

Validator Economics: Variable min validator deposit size

EF Academic Grant ID: FY23-1030

DRAFT MODEL, CHALLENGES & POTENTIAL MITIGATIONS (MAXEB - EIP-7521)

Sandra Johnson
ConsenSys Software R&D

September 15, 2023

1 Overview

This document builds on the previous document, *Milestone 1(EB): Review & analyse EIP-7521*, addressing each of the identified challenges and applying example scenarios to the expected behaviour cited in blog posts and analysis done to date.

In summary as mentioned in the previous document, the two key criteria we need to assess for this proposal, and indeed for any proposed strategy to reduce, or cap, the validator set size, are the risks and benefits introduced by that proposal.

With respect to EIP-7521:

- **Risks:** Are risks are being introduced by this proposal? Are there adverse affects on some categories of stakers, or the Ethereum ecosystem?
- **Benefits:** Do all staker categories benefit equally from EIP-7521? Apart from the expected reduction in network load, are there other benefits to the health of the ecosystem?

We need to bear in mind that regardless of the risks and benefits, EIP-7521 relies on stakers' willingness to consolidate at least some of their validators. Therefore the messaging around the benefits of consolidation and the perception that the benefits to stakers and the ecosystem definitely outweigh any perceived risks needs to be compelling.

The impact on staking pools, their operational business models, and software changes required to take advantage of the increased maximum will need to be discussed with stakeholders effective balance (EB).

2 Challenges & Additional analysis requirements

In addition to the advantages and disadvantages highlighted in the *ethresear.ch* post, *Increase the MAX_EFFECTIVE_BALANCE – a modest proposal*, by Neuder et al [34], we propose additional questions and analysis below:

1. *Proposer selection probability:* Demonstrate that this probability remains unchanged and will not unduly disadvantage small-scale solo stakers [34].

2. *Sync committee selection*: Demonstrate that this selection process works as designed even when there is a large increase in MaxEB [34].
The denominator for the acceptance probability is MaxEB which means the probability will change from $\frac{b}{32}$ to $\frac{b}{2,048}$, where $b = \text{validator effective balance}$. Check whether this adversely affects validators with a small stake, apart from the expected increase in time to select the committee, as D’Amato and Neuder pointed out [14].
3. *Slot committees*: Demonstrate that not taking validator weight into account does not have any adverse downstream effects. D’Amato and Neuder state that even if one “attestation is majority adversarial”, then the worst that can happen is that the attacker will execute a local reorg [14]. Explore in more detail, e.g. use an example or two, to ascertain the effect of variations in slot committee balances with the inclusion, or omission, of fully consolidated stakers.
4. *Worst case: Full consolidation*: D’Amato and Neuder identify full consolidation as the worst case scenario when we consider two groups of validators: honest and adversarial validators. Several reasons are given for this conclusion [14]. Using examples or other approaches we need to check the veracity of these statements, viz. that full consolidation:
 - increases the probability that one or more committees will be majority dishonest
 - increases the variance of adversarial balances
 - increases the variance of the distribution of adversarial weight over committees
 - due to the above, it follows that it is more likely that there will be “a positive deviation from the expected adversarial weight in a committee”. Apparently although there may also be “negative deviations” the adversarial party is not concerned because it merely aims to control at least one committee.
 - On the other hand, full consolidation of honest validators maximises the risk of negative deviations from the expected committee weight.
 - Honest validators benefit from spreading weight evenly across the committees because it minimises the risk of negative deviations.
5. *Aggregator selection*: Does the selection of more than one virtual validator of a consolidated validator change the probability distribution of sub-committees? Could the probability of fewer than 16 distinct aggregators increase?
6. *Virtual validators*: D’Amato and Neuder’s conjecture is that treating consolidated validators as several ‘virtual’ validators yields two main benefits [14]. Demonstrate the correctness of these statements.:
 - The total number of aggregators is unchanged, because one consolidated validator would account for only one aggregator.
 - The probability of at least one honest validator is equivalent to the current probability, because the introduction of virtual validators means that the probability of selecting an honest aggregator is the same as it is currently. The total number of honest validators prior to EIP-7251 is the same as the number of virtual and unconsolidated honest validators.
7. *Whistleblower reward*: Currently the proposer receives both the whistleblower reward and the proposer reward. Moreover, the whistleblower reward is proportional to the slashed validator’s effective balance. How is this reward influenced by the increased maximum effective balance?

