Danksharding Workshop

Ethereum Consensus R&D
Ethereum Foundation feat. Optimism
What is Danksharding?

- The latest Ethereum sharding scaling solution.
- “Sharded data” rather than many EVM shard chains.

I'm thinking about a new sharding design, where instead of having independent proposers for each shard, all shard blocks in one slot are proposed together with the beacon block. This leads to a major simplification of the sharding design 1/n

— Dr. Dankrad Feist, 2021
What is EIP-4844 aka Proto-Danksharding?

- A more feasible scaling solution before we address full danksharding’s technical TODOs
- It can greatly scale Ethereum with Layer 2 rollups 🚀
Comparison

EIP-4844
- 1-D KZG scheme
- Blob sidecar

Common
- KZG commitments
- "Blob" transactions
- Point evaluation precompile
- Fee market

Danksharding
- 2-D KZG scheme
- Sharded data
- Proposer Builder Separation (PBS)
- Data availability sampling (DAS)
Agenda

1. **Overview** - Hsiao-Wei Wang
2. **Cryptography in Danksharding** - Dankrad Feist
3. **EIP-4844**
   a. **But what is a blob really?** - George Kadianakis
   b. **Blob TXs and L2** - Protolambda
   c. **Fee Market** - Ansgar Dietrichs
4. **Full Danksharding**
   a. **2D ZKG Commitment** - Dankrad Feist
   b. **Data Availability Sampling (DAS)** - Danny Ryan
   c. **Proposer Builder Separation (PBS)** - Francesco D'Amato
5. **Q&A**
Cryptography in Danksharding

Dankrad Feist
Outline

- Motivation: Data availability sampling and erasure coding
- Finite fields
- “Hashes of polynomials”
- KZG commitments and proofs
- Random evaluations
Motivation: Data availability sampling and Erasure coding
Data Availability Sampling

- Check “random samples” to ensure availability of a data block
- Does not depend on honest majority
- Need to erasure code data, otherwise an attacker can still hide “small” amounts of data
Erasure coding

Original data

| d₀ | d₁ | d₂ | d₃ |

Polynomial extension (degree 3)

| e₀ | e₁ | e₂ | e₃ |

- Extend the data using a “Reed-Solomon code” (= polynomial interpolation)
- Property:
  - Any 50% of the chunks (d₀ to e₃) are sufficient to reconstruct the whole data
- Because of this, we can use random sampling to ensure data availability
  - E.g. query 30 random blocks; if all are available, probability that less than 50% available is $2^{-30}$
Merkle roots as Data Availability Roots

- Need to know data \((d_i)\) and extension \((e_i)\) are on one low-degree polynomial
But if we just use Merkle roots, then we still need to worry about the extension being correct.

Original data

| d₀ | d₁ | d₂ | d₃ |

Polynomial extension (degree 3)

| e₀ | e₁ | e₂ | e₃ |

- This requires fraud proofs
- Fraud proofs aren’t great: They add a lot of complexity and synchronicity conditions

What if we could find a kind of commitment (“Merkle root”) that always commits to a polynomial?

I’ll just make up the extension!!! They will never be able to reconstruct the data!!!
Finite fields
Finite fields: Definition

- **Field**: Think about rational $\mathbb{Q}$, real $\mathbb{R}$ or complex $\mathbb{C}$ numbers
  - You can do all the basic maths: $+, -, *, /$ [except by 0]
  - There are some laws: Associative, Commutative, Distributive
    - but the easiest way to think about it is just “what can you do with rational numbers”

- **Finite**: Unlike $\mathbb{Q}$, $\mathbb{R}$, $\mathbb{C}$, which have an infinite number of elements, finite fields only have a finite number of elements
  - Each element can be represented using the same number of bits
Finite fields: Let’s look at $\mathbb{F}_5$

- Consists of the numbers 0, 1, 2, 3, 4
- Every operation: Do it first in the integers, then the result is the remainder after division by 5 (“modulo” 5)
- Each element (except 0) has a “multiplicative inverse”:

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<td>3 * 2 = (6 = ) 1</td>
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<tr>
<td>4</td>
<td>4</td>
<td>4 * 4 = (16 = ) 1</td>
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- This is because 5 is a prime number (works for any prime)
“Hashing polynomials”
Reminder: polynomials

