BFTRAND: Low-latency Random Number Provider for BFT Smart Contracts

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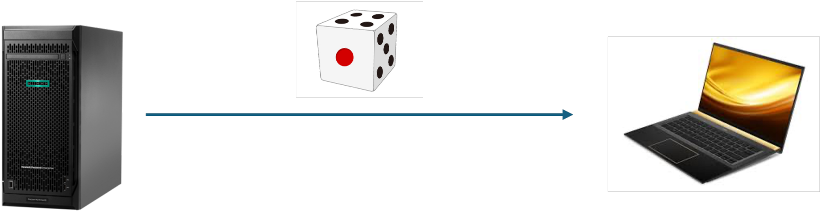
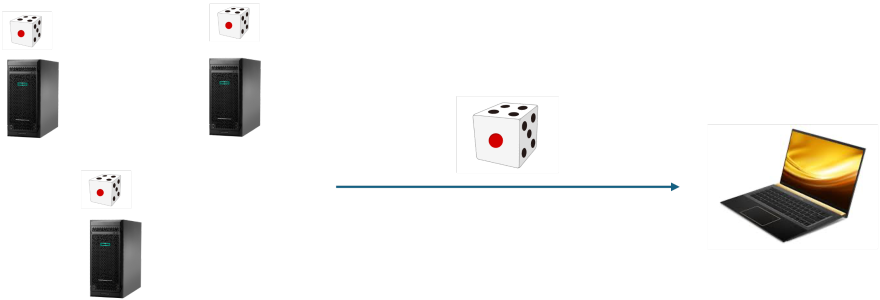
Outline

Server Client



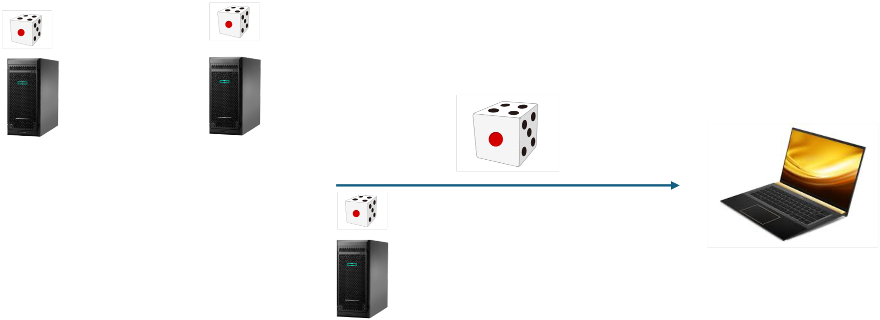
We do not trust single server.

Multi-Server Client



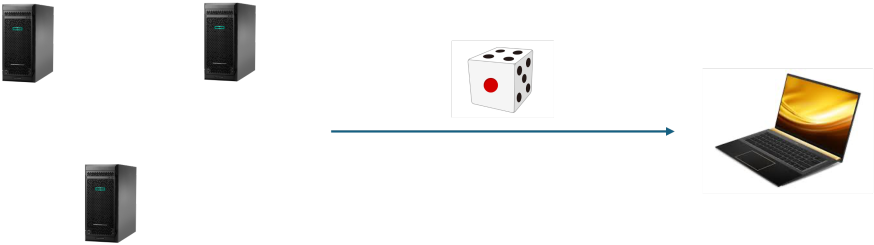
What bad guys can do?

Multi-Server Client: Bias Attack



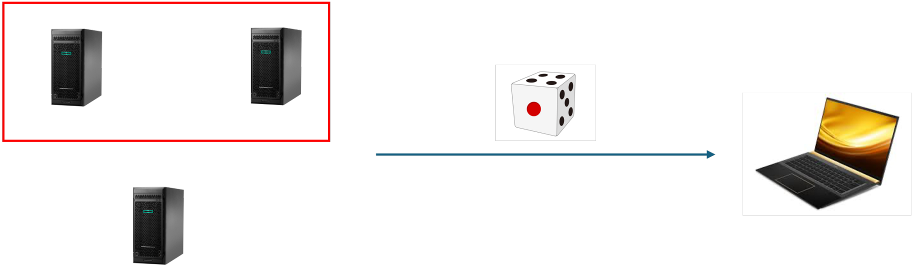
How about aggregation algorithms?