8. *Slashing penalties*: Verify the suitability of the suggested changes to slashing penalties (initial and correlation penalties), as well as those penalties remaining unchanged (attestation and inactivity leak penalties), proposed by Neuder and Monnot [35] using working examples, or other approaches.

Moreover, based on the severity of the changed slashing penalties, what situation constitutes an attack on the chain? How do we assess whether the penalties are sufficient to deter adverse behaviour? Are the proposed changes too lenient for large stakers?

9. *Bayesian network model*: Build a Bayesian network (BN) to capture current factors and interactions, including distributions around factors such as uptake of consolidation, current distribution of different categories of stakers, etc.

Use the BN model to gain insight into questions such as:

- What does the landscape look like if there is no consolidation, but some or all validators decide to compound their rewards? Is this a good or desirable outcome?
- Create some example scenarios that include solo, partial and fully consolidated stakers and how different compositions translate to the selection of validators for specific duties and ideally the probability of dishonest committees.

10. *Discouragement attacks*: Investigate potential griefing, or discouragement, attacks.
11. *Consolidating validators*: There are many challenges around exiting and activation of validators for consolidation. Therefore, as Asgaonkar points out, in-protocol consolidation needs to be in place [5].

In summary it is important to ensure that small scale solo-stakers are not unduly disadvantaged with the introduction of a 2,048 ETH MaxEB, in terms of proposer selection etc. which may disincentivise the commitment to running a validator. What is being compromised to enable consolidation? Are there other aspects we have not considered? What are the negatives for solo stakers who are considered to be the backbone of Ethereum? Does MaxEB swing it too much in favour of large stakers?

3 Analysis

3.1 Proposer selection

3.2 Sync committee selection

3.3 Slot committees

3.4 Worst case: Full consolidation

3.5 Aggregator selection

For the existing distribution of the expected number of aggregators per sub-committee, refer to Edgington's online book [16]. If more than one of the virtual validators of a consolidated validator is chosen, then it is still just that one validator in the set of aggregators.

3.6 Virtual validators

3.7 Slashing penalties

In the blogpost Neuder and Monnot propose the following for current slashing penalties [35]:

- Changes to existing penalties:
 - Changing the *initial penalty* to be either fixed, or scaled sublinearly
 - Changing the *correlation penalty* to scale quadratically rather than linearly.
- Unchanged penalties:
 - *Attestation penalties*
 - *Inactivity leak penalties*

Initial slashing penalty

The initial slashing penalty is proportional to the validator’s effective balance, with a maximum penalty of 1 ETH if the slashed validator has 32 ETH, the current MaxEB. If left unchanged, a fully consolidated validator would incur an initial slashing penalty of 64 ETH.

Neuder and Monnot suggest that this penalty could either be changed to a constant value, or through a monotonically increasing function, e.g. from the family of polynomials. The latter appears to be the preferred option.

The authors propose the following function to calculate the new initial slashing penalty:
initial penalty = $\frac{EB^x}{32}$, $x \leq 1$

In their blog post they have graphs for $x = 1, \frac{15}{16}, \frac{7}{8}, \frac{3}{4}, \frac{1}{2}$ and a line for a constant initial penalty of 1 ETH [35].

The authors conclude that visually it appears that $x = \frac{3}{4}$ and $\frac{7}{8}$ are good choices in terms of balancing the size of the initial slashing penalty and the risk for a consolidated validator.

Correlation penalty

This penalty is incurred roughly 18 days (4,096 epochs) after the slashing event, half way between its exit epoch and the slashing event [16]. The correlation penalty is important in penalising apparent coordinated attacks on the chain, and is the only other penalty that Neuder and Monnot propose to alter [35].

