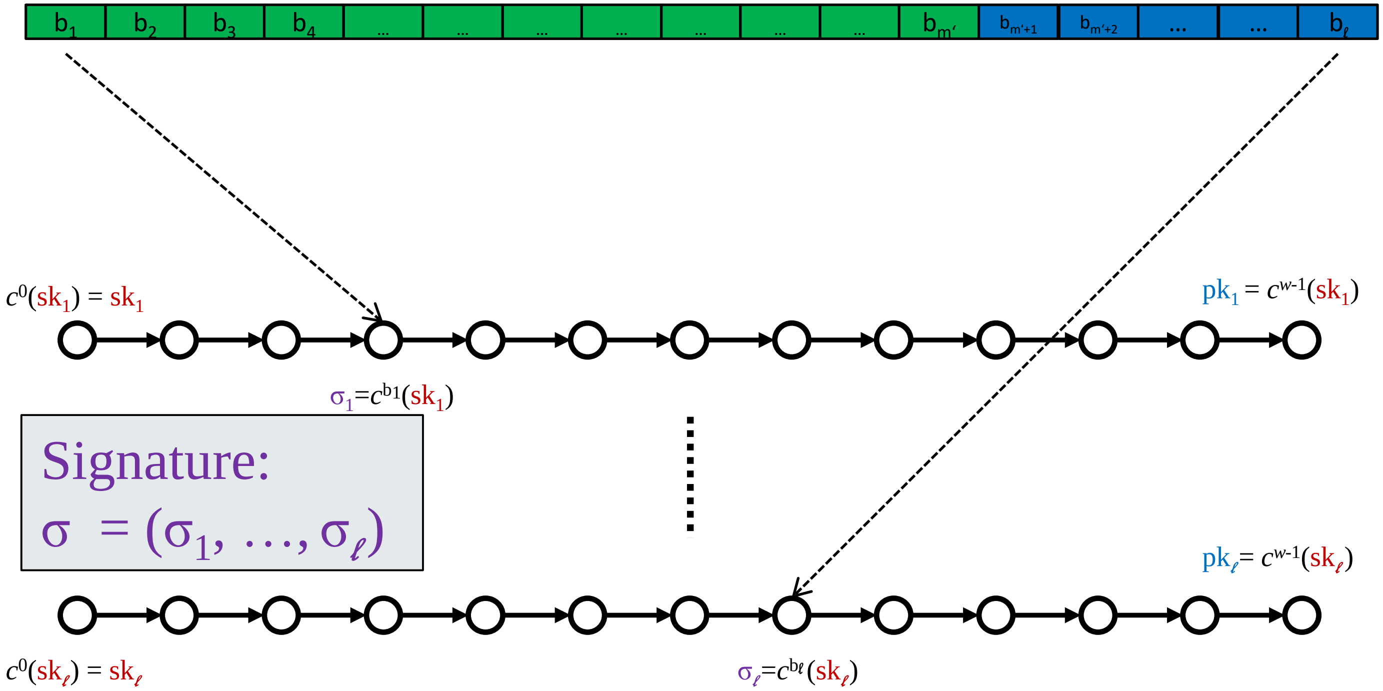
Chain: $c^i(x) = h\left(c^{i-1}(x)\right) = \underbrace{h \circ h \circ \cdots \circ h}_{i\text{-}times}(x)$



WOTS Signature generation



WOTS Signature generation



Signature:

$\sigma = (\sigma_1, \ldots, \sigma_\ell)$

WOTS+C

We remove the checksum chains by forcing it to always a pre-defined value

Signing:

Instead of signing the message m, we sign $\mathbf{d} = h(s \| m)$, where s a salt.

Search for s s.t. $\mathbf{d}$ has a checksum S, add s to the signature

S is pre-defined to be the expected checksum.