Multi-Server Client: DOS Attack



How to prevent bad guys from doing bad things?

Multi-Server Client: Threshold



Distributed Random Beacon (DRB).

Is DRB sufficient for Blockchain?

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NO

BFTRAND Overview

- A secure runtime random number generator for smart contracts
- Integrates distributed random beacons (DRB) into BFT consensus
- Achieves low latency and on-chain data savings

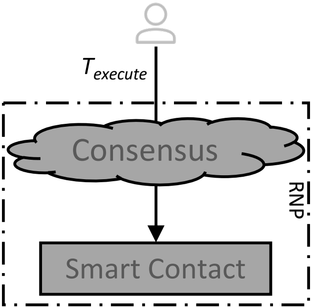

Figure: BFTRand RNP

Motivation

- Importance of randomness in blockchain applications
- Limitations of existing commit-reveal schemes
- Need for a secure and efficient runtime RNG

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Challenges

- Integrating DRB without compromising consensus security
- Mitigating post-reveal undo attacks (PUA)
- Ensuring pseudo-randomness, uniqueness, and availability

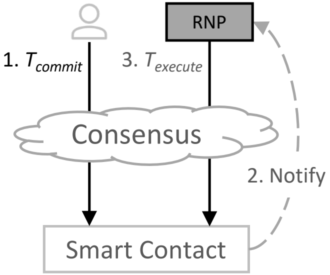
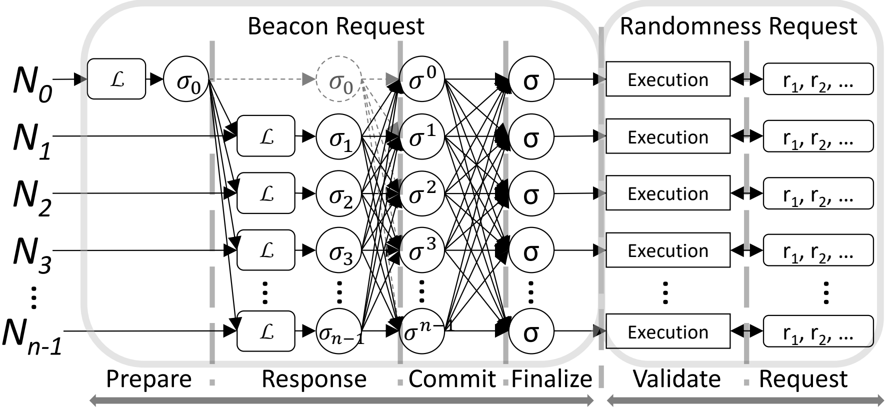


Figure: Commit-execute RNP

BFTRAND Protocol



Beacon Request

- Addressing semantic gaps between DRB and consensus
- Semantic Gap between DRB threshold k and BFT threshold t: $t < k \leq 2t + 1$
- Semantic Gap between DRB Round and Consensus Round: $\textbf{UpdateState}(\mathrm{st}_{b-1}, \perp, \perp, pk) : \mathrm{st} \leftarrow \sigma_{b-1} \parallel b - 1$ when $v = 0$, and $\textbf{UpdateState}(\mathrm{st}_{b,v-1}, \perp, \perp, pk) : \mathrm{st} \leftarrow \mathrm{st}_{b,v-1} \parallel b \parallel v$, otherwise.

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Randomness Request

- Providing random numbers to smart contracts
- Utilizing pseudo-random functions (PRF) for efficiency
- Ensuring unique and unpredictable outputs

Post-reveal Undo Attack (PUA)

- A new attack on runtime RNG schemes
- Exploiting transaction atomicity to revert unfavorable results
- Identified four types: Contract, Fallback, Fee, and Script PUA