The penalty for a slashed validator is calculated as follows using the previous 36 days from this “half-way” epoch.

$$\text{correlation penalty} = \left\lfloor \frac{3 * EB * SB}{TB} \right\rfloor, \text{ where}$$

3 = Bellatrix multiplier

EB = slashed validator’s effective balance

SB = total slashable balance

TB = total effective balance of the beacon chain

$$\therefore \text{ if } SB = \frac{1}{3} * TB \implies \text{ correlation penalty} = EB$$

Similarly, if $3 * EB * SB < TB \implies \text{ penalty} = 0$ due to integer division

There is currently no correlation penalty for isolated slashing events and this continues to be the case for a fully consolidated validator with 2,048 ETH effective balance as shown below using 24 million ETH as the total staked ETH, (TB):

$$\begin{aligned}
& SB = EB \text{ for an isolated slashing} \\
& \therefore 3 * EB * SB = 3 * EB * EB \\
& \text{Assuming } EB = 2,048 \text{ \& } TB = 2.4 * 10^7, \text{ then} \\
& 3 * EB * EB = 1.2582912 * 10^7 < 2.4 * 10^7 \\
& \therefore \text{penalty} = 0
\end{aligned}$$

For EIP-7521 the authors propose a function that preserves the requirement that when the total slashed balance is $\frac{1}{3}^{rd}$ of the total balance, the entire balance of the validator is slashed:

$$\begin{aligned}
& \text{penalty}' = \frac{3^2 * EB * SB^2}{TB^2} \\
& \therefore \text{if } SB = \frac{TB}{3}, \text{ then} \\
& \text{penalty}' = \frac{3^2 * EB * \left(\frac{TB}{3}\right)^2}{TB^2} \\
& \therefore \text{penalty}' = EB
\end{aligned}$$

Moreover, the new correlation penalty function scales quadratically as opposed to the current function that scales linearly. With the proposed new function, the slashing penalties are substantially reduced for all validators, regardless of whether they have consolidated stake.

Refer to the blogpost to view graphs showing the comparative correlated slashing penalties for solo (32 ETH), partially consolidated (256 ETH), and fully consolidated (2,048 ETH) validators applying both the current and the proposed functions [35].

Attestation penalty

Once a validator is slashed, their attestations (source, target and head votes) are deemed to be invalid and hence they incur attestation penalties for 8,192 epochs until their exit epoch.

Different weights are attached to each vote, but only the source (weight = 14) and target (weight = 26) votes incur penalties. For each of the 8,192 epochs the slashed validator will incur:

Given :

$$\text{base reward} = \frac{64}{\left\lceil \sqrt{TB} \right\rceil}, \text{ weight denominator} = 64,$$

$$\text{source weight} = 14 \ \& \ \text{target weight} = 26$$

$$\therefore \text{epoch attestation penalty} = \frac{\text{base reward} * EB * (14 + 26)}{64}$$

$$\therefore \text{ if } TB \approx 24 \text{million ETH} = 2.4 * 10^6 * 10^9 \text{ Gwei}$$

$$\text{the integer square root of } 2.4 * 10^6 * 10^9 \text{ Gwei} = 154,919,333$$

$$\text{base reward} = \frac{64 * 10^9}{154,919,333} = 413 \text{ Gwei}$$

\therefore for a **solo staker** with 32 ETH:

$$\text{total attestation penalty for 8,092 epochs} = 8192 * \frac{413 * 32 * 40}{64} \text{ Gwei} \approx 0.06767 \text{ ETH}$$

for a **fully consolidated** validator with 2,048 ETH:

$$\text{total attestation penalty for 8,092 epochs} = 8192 * \frac{413 * 2048 * 40}{64} \text{ Gwei} \approx 4.331 \text{ ETH}$$

This attestation penalty for a large slashed staker seems acceptable, but could potentially be adjusted by changing the number of epochs that the validator is deemed as being “offline”. The size of this penalty needs to be such that the security model is not compromised. In other words it should never be a better option to self-slash to avoid inactivity penalties. Therefore, it needs to be greater than the inactivity penalties for an unslashed validator that is exiting and offline [35].