Signer run-time is usually **reduced!** More work to find salt, but no checksum chains to calculate

Verifying:

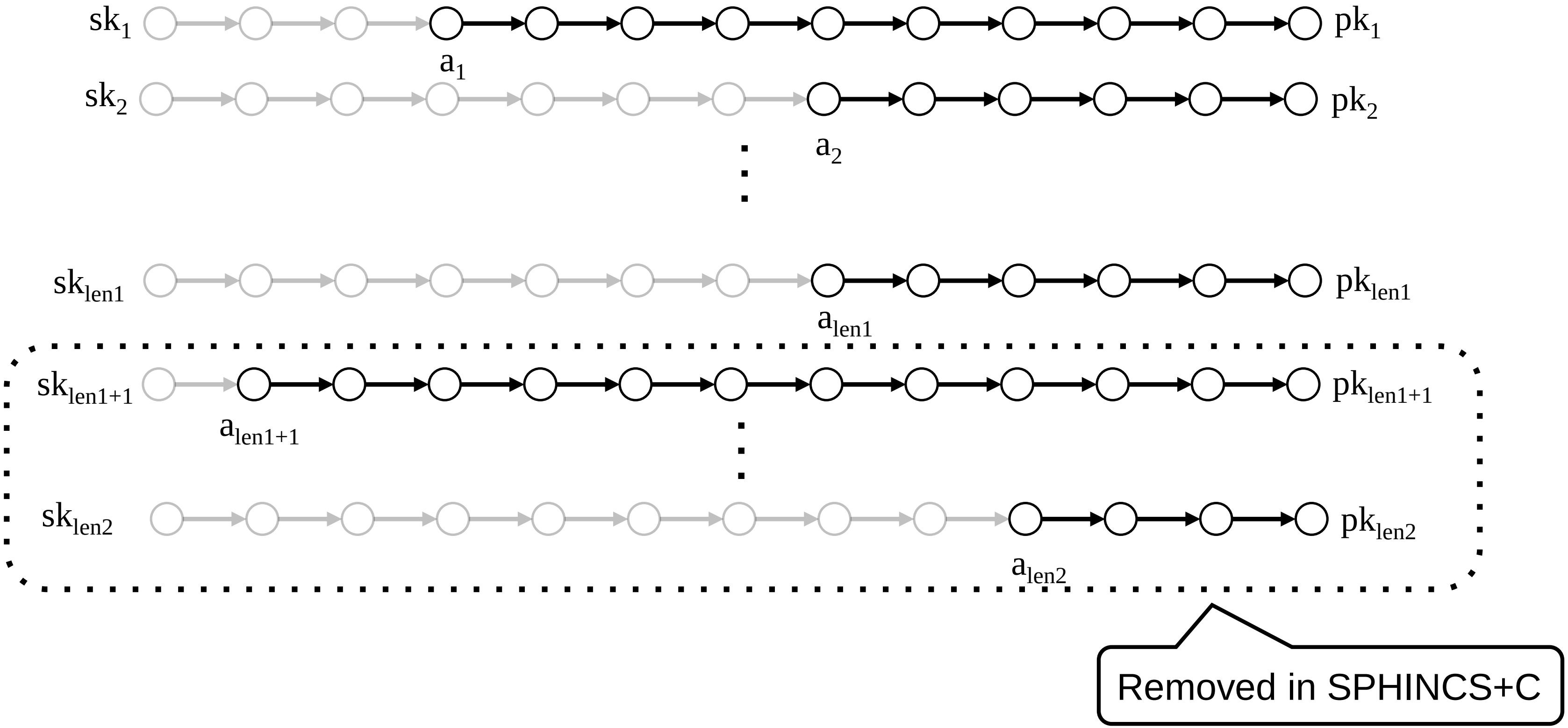
Verifier run-time is **reduced**.

No need to verify the checksum chains

Only compute $\mathbf{d} = h(s \| m)$ and verify that $\mathbf{d}$ has checksum S (and verify the signature)

Can use the same technique to reduce more chains (at the cost of increasing Sig-Gen-Time)

