

Prime-Compound Phase-Lane Token Protocol (PCPL) for Symmetric Continuous Tokenizer Devices

Abstract

I present the Prime-Compound Phase-Lane Token Protocol (PCPL), a no-handshake token system where a device emits one token per cycle and exactly one provider can validate it. PCPL combines (1) a public phase clock derived from coprime residues, (2) hidden prime-compound bouquets per provider, and (3) device-only state evolution that chains all lanes. I also introduce the symmetric continuous tokenizer device model, motivated by FPGA-based dynamic hash circuits and twin circuits for peer validation. A step-by-step algorithm description, correctness properties, and a deterministic simulation trace are provided.

1. Symmetric continuous tokenizer devices

PCPL runs on a “symmetric continuous tokenizer” device designed for consumer computing. The device is envisioned as a reconfigurable hardware unit (for example, an FPGA-based key) that can:

- Acquire unique, device-specific hashing circuits or internal start variables.
- Continuously generate short-lived tokens or keys.
- Be validated only by its twin circuit(s), which share the same circuit family or seed lineage.

The symmetry comes from pairing: two devices can load the same dynamic hash circuit and evolve internal state in the same way, enabling mutual validation without exposing the evolving secrets.

1.1 Forks by variable alternation

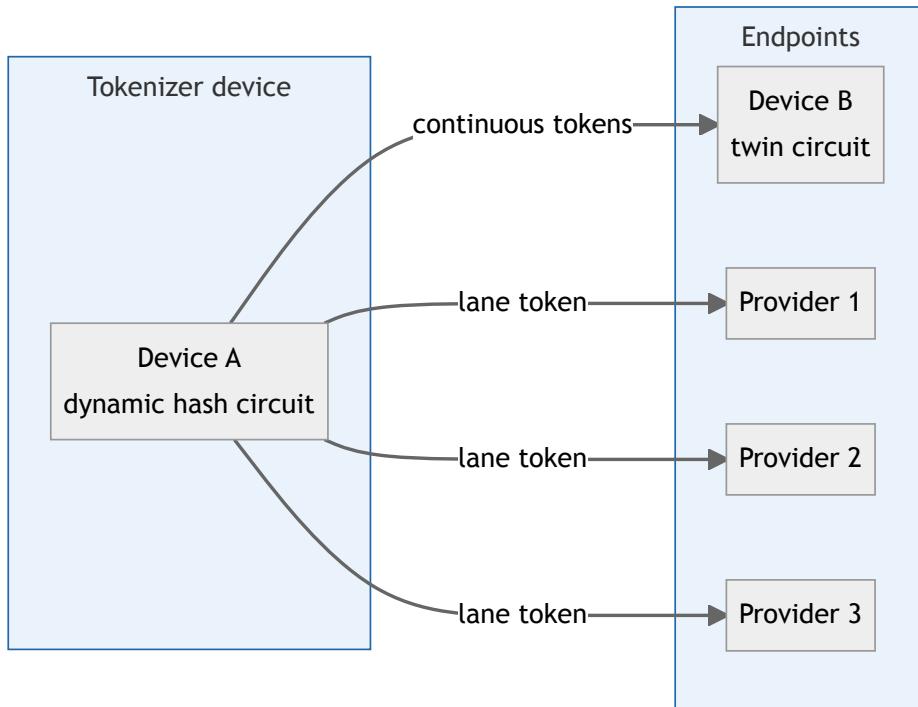
Beyond PCPL, the same circuit can be “forked” by alternating variable sets over time windows. Let a device maintain a base circuit C and a family of variables V_k selected by time window W_k . Each fork evolves as:

$$S_{t+1}^{(k)} = H(C, S_t^{(k)}, V_k, t), \\ t \in W_k.$$

This creates multiple parallel token streams sharing the same circuit but with distinct, time-delimited variable schedules. Such forks can be used for provider lanes (as in PCPL) or for isolated peer-to-peer sessions that are difficult to parallelize or replay.

1.2 Peer-to-peer continuity

The device model also targets in-loco connections among peers. Two devices that share a circuit family and seed lineage can establish an isolated encryption context by evolving state in lockstep without querying a central provider.



2. System model and goals

PCPL is designed for:

- No runtime challenge/response or synchronization negotiation.
- One token per cycle, routed to exactly one provider out of x .
- Provider-side validation by local recomputation.

Threat model (minimal):

- A provider should not compute tokens for other providers.
- Observing accepted tokens should not reveal other lanes.
- Public time/phase information should not enable cross-lane forgery.

3. Notation and public parameters

Let:

- x be the number of providers (lanes).
- P, Q, R be pairwise coprime primes (also coprime with x).
- M be a prime modulus for multiplicative-group arithmetic.
- $H(\cdot)$ be a cryptographic hash (or a dynamic hash circuit).
- $\text{Trunc}_k(\cdot)$ be truncation to k bits.