Inactivity leak penalty

An *inactivity leak* is signalled by the protocol when the chain has not been finalising for 4 epochs. During an inactivity leak online validators will not be penalised, so although no rewards are being earned, the penalty is 0.

On the other hand, offline validators, which includes slashed validators waiting to exit, start ‘leaking’ state. The loss of stake means that the relative weight of the online validators will increase, which helps the chain to start finalising again. The inactivity penalty can be quite severe.

Using the current method, the authors calculated the penalty for three different effective balances: 32 ETH (solo validator), 256 ETH (partially consolidated validator), and 2,048 ETH (fully consolidated validator).

Table 1: Inactivity leak penalties

validator size	16 epoch leak	128 epoch leak	1024 epoch leak
32 ETH	0.000259 ETH	0.0157 ETH	1.00 ETH
256 ETH	0.00208 ETH	0.126 ETH	8.01 ETH
2048 ETH	0.0166 ETH	1.01 ETH	64.1 ETH

3.8 Whistleblower reward

3.9 Bayesian network model

We build a BN model to capture the key factors and interactions for an increase in MaxEB as proposed in EIP-7521.

We assume that different groups, or categories, of stakers have different characteristics which will in turn influence their willingness to consolidate stake, as well as the uptake of validator consolidation.

3.10 Key factors

Staker categories

Vitalik Buterin suggested potential categories as follows:

- Small-scale solo stakers (32 - a few hundred ETH)
- Large-scale individual solo stakers (1000+ ETH)
- Large-scale institutional solo stakers (ie. companies staking their own ETH)
- Centralised staking pools
- Semi-decentralised staking pools (Rocketpool, Lido... each one is different)
- Each of the above, but using distributed validator technology (DVT)

Although each of the categories will differ with the use of DVT, we do not anticipate that DVT will influence their behaviour with respect to validator consolidation in any meaningful way.

It will be challenging to assign a distribution across the proposed staker categories. However with current work on identifying validators, we would be able to assign some validators to staker categories and for those that are unknown, we can either replicate the distribution across the validators, or adjust them based on an assumption on the probability distribution across the unknown group. With the BN we can also apply other distributions and see to what extent they affect the downstream probabilities.

Validator consolidation

The implementation of EIP-7521 is likely to eventuate in a varying degree of consolidation within and across the various categories. We can use intuition for an initial uptake and vary this to test the downstream consequences of various scenarios.

3.11 Griefing/discouragement attacks

According to Buterin a griefing attack is when a validator acts maliciously inside a consensus mechanism to reduce other validators’ revenue even at some cost to themselves to encourage the victims to drop out of the mechanism [8].

The two main motivations for reducing the number of participants are most likely because fewer participants:

- mean greater rewards for those remaining in the mechanism
- helps to prepare an attack on the chain by reducing the cost of an attack

Some strategies have already been put in place to avoid discouragement attacks [16]:

- inverse square root scaling of validator rewards
- scaling of rewards with participation (viz. for each “source, target, and head vote, the attester’s reward is scaled by the proportion of the total stake that made the same vote”)
- zeroing attestation rewards during an inactivity leak
- rate limiting of validator exists, which means that an attacker needs to sustain an attack for longer and at greater cost in order to achieve the same outcome.

3.12 Centralisation forces

Centralisation needs to be assessed within the context of this grant and the proposed increase in maximum effective balance, especially with respect to large stakers and staking pools.

3.13 Health of the Ethereum ecosystem

Ether alpha combines various aspects of the ecosystem to give an overall impression of the health of the network. They pull information from various sources for ‘Project Sunshine’ dashboard [3].

Historic and current trends for stake concentration are important to observe as these are warning signs that the chain is becoming more vulnerable to collusion. The consolidation of stake through EIP-7251 (currently in draft form) [32] is unlikely to change the dynamics of stake concentration, since it is encouraging consolidation of validators already being operated by stakers. However, with more node operators and validators joining larger staking pools staked ETH will become more one-sided in favour of staking pools.