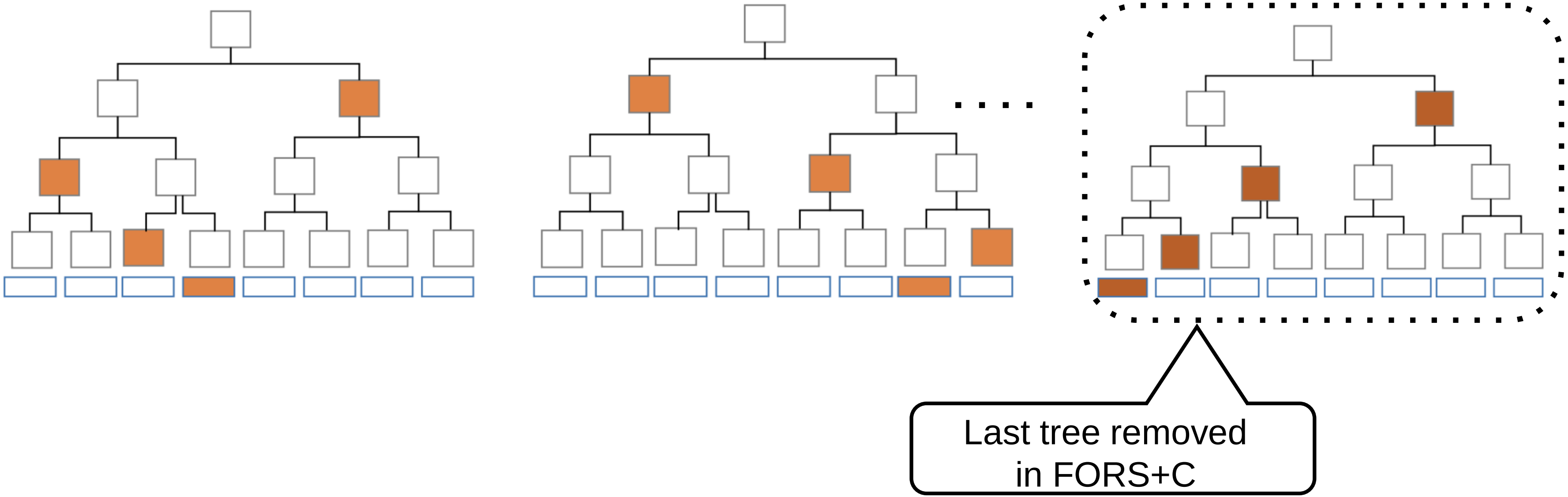
WOTS+C


sk_1
pk_1
a_1
sk_2
pk_2
a_2
sk_{len1}
pk_{len1}
a_{len1}
sk_{len1+1}
pk_{len1+1}
a_{len1+1}
sk_{len2}
pk_{len2}
a_{len2}
Removed in SPHINCS+C

FORS+C

- FORS includes multiple Merkle trees, opening one leaf in each tree
- Using similar techniques, we remove the last tree of the FORC+ signature
- **Idea:** force the hash for the last tree to always open the first leaf (leaf index 0)
- Find a salt s that satisfies the above
- **Tweak:** we can make the last tree larger than other to gain savings
- Verifier run-time is **reduced** (simply check that last tree has index 0)

