SOFTWARE AUDIT REPORT

for

HARMONY

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PeckShield

Jan. 17, 2021

Document Properties

Client	Harmony
Title	Software Audit Report
Target	Harmony Blockchain
Version	1.0
Author	Jeff Liu
Auditors	Edward Lo, Ruiyi Zhang, Xudong Shao, Jeff Liu
Reviewed by	Chiachih Wu
Approved by	Xuxian Jiang
Classification	Public

Version Info

Version	Date	Author	Description
1.0	Jan. 17, 2021	Jeff Liu	Final Release Version
0.4	Jul. 06, 2020	Jeff Liu	Update Finding Status
0.3	Apr. 22, 2020	Jeff Liu	More Findings Added
0.2	Jan. 08, 2020	Jeff Liu	Add Two Findings
0.1	Sep. 30, 2019	Jeff Liu	Initial Draft

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Contents

1 Introduction

Given the opportunity to review the **Harmony Blockchain** design document and related source code, we in this report outline our systematic method to evaluate potential security issues in the Harmony Blockchain implementation, expose possible semantic inconsistency between the source code and the design specification, and provide additional suggestions and recommendations for improvement. Our results show that the given branch of Harmony Blockchain can be further improved due to the presence of several issues related to either security or performance. This document describes our audit results in detail.

1.1 About Harmony Blockchain

Harmony [1] is a high performance, sharding-based blockchain developed by Harmony company, and its Day ONE mainnet was launched on June 28th, 2019. The goal of Harmony blockchain is to deliver scalability without sacrificing decentralization, with innovations in consensus, systems, and networking layers. Harmony uses a PBFT based consensus algorithm, named Fast Byzantine Fault Tolerance (FBFT), and PoS-based Sharding as a scalability solution. Harmony's randomness generation function is a combination of Verifiable Random Function (VRF) and Verifiable Delay Function (VDF).

The basic information of Harmony Blockchain is as follows:

Table 1.1: Basic Information of Harmony Blockchain

Item	Description
Issuer	Harmony
Website	https://harmony.one
Type	Harmony Blockchain
Platform	Go, C++, Solidity
Audit Method	White-box
Latest Audit Report	Jan. 17, 2021

The audited Git repositories and the commit hash values are as follows:

Table 1.2: The Commit Hash List Of Audited Branches

Git Repository	Commit Hash Of Audited Branch
https://github.com/harmony-one/harmony	00b3abe94f9b3c29c34723973a66943b1e9266a1
https://github.com/harmony-one/vdf	b6aa89d16fd0d4f59b26c96dd1db6f35960222bf
https://github.com/harmony-one/bls	7d37e0af371482e08e32a7cb1f0a9d0a71d7b03f
https://github.com/harmony-one/ida	2993dd502a3de9d1aaa530717a334b8371539b32

1.2 About PeckShield

PeckShield Inc. [2] is a leading blockchain security company with the goal of elevating the security, privacy, and usability of current blockchain ecosystem by offering top-notch, industry-leading services and products including security audits. We are reachable at Telegram (https://t.me/peckshield), Twitter (http://twitter.com/peckshield), or Email (contact@peckshield.com).

1.3 Methodology

In the first phase of auditing Harmony Blockchain, we use fuzzing to find out the corner cases NOT covered by in-house testing. Next we do white-box auditing, in which PeckShield security auditors manually review Harmony Blockchain design and source code, analyze them for any potential issues, also follow up with issues found in the fuzzing phase. We also design and implement test cases to further reproduce and verify the issues if necessary. In the following subsections, we will introduce the risk model as well as the audit procedure adopted in this report.

Table 1.3: Vulnerability Severity Classification

Impact	*High*	*Medium*	*Low*
High	Critical	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low
	Likelihood		

1.3.1 Risk Model

To standardize the evaluation, we define the following terminology based on OWASP Risk Rating Methodology [3]:

- Likelihood represents how likely a particular vulnerability is to be uncovered and exploited in the wild;

- Impact measures the technical loss and business damage of a successful attack;

- Severity demonstrates the overall criticality of the risk;

Likelihood and impact are categorized into three ratings: *H*, *M* and *L*, i.e., *high*, *medium* and *low* respectively. Severity is determined by likelihood and impact and can be classified into four categories accordingly, i.e., *Critical*, *High*, *Medium*, *Low* shown in Table 1.3.

1.3.2 Fuzzing

In the first phase of our audit, we use fuzzing to find out possible corner cases or unusual inter-module interactions that may not be covered by in-house testing.

Fuzzing or fuzz testing is an automated software testing technique of discovering software vulnerabilities by providing unintended input to the target program and monitoring the unexpected results. As one of the most effective methods for exploiting vulnerabilities, fuzzing technology has been the first choice for many security researchers to discover vulnerabilities in recent years. At present, there are many fuzzy testing tools and supporting software, which can help security personnels to complete fuzzing and find vulnerabilities more efficiently. Based on the characteristics of the Harmony Blockchain, we use AFL [4] and go-fuzz [5] as the primary tool for fuzz testing.

AFL (American Fuzzy Lop) is a security-oriented fuzzer that employs a novel type of compile-time instrumentation and genetic algorithms to automatically discover clean, interesting test cases that trigger new internal states in the targeted binary. Since its inception, AFL has gained growing popularity in the industry and has proved its effectiveness in discovering quite a few significant software bugs in a wide range of major software projects. The basic process of AFL fuzzing is as follows:

- Generate compile-time instrumentation to record information such as code execution path;

- Construct some input files to join the input queue, and change input files according to different strategies;

- Files that trigger a crash or timeout when executing an input file are logged for subsequent analysis;

- Loop through the above process

Throughout the AFL testing, we will reproduce each crash based on the crash file generated by AFL. For each reported crash case, we will further analyze the root cause and check whether it is indeed a vulnerability. Once a crash case is confirmed as a vulnerability of the Harmony Blockchain, we will further analyze it as part of the white-box audit.

go-fuzz is a fuzzing tool inspired by AFL, for code written in Go language. It's a coverage guided fuzzing solution and mainly applicable to packages that parse complex inputs (both text and binary), and is especially useful for hardening of systems that parse inputs from potentially malicious users (e.g., anything accepted over a network).