The Rated network also provides detailed metrics and visualisations to gauge the health of the network [31].

4 Bibliography

References

- [1] Laurence Aitchison, Nicola Corradi & Peter E Latham (2016): *Zipf’s Law Arises Naturally When There Are Underlying, Unobserved Variables*. *PLoS computational biology* 12(12), p. e1005110, doi:10.1371/journal.pcbi.1005110.
- [2] Ether alpha (2023): *Client diversity: Resource site to assist in Ethereum client diversity efforts*. Available at <https://clientdiversity.org/>.

- [3] Ether alpha (2023): *Project Sunshine*. Available at <https://ethsunshine.com/>.
- [4] Ether alpha (2023): *Validator queue: Dashboard to monitor validator enter/exit queues and wait times*. Available at <https://www.validatorqueue.com/>.
- [5] Aditya Asgaonkar (2023): *Removing Unnecessary Stress from Ethereum's P2P Network*. Available at <https://ethresear.ch/t/removing-unnecessary-stress-from-ethereums-p2p-network/15547>.
- [6] Andrew Breslin (2022): *What is staking?* Available at <https://consensys.net/blog/ethereum-2-0/what-is-staking/>.
- [7] Vitalik Buterin (2017): *The Meaning of Decentralization*. Available at <https://medium.com/@VitalikButerin/the-meaning-of-decentralization-a0c92b76a274>.
- [8] Vitalik Buterin (2018): *Discouragement Attacks*. Available at <https://eips.ethereum.org/assets/eip-2982/ef-Discouragement-Attacks.pdf>.
- [9] Vitalik Buterin (2023): *Don't overload Ethereum's consensus*. Available at https://vitalik.ca/general/2023/05/21/dont_overload.html.
- [10] Vitalik Buterin (2023): *Paths toward single-slot finality*. Available at https://notes.ethereum.org/@vbuterin/single_slot_finality.
- [11] Rajan Chattamvelli (2020): *Discrete distributions in engineering and the applied sciences*. Synthesis lectures on mathematics and statistics ; 34, Morgan & Claypool Publishers.
- [12] Liquid Collective (2023): *Ethereum's activation and exit queues*. Available at <https://liquidcollective.io/eth-activations-and-exits/>.
- [13] Matt Corva & Bill Hughes (2023): *Staking is Data Validation, Not Investment*. Available at <https://consensys.net/blog/news/staking-is-data-validation-not-investment/>.
- [14] Francesco D'Amato & Mike Neuder (2023): *Security Considerations and Spec Changes for a MAX_EFFECTIVE_BALANCE Increase*. Available at <https://notes.ethereum.org/@fradamt/meb-increase-security>.
- [15] dapplion (2023): *Ethereum specs pull request: Add upper epoch churn limit #3448*. Available at <https://github.com/ethereum/consensus-specs/pull/3448>.
- [16] Benjamin Edgington (2023): *A technical handbook on Ethereum's move to proof of stake and beyond*. Technical Report. Available at <https://eth2book.info/latest>.
- [17] ethereum.org (2022): *Pooled staking*. Available at <https://ethereum.org/en/staking/pools/>.
- [18] ethereum.org (2022): *Solo staking*. Available at <https://ethereum.org/en/staking/solo/>.
- [19] ethereum.org (2022): *Staking as a service (Saas)*. Available at <https://ethereum.org/en/staking/saas/>.
- [20] ethereum.org (2022): *Staking with Ethereum*. Available at <https://ethereum.org/en/staking/>.