- A polynomial is an expression of the form
  \[ f(X) = \sum_{i=0}^{n} f_i X^i \]
- The \( f_i \) are the coefficients of the polynomial
- The degree of the polynomial is \( n \) (if \( f_n \) is not zero)
- Each polynomial defines a polynomial function
- For any \( k \) points, there is a polynomial of degree \( k-1 \) or lower that goes through all \( k \) points
- A polynomial of degree \( n \) that is not constant has at most \( n \) zeros
Polynomial commitments: “Hash function” for polynomials

- Imagine a hash function $H(f)$ that takes a polynomial with some extra functionality:
  - For each $z$ you can construct a proof $P(f, z)$, that proves that $f(z) = y$
- $H(f)$ and $P(f, z)$ should be small
Step 1: Choose a random number, say… 3
Step 2: To hash a polynomial, you evaluate it at 3 (set \( X = 3 \)):

- \( f(X) = X^2 + 2X + 4 \rightarrow H(f) = (9 + 6 + 4) \mod 5 = 4 \)
- \( g(X) = 2X^3 + 4X^2 + X + 2 \rightarrow H(g) = (54 + 36 + 3 + 2) \mod 5 = 0 \)

If the modulus has 256 bits, it’s actually very unlikely that two polynomials have the same “hash”, just like for a normal hash function.
Polynomial hashes: Properties of “random evaluation”

- We can add two “polynomial hashes”:
  - \( H(f) + H(g) = H(f + g) \)
  - This is because \( f(3) + g(3) = (f + g)(3) \)

- We can also multiply two “polynomial hashes”:
  - \( H(f) \times H(g) = G(f \times g) \)
  - This is because \( f(3) \times g(3) = (f \times g)(3) \)
The problem with “random evaluation”

- An adversary can easily create a collision if they know the random number

- What we want: a way to use finite field elements inside a “black box”
- Let’s say we have a way to put a secret number in a black box
  - \([s], [s^2], [s^3], \ldots\)
- Such that we can multiply it with another number and add it (but not multiply two numbers in a black box)
Elliptic curves to the rescue

● Elliptic curves are exactly that! A “black box” field element
  ○ Elliptic curve $G_1$ with generator $g_1$ of order $p$
  ○ To represent a field element $x \in \mathbb{F}_p$ multiply the generator with $x$:
    ■ $x \cdot g_1$
  ○ We can add elliptic curve elements ($g$ and $h$) and multiply by field elements ($x$ and $y$):
    ■ $x \cdot g$, $g + h$, $x \cdot g + y \cdot h$ ✔
    ■ $g \cdot h$ ✗
  ○ Notation $[x]_1 = x \cdot g_1$
KZG commitments
KZG (Kate) commitments

- Assume we have the trusted setup \([s^i_1], [s^i_2]\), for \(i = 0, 1, \ldots, n\)
- For a polynomial \(f(X)\) defined by

\[
f(X) = \sum_{i=0}^{n} f_i X^i
\]

we define the KZG commitment to \(f\) as

\[
\sum_{i=0}^{n} f_i [s^i_1] = \sum_{i=0}^{n} [f_i s^i]_1 = \left[\sum_{i=0}^{n} f_i s^i\right]_1 = [f(s)]_1 = C_f
\]
Elliptic curve pairings

- Input: Elements from two elliptic curves $G_1$, $G_2$ and output in the “target group” $G_T$
- Notation: $e(g, h)$
- The pairing is “bilinear”:
  - $e([a*x]_1, [z]_2) = a e([x]_1, [z]_2)$
  - $e([x]_1, [b*z]_2) = b e([x]_1, [z]_2)$
  - $e([x + y]_1, [z]_2) = e([x]_1, [z]_2) + e([y]_1, [z]_2)$
  - $e([x]_1, [z+w]_2) = e([x]_1, [z]_2) + e([x]_1, [w]_2)$
Doing multiplications using pairings

- This means we can do “multiplications”:
  - $e([x]_1, [y]_2) = x e([1]_1, [y]_2) = x * y e([1]_1, [1]_2)$