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Post-reveal Undo Attack (PUA): Vulnerable BlindBox

```
function MintNFT(from, target, amount)
    CheckWitness(from)
    Require(amount == 1)
❶   Transfer(from, this, amount)
    rarity = GetRandom(1) % 2
    if (rarity == 1){
        // Cost 0.5 GAS
        blindBox = RareBlindBox(target, rarity)
❷   }else{
        // Cost 0.6 GAS
        blindBox = CommonBlindBox(target, rarity)
    }
    Mint(target, blindBox)
❸   Transfer(this, target, 1, {blindBox})
    StoreBlindBox(blindBox, rarity)
    return blindBox
end function

function GetRarity(blindBox)
    return StoreBlindBox[blindBox]
end function
```

Post-reveal Undo Attack (PUA): Contract PUA

```
function ContractPUA(user)
❹   blindBox = call NFT.MintNFT with (user, 1)
    rarity = call NFT.GetRarity with (blindBox)
    if rarity == 0 then
❺       call revert();
    end
    return true
end function
```

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Post-reveal Undo Attack (PUA): Fallback PUA

```
function Fallback(from, amount, object)
    rarity = call NFT.GetRarity with (blindBox)
❻   if rarity == 0 then
        call revert();
    end
    return true
end function
```

Post-reveal Undo Attack (PUA): Fee-based PUA

```
function MintNFT(from, target, amount)
    CheckWitness(from)
    Require(amount == 1)
    Transfer(from, this, amount)
    rarity = GetRandom(1) % 2
    if (rarity == 1){
        // Cost 0.5 GAS
        blindBox = RareBlindBox(target, rarity)
    }else{
        // Cost 0.6 GAS
        // revert if fee insufficient
        blindBox = CommonBlindBox(target, rarity)
    }
    Mint(target, blindBox)
    Transfer(this, target, 1, {blindBox})
    StoreBlindBox(blindBox, rarity)
    return blindBox
end function
```

Post-reveal Undo Attack (PUA): Script-based PUA

```
load "Blindbox Contract"
push amount
push target
push from
call "MintNFT" // push blindBox to the stack
call "GetRarity" //pop blindBox, push rarity
jmpz revert() // if rarity == 0, jump to revert() ❾
```

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Input Validation-based Detection (IVD)

- A countermeasure against PUA
- Validates user inputs and detects malicious transactions
- Maintains transaction atomicity and security properties

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IVD

Input Validation-based Detection (IVD) $(C, \mathcal{T}, \sigma)$

For simplicity, we use the name of the contract as the contract address and the abstract invoking function of C as invoking C:

```
if ({C,tx} ≠ ⊥) {
    // Minimum transaction fee
    // and maximum script size from C
    ($G_min, S_max) ⟵ C;

    ($g_max, S) ⟵ tx
    // Fee PUA Detected
    if ($G_min ≤ $g_max) Revert();
    // Script PUA Detected
    if (S_max ≥ |S|) Revert()t;
    // Acquire the entry script
    // from the virtual machine
    C_entry ⟵ EntryScriptFromVM;
    // Contract PUA Detected
    if (C_entry ≠ S) Revert();
} else {
    // Get the script from the blockchain
    S ⟵ GetContract(Addr)
     // Fallback PUA Detected
    if (S ≠ ⊥) Revert();
}
```

Security Analysis - Pseudorandomness

- Leveraging the pseudo-randomness of DRB and PRF
- Ensuring unpredictable and unbiased random numbers
- Resilient against precomputation attacks

Security Analysis - Uniqueness

- Guaranteeing deterministic uniqueness of random numbers
- Mitigating replay attacks and validator collusion
- Utilizing threshold-based DRB and secure PRF

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Security Analysis - Availability

- Ensuring consistent random number generation
- Tolerating Byzantine faults and DoS attacks
- Leveraging the robustness of the underlying BFT consensus

Implementation and Evaluation

- Prototype implementation on Neo blockchain
- Utilizing DBLS scheme for DRB and BLS signature
- Demonstrating efficiency and scalability advantages

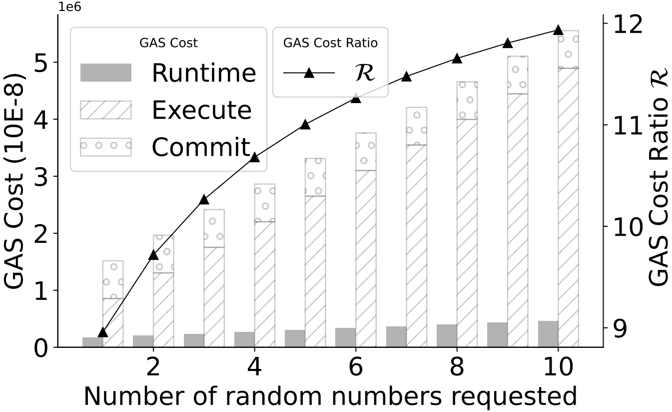
Evaluation - Transaction Cost

Table: Applications Transaction Fee (GAS/$).