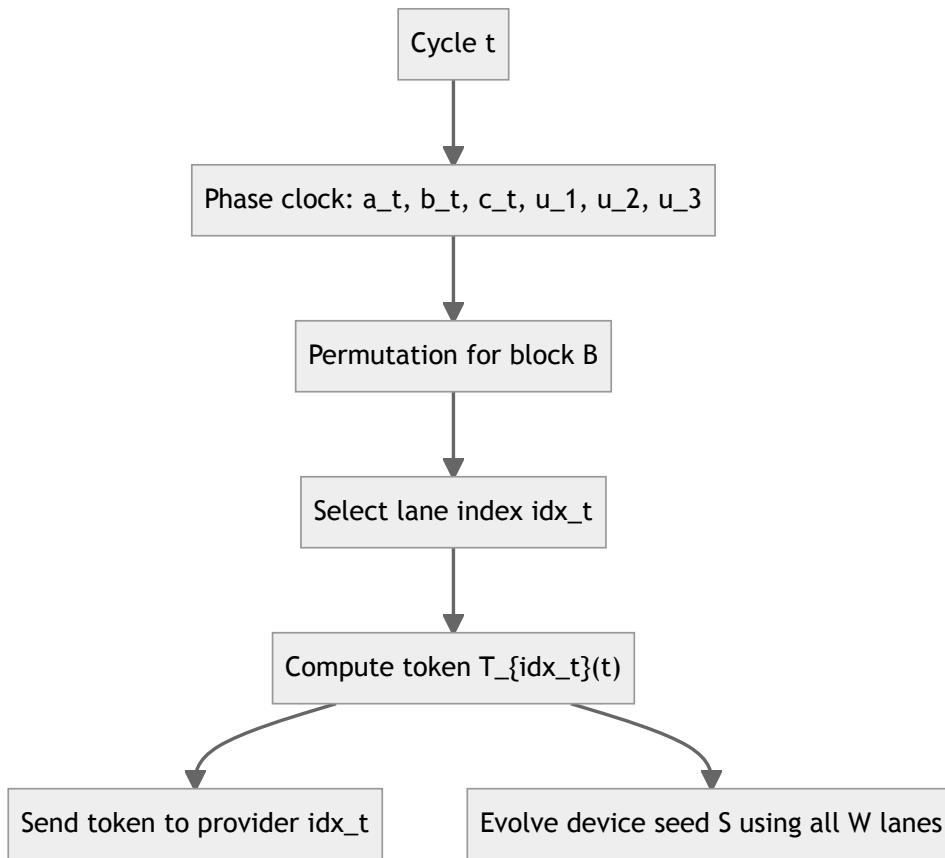
- t be the cycle counter.
- \parallel denote byte/bit-string concatenation.

Each provider i has three secret bouquets: BouquetA $_i$, BouquetB $_i$, BouquetC $_i$, each a list of prime compounds.

4. PCPL protocol overview

The protocol uses:

1. A public phase clock (CRT residues and coupled products).
2. A per-block permutation schedule to enforce “returns every x ”.
3. Hidden bouquets to derive lane-specific tokens.
4. Device-only seed evolution that chains all lanes.



5. Step-by-step algorithm

5.1 Phase clock

For cycle t :

$$\begin{aligned} a_t &= (a_0 + t) \bmod P, \\ b_t &= (b_0 + t) \bmod Q, \\ c_t &= (c_0 + t) \bmod R. \end{aligned}$$

Coupled products:

$$\begin{aligned} u_1 &= (a_t b_t) \bmod M, \\ u_2 &= (b_t c_t) \bmod M, \\ u_3 &= (c_t a_t) \bmod M. \end{aligned}$$

Phase digest:

$$\Phi_t = H(a_t \| b_t \| c_t \| u_1 \| u_2 \| u_3 \| "PHASE").$$

5.2 Permutation schedule (“returns every x”)

Let:

$$B = \left\lfloor \frac{t}{x} \right\rfloor, \quad s = t \bmod x.$$

Compute a permutation π_B of $\{0, \dots, x - 1\}$ using a hash-driven shuffle seeded by a block-level phase digest (computed at $t = B \cdot x$) so the schedule is stable within each block. Then:

$$\text{idx}_t = \pi_B[s].$$

This guarantees each provider appears exactly once per block.