- Notation: $[x]_T = x e([1]_1, [1]_2)$

- $e([x]_1, [y]_2) = [x * y]_T$
Doing **polynomial** multiplications using pairings

- Now assume we have two polynomials $f(X)$ and $g(X)$
  - Let’s commit to $f(X)$ in $G_1$: $[f(s)]_1$
  - and $g(X)$ in $G_2$: $[g(s)]_2$

- Then:
  - $e([f(s)]_1, [g(s)]_2) = [f(s) \times g(s)]_T$
The last missing piece: Polynomial quotients

- Let $f(X)$ be a polynomial and $y, z$ be field elements
- Then (by the Factor Theorem) the quotient
  \[ q(X) = \frac{f(X) - y}{X - z} \]
  is a polynomial exactly if $f(z) = y$.

  Restating, there exists a polynomial $q(X)$ that fulfills the equation
  \[ q(X)(X - z) = f(X) - y \]
  if and only if $f(z) = y$
The KZG proof

- To prove that \( f(z) = y \), compute

\[
q(X) = \frac{f(X) - y}{X - z}
\]

and send \( \pi = [q(s)]_1 \)

- The verifier checks that

\[
e([f(s) - y]_1, [1]_2) = e([q(s)]_1, [s - z]_2) = [q(s)^* (s - z)]_T = [f(s) - y]_T
\]
Recap: KZG commitment

- Allows us to:
  - **Commit** to any polynomial using a single $G_1$ element $[f(s)]_1$
- Then we can **open** the commitment at any point $z$:
  - Compute $f(z) = y$
  - Compute the quotient $q(X) = \frac{f(X)-y}{X-z}$
  - Proof: $\pi = [q(s)]_1$
- To verify a proof, use the pairing equation
  - $e([f(s)-y]_1, [1]_2) = e([q(s)]_1, [s-z]_2)$
Random evaluations
Recall

- KZG commitments are nothing but
  - “evaluate the polynomial $f$ at a secret point $s$ inside the elliptic curve black box”
- More generally the random evaluation trick can be used to verify polynomial identities
- The reason for this is the “Schwarz-Zippel Lemma”
Schwarz-Zippel Lemma

- Schwarz-Zippel Lemma in one dimension:
  - $f(X)$ polynomial of degree $<n$, $f(X) \neq 0$ (the zero polynomial)
  - Pick random $z \in \mathbb{F}_p$
  - Probability that $f(z) = 0$ is at most $n / p$

- Reason: $f$ can have at most $n$ zeros in $\mathbb{F}_p$
Random evaluation 1: Transaction blob verification

- Computing a KZG commitment is expensive
  - blst, 4096 points: ~50ms
- Verifying a KZG proof is cheaper: ~2ms
- Can we use this to our advantage
Random evaluation 1: Transaction blob verification

- Protocol:
  - Input: $C$ (blob commitment), $f$ (blob data)
  - $z = \text{hash}(C, f)$, $y = f(z)$
  - $\pi$ KZG proof that $f(z) = y$
  - Add $\pi$ to the transaction blob wrapper

- To verify, compute $z = \text{hash}(C, f)$, compute $f(z) = y$ and check $\pi$
Random evaluation 2: Use blob commitments in ZKRollups

- ZKRollups can use many different proof schemes
- Only a handful will be able to natively incorporate BLS12_381 based KZG commitments
- How can others make efficient use of blob commitments?
Random evaluation 2: Use blob commitments in ZKRollups

- Protocol:
  - Input: $C$ (blob commitment), $R$ (native rollup blob commitment), $f$ (blob data)
  - $z = \text{hash}(C, R)$, $y = f(z)$
  - $\pi$ KZG proof that $f(z) = y$
  - Use $z$, $y$ and $\pi$ in the blob evaluation precompile

- Inside the proof, verify that $y = f(z)$ and $R$ is the commitment corresponding to $f$
Further reading materials

● Elliptic curve pairings: https://vitalik.ca/general/2017/01/14/exploring_ecp.html

● How to use KZG commitments in rollup proofs: https://notes.ethereum.org/wLhOjzu1ROqTvLqX5vTCCq

● Alternatives to KZG: https://ethresear.ch/t/arithmetic-hash-based-alternatives-to-kzg-for-proto-danksharding-eip-4844/13863