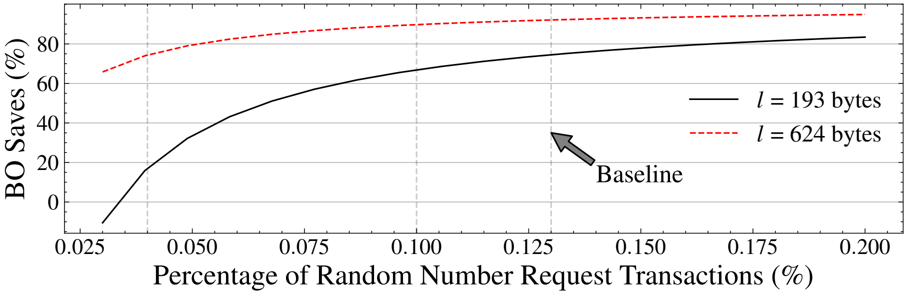
Method	**Network Fee**	**System Fee**
Loot::tokenURI	0.00593250/0.013	0.20694257/0.459
Neoverse:: UnBoxing	0.00119552/0.002	0.07313472/0.162
Neoverse:: BulkUnBoxing	0.00125752/0.002	0.36183988/0.803
RPS:: Play	0.00616260/0.013	0.06588677/0.146

Evaluation - GAS Cost

- The left y-axis is the total GAS consumption, while the right y-axis is the GAS cost ratio R = (Commit + Execute)/Runtime.



Evaluation - Blockchain Overhead



Comparison with Existing RNG Solutions

- Superior efficiency and scalability
- Lower on-chain storage and computational overhead
- Secure against various random number attacks

Protocol	Platform Consensus	Method(s)	Resistance (t)	# random values (r)	Latency (Consensus round)
Drand [31]	PABFT	Threshold SecretBLS	$t < n/2$	$\mathcal{O}(\sigma)$	≥ 2
HERB [36]	∅	Threshold ElGamal	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
RandChain [56]	Sequential PoW	PoW	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
RandHerd [93]	BFT	Threshold Schnorr	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
RandHound [93]	BFT	Client based, PVSS	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
BRandRiper [19]	BFT	VSS, q-SDH	$t < n/2$	$\mathcal{O}(\sigma)$	≥ 2
Dfinity [2]	BFT	Threshold BLS	$t < n/2$	∞	≥ 2
Secret [24]	DPoS	Scrt-RNG,TEE	$t < n/2$	∞	≥ 2
Elrond [21]	Secure PoS	BLS,onchain data	$t < n/3$	∞	≥ 2
Klaytn [23]	Istanbul BFT	VRF	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
Harmoney [22]	Fast BFT	VRF,VDF	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
⋆Chainlink VRF [35]	∅	VRF, TEE	$t < n/2$	$\mathcal{O}(\sigma)$	≥ 2
⋆Automata [76]	∅	VRF, TEE	$t < n/2$	∞	1
BFTRAND$_{commit-execute}$	BFT	∅	$t < n/3$	$\mathcal{O}(\sigma)$	≥ 2
BFTRAND	BFT	Threshold BLS	$t < n/3$	∞	1§

In the table, n denotes the number of consensus nodes, t is the maximum number of Byzantine nodes allowed in the system, and σ denotes the beacon. **Resistance** refers to the tolerance of the system for Byzantine faults. ⋆ is the off-chain third-party Oracle RNP. ∞ means the number of random numbers is upper-bounded by consensus. §BFTRAND is the first smart contract solution in runtime RNP on a BFT-based blockchain.

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Thank You!

Questions and Comments are Welcome.