FORS+C

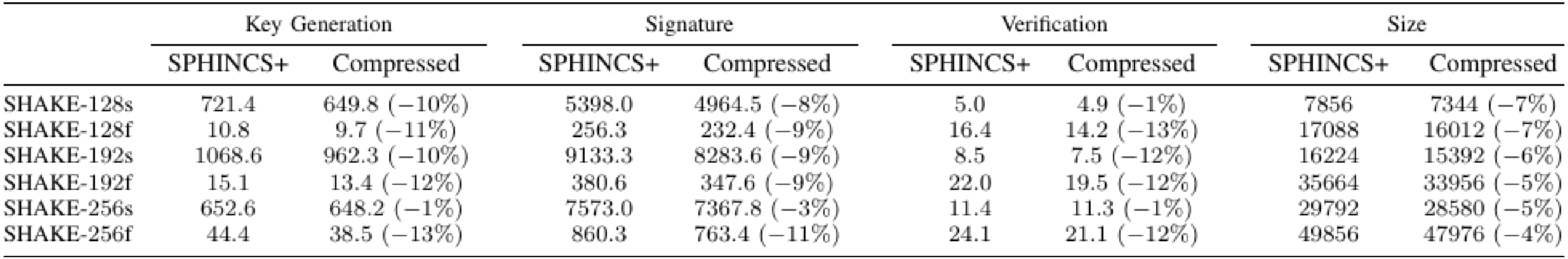


Last tree removed in FORS+C

SPHINCS+C

SPHINCS+C Parameter Sets

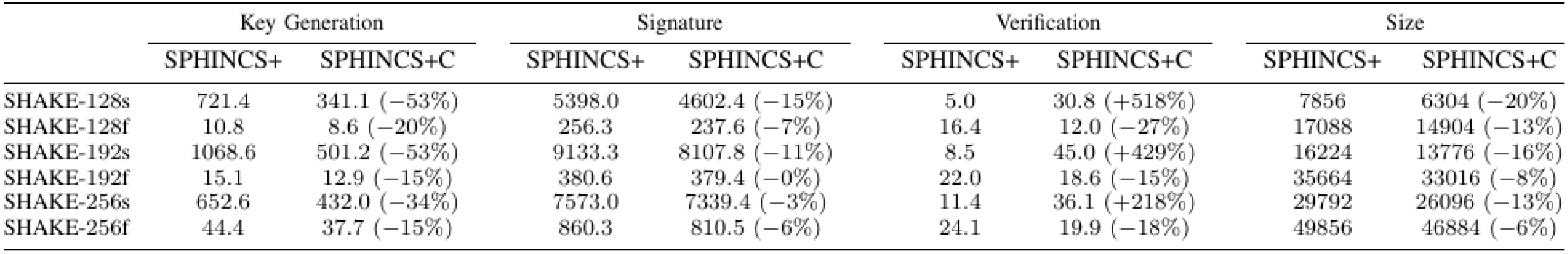
- As a starting point we can use the original SPHINCS+ parameter sets
- This results in a “compressed” version of SPHINCS+ that is strictly better
  - Faster Key-Gen-Time, Sig-Gen-Time, Sig-Ver-Time
  - Smaller Sig-Size



	Key Generation		Signature		Verification		Size	
	SPHINCS+	Compressed	SPHINCS+	Compressed	SPHINCS+	Compressed	SPHINCS+	Compressed
SHAKE-128s	721.4	649.8 (−10%)	5398.0	4964.5 (−8%)	5.0	4.9 (−1%)	7856	7344 (−7%)
SHAKE-128f	10.8	9.7 (−11%)	256.3	232.4 (−9%)	16.4	14.2 (−13%)	17088	16012 (−7%)
SHAKE-192s	1068.6	962.3 (−10%)	9133.3	8283.6 (−9%)	8.5	7.5 (−12%)	16224	15392 (−6%)
SHAKE-192f	15.1	13.4 (−12%)	380.6	347.6 (−9%)	22.0	19.5 (−12%)	35664	33956 (−5%)
SHAKE-256s	652.6	648.2 (−1%)	7573.0	7367.8 (−3%)	11.4	11.3 (−1%)	29792	28580 (−5%)
SHAKE-256f	44.4	38.5 (−13%)	860.3	763.4 (−11%)	24.1	21.1 (−12%)	49856	47976 (−4%)