● This, “in a blog post”: https://dankradfeist.de/ethereum/2020/06/16/kate-polynomial-commitments.html

EIP-4844
Avg Transaction Fee Share by Contributor  Optimism - L1 Batch Submission Fees

Dune

L1 Data Fees
L2 Execution Fees
But what is a blob really?
\[a_n x^n + a_{n-1} x^{n-1} + \cdots + a_2 x^2 + a_1 x + a_0\]
\( p(x) = x^3 + 4x^2 + x + 6 \)
$a_n x^n + a_{n-1} x^{n-1} + \cdots + a_2 x^2 + a_1 x + a_0$

$0 \leq a_i < 52435875175126190479447740508185965837690552500527637822603658699938581184513$

254 bits plus some change (a bit more than 31 bytes)

A polynomial with 4096 coefficients can fit ~128kb
$$p(1) = 1$$

$$p(2) = 4$$

$$p(3) = 1$$

$$p(4) = 6$$

$$p(x) = 34x^3 + 19x^2 + 39x + 30$$

working mod 97
p(x) \rightarrow \text{KZG commit} \rightarrow \text{KZG commitment}

the commitment is a G1 point in BLS12-381 (48 bytes)
Verifier accepts only if $p(x) == q(x)$
p(x) → KZG prove → Proof p(z) = y → True/False

KZG commitment → KZG verify → Proof p(z) = y → the proof is also a G1 point (48 bytes)
Is $p(x) = q(x)$?

Is $p(z) = q(z)$ for random $z$?
Blob TXs and L2
EIP-1559 transaction

Same functionality as EIP-1559 tx, including calldata

EIP-4844 extends it with two fields: data, fee

Separate the signature

Keccak256

Cheaper to verify than to recompute commitments

MAX_DATA_GAS_PER_BLOCK = 2**21
LIMIT_BLOBS_PER_TX = 2**24

1 Blob = 40,960 field elements = ~ 128 KB

Enables us to batch-verify blob commitments

Separate blobs

Point to blobs
Same functionality as EIP-1559 tx, including calldata

EIP-4844 extends it with two fields:
- data fee
- data hashes

Separate the signature

Cheaper to verify than to recompute commitments

\[
\text{MAX} \text{ DATA GAS PER BLOCK} = 2^{21} \\
\text{LIMIT_BLOBS_PER_TX} = 2^{24}
\]

1 Blob = 4096 Field elements = ~ 128 KB

Enables us to batch-verify blob commitments
No direct blob-content in EVM
**Blob Lifecycle**

- **L2 Transaction**
- **L2 TX bundle or state diff**
- **Blob TX w/ embedded blobs data**
- **Blob TX in exec payload + blobs sidecar**
  - Exec payload stays in L1
  - Blobs available for 1 month
  - L2 Persists

**Roles**
- L2 User
- Rollup operator
- L1 TX Pool
- Beacon chain
- For L2 usage
- Forever after
How do rollups work with 4844?
Simplified
ZK validity proof
Part 1/2

Proof of equivalence (simplified):

Step 1: Proof **secure random** point in blob data
Simplified ZK validity proof

Part 2/2

Step 2: Proof same point is in ZK data

verify ZK validity proof

persist ZK commitment

ZK curve util

point-index, point-value, commitment, proof

check index range

check value range

verify proof

ZK validity proof verifier

rollup specific

return or revert

return or revert

ZK commitment (pop stack)

SSTORE opcode
Simplified Interactive Fraud proof

Pre-image oracle

prepared by challenger/proposer

pre-image data

Point evaluation precompile

versioned hash, point-index, point-value, commitment, proof

check index range

check value range

check commitment matches hash

verify proof

return or revert

SLOAD, or transient storage: hold onto verified pre-images

Update VM memory

blob hash, value index

piece of L2 input data, or revert

Load piece of L2 input data from L1

Single-step verifier
Ansgar Dietrichs

Fee Market
# Ethereum Resources

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# Ethereum Resources

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## Ethereum Resources

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**burst limits**  **sustained limits**
### Ethereum Resources