5.3 Bouquet evaluation

Each bouquet is a list of compounds C_j , each a product of primes. For a residue x_{res} and coupling u , define:

$$e_j = H(x_{\text{res}} \| u \| j \| "EXP") \bmod (M - 1).$$

$$\text{Eval}(\text{Bouquet}, x_{\text{res}}, u) = \prod_j C_j^{e_j} \bmod M.$$

For provider i :

$$\begin{aligned} EA_i(t) &= \text{Eval}(\text{BouquetA}_i, a_t, u_1), \\ EB_i(t) &= \text{Eval}(\text{BouquetB}_i, b_t, u_2), \\ EC_i(t) &= \text{Eval}(\text{BouquetC}_i, c_t, u_3). \end{aligned}$$

5.4 Token derivation

Key derivation:

$$K_i(t) = H(EA_i \| EB_i \| EC_i \| \Phi_t \| "KDF") .$$

Token:

$$T_i(t) = \text{Trunc}_k(H(K_i \| t \| \Phi_t \| "TOK")) .$$

5.5 Device emission and state evolution

The device computes only $T_{\text{idx}_t}(t)$ and updates internal state:

- $W[i]$ stores the last token for lane i .
- The seed S evolves using all lanes and adjacent products.

For x lanes, define (non-cyclic adjacency):

$$m_\ell = (W_\ell \cdot W_{\ell+1}) \bmod M, \quad \ell = 0, \dots, x-2.$$

$$S_{t+1} = H(S_t \| W_0 \| \dots \| W_{x-1} \| m_0 \| \dots \| m_{x-2} \| \Phi_t \| "EVOLVE") .$$

5.6 Provider verification

Provider i recomputes $T_i(t)$ and accepts the token iff it matches.

6. Correctness and periodicity

6.1 Exact 1-of-x matching

Within each block of length x , π_B is a permutation. Therefore each provider index appears exactly once per block, and exactly one provider matches per cycle.

6.2 Phase periodicity

If P, Q, R are coprime, the tuple (a_t, b_t, c_t) repeats after PQR . If P, Q, R are also coprime with x , the deterministic schedule repeats after $PQRx$.

6.3 Modular exponent correctness

With M prime, the multiplicative group \mathbb{F}_M^* has order $M - 1$. Reducing exponents modulo $M - 1$ makes $C_j^{e_j} \bmod M$ well-defined for any base C_j not divisible by M .

7. Security intuition (informal)

- **Lane isolation:** each provider uses distinct secret bouquets, so observing one lane does not reveal others.
- **Phase coupling:** public residues are mixed and hashed, preventing linear predictability from the CRT clock alone.
- **Device chaining:** even stale lanes influence future state, reinforcing the requirement that “every token matters”.

8. Experimental validation (deterministic simulation)

We implemented a cycle-by-cycle simulator to validate correctness. The demo verifies:

- Each block yields a valid permutation.
- Exactly one provider matches each cycle.
- Each provider appears once per block.

8.1 Sample token trace ($x=4$, seed=1337)

For PDF export, the original wide table was replaced with an A4-friendly summary table and a sequence diagram (tokens truncated for readability; the matched provider's recomputed token equals the device token by construction).

t	block	slot	idx_t	device token (truncated)	matched provider
0	0	0	3	0xaa81443d...6e0e02	3
1	0	1	0	0x21faa3d7...2dbe77	0
2	0	2	2	0x888b2137...903179	2
3	0	3	1	0xa591e8bf...03b4b4	1
4	1	0	2	0x5da9a61c...1d52ff	2
5	1	1	0	0x8abe0866...9d17b6	0
6	1	2	1	0x39d33ef1...6fd92e	1
7	1	3	3	0xe25bb134...064674	3



8.2 Full token trace (verbatim values)

The full deterministic trace (block permutations, schedule, device tokens, and per-lane tokens) is exported to a separate, auto-generated file to keep the paper A4-friendly, following the papers and script developed in repository [cekkr/phaselane-algorithm@github.com](https://github.com/cekkr/phaselane-algorithm). See `papers/token-trace.md`, generated by `demo/export_token_trace.py`.

Regenerate with:

```
python3 demo/export_token_trace.py --blocks 4 --out papers/token-trace.md
```

9. Discussion and limitations

- Parameter choice matters; P, Q, R, M must be prime and pairwise coprime.
- The permutation schedule is device-only; leakage of the permutation key can reveal lane order, but not lane tokens.
- The security of the scheme relies on the strength of $H(\cdot)$ and the secrecy of bouquets, not on the hardness of factoring revealed integers.
- This paper was developed and formatted with an heavy OpenAI models' help.

10. Conclusion

PCPL provides a deterministic, no-handshake token protocol with exact 1-of- x matching and a device-only chaining mechanism. Combined with symmetric continuous tokenizer devices, it supports both provider validation and peer-to-peer isolation with dynamic, evolving secrets. The included simulation and trace demonstrate the protocol's behavior cycle by cycle.