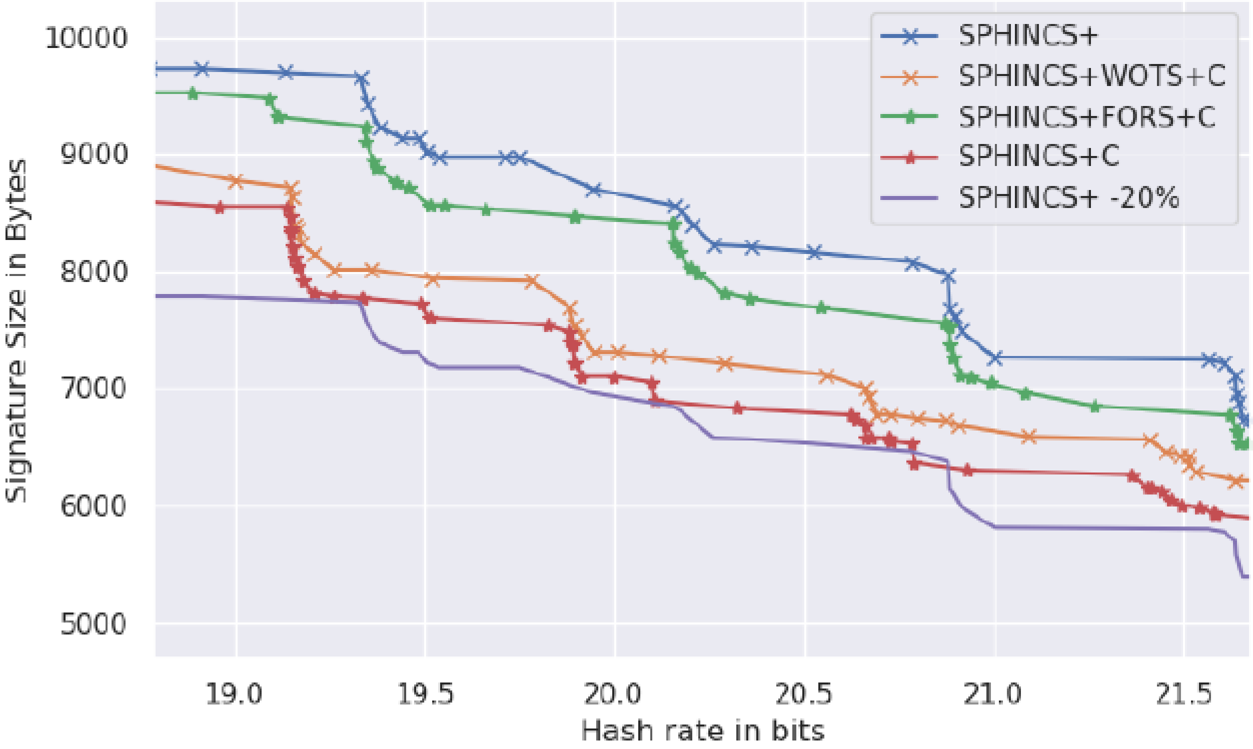
SPHINCS+C Parameter Sets

- However, we can do better.
- We can optimize parameter sets for different constraints and use cases
- E.g., we optimized SPHINCS+C paramters to:
    - Minimize Sig-Size
    - Keeping Sig-Gen-Time at least as fast as SPHINCS+



	Key Generation		Signature		Verification		Size	
	SPHINCS+	SPHINCS+C	SPHINCS+	SPHINCS+C	SPHINCS+	SPHINCS+C	SPHINCS+	SPHINCS+C
SHAKE-128s	721.4	341.1 (−53%)	5398.0	4602.4 (−15%)	5.0	30.8 (+518%)	7856	6304 (−20%)
SHAKE-128f	10.8	8.6 (−20%)	256.3	237.6 (−7%)	16.4	12.0 (−27%)	17088	14904 (−13%)
SHAKE-192s	1068.6	501.2 (−53%)	9133.3	8107.8 (−11%)	8.5	45.0 (+429%)	16224	13776 (−16%)
SHAKE-192f	15.1	12.9 (−15%)	380.6	379.4 (−0%)	22.0	18.6 (−15%)	35664	33016 (−8%)
SHAKE-256s	652.6	432.0 (−34%)	7573.0	7339.4 (−3%)	11.4	36.1 (+218%)	29792	26096 (−13%)
SHAKE-256f	44.4	37.7 (−15%)	860.3	810.5 (−6%)	24.1	19.9 (−18%)	49856	46884 (−6%)

Improved Tradeoff with SPHINCS+C



SPHINCS+C Parameter Sets

- SPHINCS+C can provide better tradeoffs compare to SPHINCS+
- We are looking for feedback on real-world requirements and tradeoffs
  - Sig-Gen-Time Vs. Sig-Ver-Time
  - Sig-Size Vs. Sig-Ver-Time
  - Low q_{sign} variants
- The paper includes a sage script for finding suitable parameter sets

Future Work

- In the paper we propose other optimization that require bigger code changes and are not included in SPHINCS+C
    - Interleaved Trees for better FORS compression
    - Small trees of FORS+C
    - Soft-state-full variant to XMSS based on a tree of FORS+C
        - Only need to make sure you don’t pass the signature number limit

- Fine-tuning parameter sets choice

Conclusion

- We presented SPHINCS+C a “compressed” variant of SPHINCS+
  - Based on WOTS+C and FORS+C variants of WOTS+ and FORS used in SPHINCS+
  - Full **tight** security proof as in SPHINCS+
- SPHINCS+C allows for better tradeoffs and optimization of parameter sets
- WOTS+C optimizations can also be used in XMSS
- Improved tradeoffs and optimization also for low q_{sign} variants

- Paper available at: ia.cr/2022/778
- Code: https://github.com/eyalr0/sphincsplusC/
- Any questions?