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**burst limits**  **sustained limits**
Possible resource usage (today)
Possible resource usage (ideal)
PR 5707: Fee Market Update

Introduce **data gas** as a second type of gas, used to charge for blobs (1 byte = 1 data gas)

Data gas has its own EIP-1559-style dynamic pricing mechanism
fee changes

max blobs

target blobs

no blobs
PR 5707: Fee Market Update

Introduce **data gas** as a second type of gas, used to charge for blobs (1 byte = 1 data gas)

Data gas has its own EIP-1559-style dynamic pricing mechanism:

- **MAX_DATA_GAS_PER_BLOCK**, target half of that
- **transactions specify** `max_fee_per_data_gas`
- no separate tip for simplicity
- **MIN_DATA_GASPRICE** so that one blob costs at least ~0.00001 ETH
- **track** `excess_data_gas` instead of basefee
def calc_data_fee(tx: SignedBlobTransaction, parent: Header) -> int:
    return get_total_data_gas(tx) * get_data_gasprice(header)

def get_total_data_gas(tx: SignedBlobTransaction) -> int:
    return DATA_GAS_PER_BLOB * len(tx.message.blob_versioned_hashes)

def get_data_gasprice(header: Header) -> int:
    return fake_exponential(
        MIN_DATA_GASPRICE,
        header.excess_data_gas,
        DATA_GASPRICE_UPDATE_FRACTION
    )
## Ethereum Resources

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**burst limits**  **sustained limits**
Full Danksharding
2D ZKG Commitment

Dankrad Feist
KZG 2d scheme

- Why not encode everything in a single KZG commitment?
  - Needs a supernode (“builder”) to build AND to reconstruct in case of failure
  - We want to avoid this assumption for validity
- Goal: Encode $m$ shard blobs using KZG commitments
  - If we do this naively, need $m \times k$ samples – that’s a lot
  - Instead, we can use Reed-Solomon codes again to extend the $m$ commitments to $2^*m$ commitments
These 8 commitments lie on a polynomial of degree 3 (i.e., determined by the four data commitments)
KZG 2d scheme math

- 2D polynomial

\[ f(X, Y) = \sum_{i=0}^{n} \sum_{j=0}^{m} f_{ij} X^i Y^j \]

- Evaluate at row \( k \) (\( Y=k \))

\[ f_k(X) = \sum_{i=0}^{n} \sum_{j=0}^{m} f_{ij} X^i k^j \]

- Commitment to row \( k \) (\( Y=k \))

\[ [f_k(s)]_1 = [\sum_{i=0}^{n} \sum_{j=0}^{m} f_{ij} s^i k^j]_1 = C(k) \]

- Result: Commitments are “on a polynomial”
KZG 2d scheme commitment

- Commit to $2m$ rows $C(0), \ldots, C(2m-1)$
- Can verify all commitments are on a polynomial using “random evaluation” trick
  - Evaluate $C(0), \ldots, C(m-1)$ at random point and the same for $C(m), \ldots, C(2m-1)$
  - If same result, then valid commitment to polynomial of degree $m-1$

- Compare to 2d KZG commitment using setup of the form $[s^i t^j]$:  
  - Requires quadratic size setup
  - No direct correspondence between blob transactions and commitment (needs additional proof)
  - Samples require 2 step proof (row + column)
KZG 2d scheme properties

● All samples can be verified directly against commitments. No fraud proofs!
● Constant number of samples ensures probabilistic data availability
● If 75% of samples are available:
  ○ All data is available
  ○ It can be reconstructed from validators who observe only rows and columns
  ○ No node observing the full square is necessary
Danksharding honest majority validation

- Each validator picks $r = 2$ random rows and columns.
- Only attest if the assigned row/column are available for the entire epoch.
- An unavailable block (<75% available) cannot get more than $2^{-2r} = 1/16$ attestations.
Danksharding reconstruction

- Each validator should reconstruct any incomplete rows/columns they encounter.
- While doing so, they should transfer missing samples to the orthogonal lines.
- Each validator can transfer 4 missing samples between rows/columns (ca. 55,000 online validators guarantee full reconstruction).
Danksharding DA sampling (malicious majority safety)