- [21] Etherscan (2023): *BeaconScan: The Official Etherscan Beacon Chain Ethereum 2.0 Explorer*. Available at <https://beaconscan.com/>.
- [22] Adem Efe Gencer, Soumya Basu, Ittay Eyal, Robbert Van Renesse & Emin Gün Sirer (2018): *Decentralization in Bitcoin and Ethereum Networks*. Technical Report, Berlin, Heidelberg. arXiv:1801.03998v2.
- [23] Hex (2023): *Lido on Ethereum Validator & Node metrics*. Available at <https://app.hex.tech/8dedcd99-17f4-49d8-944e-4857a355b90a/app/3f7d6967-3ef6-4e69-8f7b-d02d903f045b/latest>.
- [24] Charles I Jones (2015): *Pareto and Piketty: The Macroeconomics of Top Income and Wealth Inequality*. *The Journal of economic perspectives* 29(1), pp. 29–46.
- [25] Aris Koliopoulos (2023): *Solo stakers: The backbone of Ethereum*. Available at <https://blog.rated.network/blog/solo-stakers>.
- [26] Dániel Kondor, Márton Pósfai, István Csabai & Gábor Vattay (2014): *Do the rich get richer? An empirical analysis of the Bitcoin transaction network*. *PloS one* 9(2), pp. e86197–e86197.
- [27] Qinwei Lin, Chao Li, Xifeng Zhao & Xianhai Chen (2021): *Measuring Decentralization in Bitcoin and Ethereum using Multiple Metrics and Granularities*, pp. 1–8. arXiv:2101.10699.
- [28] Nansen (2023): *Eth2 Dashboard*. Available at <https://pro.nansen.ai/eth2-deposit-contract>.
- [29] Nansen (2023): *The Ethereum Shanghai (Shapella) Upgrade Dashboard*. Available at <https://query.nansen.ai/public/dashboards/Hk93n66vs00uvycfui8ypF2xcpNhpraxfwX5AWZJ>.
- [30] U Natale (2022): *Analyzing Ethereum Cryptoeconomics: the validator’s perspective*. Technical Report, Chorus. Available at https://docs.google.com/document/d/1r640UQOm2z-Q9nsJzqBq3BVgCtTL1_Yc7WnPp4jEBgk.
- [31] Rated network (2023): *Network overview*. Available at <https://www.rated.network/overview?network=mainnet&timeWindow=all&rewardsMetric=average>.
- [32] Mike Neuder (2023): *EIP 7251 Maximum effective balance increase proposal [DRAFT]*. Available at <https://github.com/michaelneuder/EIPs/blob/max-eb-increase/EIPs/eip-increase-maxeb.md>.
- [33] Mike Neuder (2023): *Security Considerations and Spec Changes for a MAX_EFFECTIVE_BALANCE Increase*. Available at https://notes.ethereum.org/nHq0N517SACkL_nPwz8Vqw.
- [34] Mike Neuder, Francesco D’Amato, Aditya Asgaonkar & Justin Drake (2023): *Increase the MAX_EFFECTIVE_BALANCE – a modest proposal*. Available at <https://ethresear.ch/t/increase-the-max-effective-balance-a-modest-proposal/15801/3>.
- [35] Mike Neuder & Barnabé Monnot (2023): *[DRAFT] Slashing penalty analysis; EIP-7251*. Available at <https://notes.ethereum.org/@mikeneuder/slashing-eip-7251>.

- [36] Rocket Pool (2023): *Rocket Pool: How Ethereum Staking Works*. Technical Report. Available at <https://docs.rocketpool.net/guides/staking/overview.html#how-ethereum-staking-works>.
- [37] Roberto Saltini (2023): *Upper bound on the probability of one majority dishonest committee in the context of MAX_EFFECTIVE_BALANCE increase*. Available at https://notes.ethereum.org/nHqQN517SACKL_nPwz8Vqw.
- [38] James Smith & Rodrigo Vasquez (2023): *Staking survey: Key trends, take aways, and predictions*. Technical Report, Ethereum Foundation and EthStaker. Available at https://lookerstudio.google.com/u/0/reporting/cafcee00-e1af-4148-bae8-442a88ac75fa/page/p_ja2srdhh2c.
- [39] Balaji S. Srinivasan & Leland Lee (2017): *Quantifying Decentralization*. Available at <https://news.earn.com/quantifying-decentralization-e39db233c28e>.
- [40] Gavin Wood (2016): *Ethereum: a secure decentralized generalised transaction ledger*. Available at <https://github.com/ethereum/yellowpaper>.