- Future upgrade
- Each full node checks 75 random samples on the square
- This ensures the probability for an unavailable block passing is $< 2^{-30}$
- Bandwidth $75 \times 512 \text{ B} / 16\text{s} = 2.5 \text{ kb/s}$
Data Availability Sampling (DAS)

Danny Ryan
The blockchain scalability trilemma

- It is difficult to design a blockchain that provides scalability, security and decentralization.
The blockchain scalability trilemma

- It is difficult to design a blockchain that provides scalability, security and decentralization.
The blockchain scalability trilemma

Execution

Bandwidth
The blockchain stack

- Execution
- Settlement
- Data Availability
- Consensus
The blockchain stack

- Execution
- Settlement
- Data Availability
- Consensus

Scaling required!
The blockchain stack

Execution
Settlement
Data Availability
Consensus

Scalability from Rollups: Fraud proofs or Validity proofs (“zk”)
The blockchain stack

- Execution
- Settlement
- Data Availability
- Consensus

Data Availability Sampling
The data availability problem

Definition:

Data availability means that no network participant, including a colluding supermajority of full nodes, has the ability to withhold data.

- Current blockchains:
  - All full nodes download all the data (impossible to withhold data)
- How to make this scalable?
  - Scalable means that the work required should be less than downloading the full blocks, e.g. constant or a logarithmic amount of work.
Data availability
= Assurance data was not withheld
= Assurance data was published
Data availability
≠ Data storage
≠ Continued availability
This sounds like an unimportant detail. Is it really that important?

Let’s look at our two scalable execution options:

- Optimistic rollups (using fraud proofs):
  - Any missing data could be fraudulent, e.g., a state change printing 1 trillion Ether. All data needs to be available unconditionally or fraud proofs cannot be constructed.

- ZKRollups (using validity proofs):
  - Missing data can contain an update to your account. If you don’t know how to access your account (missing witness), you will lose access.
Network models
Neutral network model

Neutral P2P network

Block producer
Consensus nodes

Sampling nodes
The “neutral network” model

- Very attractive due to the individual security guarantee it can give
  - Any node doing DAS can get “statistical security”
  - E.g. Probability that unavailable block passes check $<10^{-9}$
- But it seems unrealistic in context of other security assumptions
  - Remember that DAS is required to protect against a malicious consensus majority
  - An attacker that is able to control the consensus majority but not large fractions of the network seems unrealistic!
Attacking network model

Attacker controlled P2P network

Block producer
Consensus nodes

Sampling nodes
The attacker controlled network model

- In this model, we assume that the attacker does not only control consensus, but can also control the P2P network.
- This cannot provide guarantees for individual nodes because the attacker can simply feed the samples to your node while withholding from all other nodes.
- The guarantee therefore becomes a collective guarantee:
  - The attacker cannot fool more than a fixed number of sampling nodes.
  - Example: 10k samples per block, nodes sample 100: Cannot fool more than 100 nodes.
- Likely “correct” model, but makes the problem harder.
P2P problem
P2P for DAS goals

● We want a P2P data structure that:
  ○ Can reliably serve samples
  ○ Low overhead on nodes
  ○ Is robust against attacks
    ■ Liveness attacks (e.g. DOS)
    ■ Network splitting attacks (some nodes see samples while others don’t)
  ○ Low latency (seconds)
P2P for DAS challenges

- Sample dissemination into P2P structure
- Support queries of disseminated sample for X time
- Identify and reconstruct missing data
Actors involved for DAS

● Builders
  ○ original source of data

● Validators
  ○ Have rows/columns
  ○ Also perform DAS

● Users
  ○ Perform DAS
  ○ Hopefully leveraged in serving
DAS Desiderata

- Data size – 32MB (128MB)
- Chunks (samples) per block – ~250k
- Samples per node – 72
- Latency –
  - Vals in 4s
  - Users in 12s (1 slot) [can we relax this?]
- Nodes
  - 4k to 100k val nodes
  - 100k to 1M user nodes
- Bandwidth assumption
  - 10 to 25 Mbps?
- Persistence
  - 2 epochs? 2 weeks?
Idea 1: Supernode model (Celestia)

- Nodes request samples from their peers
- Some peers are supernodes so able to provide all samples
  - Supernodes will send each other full blocks so work the same as traditional blockchain P2P nodes
- Leveraging Ethereum validator row/columns looks similar
Supernode model

- **Good**
  - Can be realized using well established, robust P2P paradigms
    - Assumption: Connected to one honest supernode
  - If validators=supernodes, good liveness as long as honest majority present (best we can hope anyway)

- **Bad**
  - Does not fit well with Ethereum node model
  - Validators should not require a lot of resources (Raspberry Pi)
    - Solution could be paid supernodes (very significant change in P2P model)
Idea 2: Plain DHT

- Distributed Hash Tables (DHT) like Kademlia can provide random access to data without requiring any one node to store much of it
Plain DHT

- **Good**
  - Fits well with Ethereum network model (no supernodes)
  - Excellent scalability

- **Bad**
  - Prone to liveness attacks
    - Tables can be flooded locally (key range) or globally
    - Any malicious node can only return malicious nodes and break the lookup
Idea 3: Secured DHT

- S/Kademlia and other hardened DHTs can provide some security guarantees provided that there is a Sybil resistance mechanism.
- We can bootstrap this from the validator set and maybe other sets.
**Secured DHT**

- Create primary DHT using all nodes
  - This provides good "average case performance" when no attack is happening
- Create secondary DHT using S/Kademlia on validator set
  - Has liveness as long as majority of validators are honest
Secured DHT

● Good
  ○ Fits well with Ethereum network model (no supernodes)
  ○ Good scalability
  ○ Resistance to liveness attacks (unless initiated by validators)

● Bad
  ○ Validators need to do more work than other nodes
    ■ To protect against DOS attacks they cannot serve unlimited requests
    ■ This leads to a two tier network (validators have better liveness guarantees than other nodes)
    ■ To remedy, can create other subnets with alternative Sybil protection (Ethereum addresses, Proof of Humanity, etc.)
  ○ Validator privacy and optionality
Proposer Builder Separation (PBS)

Francesco D’Amato
What is PBS?
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**Proposing**: the process of extending the Beacon Chain with a new Beacon block, which includes important consensus messages. *Hardly any specialization, low requirements*
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Proposing: the process of extending the Beacon Chain with a new Beacon block, which includes important consensus messages. *Hardly any specialization, low requirements*

PBS separates the two: proposers outsource the specialized activities to builders
Why PBS?
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Danksharding (simplification)

The proposer is tasked with quickly computing the commitments and distributing the entirety of the data (up to 128 MBs). Prohibitive upstream and CPU requirements for a home staker.
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**Danksharding (simplification)**

The proposer is tasked with quickly computing the commitments and distributing the entirety of the data (up to 128 MBs). Prohibitive upstream and CPU requirements for a home staker.

**MEV (fundamental)**

The proposer has a temporary monopoly on the execution payload, which generates significant profit opportunities, requiring sophistication (algorithmic, infrastructural) and access to order flow to be realized.
PBS today: MEV-Boost

1. Send payload
2. Send header
3. Send proposal
4. Broadcast
What’s missing?
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Relays are trusted parties, need to be (locally) whitelisted and monitored for misbehavior.
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With Danksharding, catastrophic relay failure is a threat to network liveness: few points of failure.
Two-slot PBS

- Exec headers
- Beacon block
  - Attestation agg sigs
  - Other stuff
  - Winning exec header
- Attestations on header (only one committee)
- Intermediate block
  - Attestation agg sig
  - Exec block body
  - Builder sig
- Intermediate block deadline
- Attestations on body (N-1 committees)
- Aggregation on body (N-1 committees)
- Beacon block
  - Attestation agg sigs

Body and builder identity must match header.
“In-protocol MEV Boost”

1. Send header
2. Send signatures
3. Send header + aggregate sig
4. Send proposal
5. Decrypt and broadcast
Danksharding and censorship-resistance

PBS (in or out of protocol) degrades censorship resistance, but there are good options to safeguard it: inclusion lists.

Inclusion lists are simple if validators have the ability to easily determine the availability and validity of transactions.

With Danksharding, determining availability of transactions needs some sharded mempool construction. Possibly, only transactions which are being censored would need to go through it.
Q&A
Thank you

Ethereum Foundation
Optimism