1.3.3 White-box Audit

After fuzzing, we continue the white-box audit by manually analyzing source code. Here we test target software's internal structure, design, coding, and we focus on verifying the flow of input and output through the application as well as examining possible design and implementation trade-offs for strengthened security. PeckShield auditors first fully review and understand the source code, then we create specific test cases, execute them and analyze the results. Issues such as internal security holes, unexpected output, broken or poorly structured paths, etc., in the targeted software will be inspected.

Blockchain is a secure method of creating a distributed database of transactions, and three major technologies of blockchain are cryptography, decentralization, and consensus model. Blockchain does come with unique security challenges, and based on our understanding of blockchain general design, during this audit we divide the blockchain software into the following major areas and inspect each of them:

- Data and state storage, which is related to the database and files where blockchain data are saved.

- P2P networking, consensus, and transaction model, which is the networking layer. Note that the consensus and transaction logic is tightly coupled with networking.

- VM, account model, and incentive model. These are the execution and business layer of the blockchain, and many blockchain business specific logic is concentrated here.

- System contracts and services. These are system-level, blockchain-wide operation management contracts and services.

- Others. Software modules not included above are checked here, such as common crypto or other 3rd-party libraries, best practice or optimization used in other software projects, design and coding consistency, etc.

Table 1.4: The Full List of Audited Items

Category	Check Item
Data and State Storage	Blockchain Database Security
	Database State Integrity Check
Node Operation	Default Configuration Security
	Default Configuration Optimization
	Node Upgrade And Rollback Mechanism
Node Communication	External RPC Implementation Logic
	External RPC Function Security
	Node P2P Protocol Implementation Logic
	Node P2P Protocol Security
	Serialization/Deserialization
	Invalid/Malicious Node Management Mechanism
	Communication Encryption/Decryption
	Eclipse Attack Protection
	Fingerprint Attack Protection
Consensus	Consensus Algorithm Scalability
	Consensus Algorithm Implementation Logic
	Consensus Algorithm Security
Transaction Model	Transaction Privacy Security
	Transaction Fee Mechanism Security
	Transaction Congestion Attack Protection
VM	VM Implementation Logic
	VM Implementation Security
	VM Sandbox Escape
	VM Stack/Heap Overflow
	Contract Privilege Control
	Predefined Function Security
Account Model	Status Storage Algorithm Adjustability
	Status Storage Algorithm Security
	Double Spending Protection
System Contracts And Services	System Contracts Security
Others	Third Party Library Security
	Memory Leak Detection
	Exception Handling
	Log Security
	Coding Suggestion And Optimization
	White Paper And Code Implementation Uniformity

Based on the above classification, here is the detailed list of the audited items as shown in Table 1.4.

To better describe each issue we identified, we also categorize the findings based on Common Weakness Enumeration (CWE-699) [6], which is a community-developed list of software weakness types to better classify and organize weaknesses around concepts frequently encountered in software development. We use the CWE categories in Table 1.5 to classify our findings.

1.4 Disclaimer

Note that this security audit is not designed to replace functional tests required before any software release, and does not give any warranties on finding all possible security issues of the given blockchain software, i.e., the evaluation result does not guarantee the nonexistence of any further findings of security issues. As one audit cannot be considered comprehensive, we always recommend proceeding with several independent audits and a public bug bounty program to ensure the security of blockchain software. Last but not least, this security audit should not be used as investment advice.

Table 1.5: Common Weakness Enumeration (CWE) Classifications Used In This Audit

Category	Summary
Configuration	Weaknesses in this category are typically introduced during the configuration of the software.
Data Processing Issues	Weaknesses in this category are typically found in functionality that processes data.
Numeric Errors	Weaknesses in this category are related to improper calculation or conversion of numbers.
Security Features	Weaknesses in this category are concerned with topics like authentication, access control, confidentiality, cryptography, and privilege management. (Software security is not security software)
Time and State	Weaknesses in this category are related to the improper management of time and state in an environment that supports simultaneous or near-simultaneous computation by multiple systems, processes, or threads.
Error Conditions, **Return Values,** **Status Codes**	Weaknesses in this category include weaknesses that occur if a function does not generate the correct return/status code, or if the application does not handle all possible return/status codes that could be generated by a function.
Resource Management	Weaknesses in this category are related to improper management of system resources.
Behavioral Problems	Weaknesses in this category are related to unexpected behaviors from code that an application uses.
Business Logic	Weaknesses in this category identify some of the underlying problems that commonly allow attackers to manipulate the business logic of an application. Errors in business logic can be devastating to an entire application.
Initialization and Cleanup	Weaknesses in this category occur in behaviors that are used for initialization and breakdown.
Arguments and Parameters	Weaknesses in this category are related to improper use of arguments or parameters within function calls.
Expression Issues	Weaknesses in this category are related to incorrectly written expressions within code.
Coding Practices	Weaknesses in this category are related to coding practices that are deemed unsafe and increase the chances that an exploitable vulnerability will be present in the application. They may not directly introduce a vulnerability, but indicate the product has not been carefully developed or maintained.
Input Validation Issues	Weaknesses in this category are related to a software system's input validation components.

2 Findings

2.1 Finding Summary

Here is a summary of our findings after analyzing Harmony Blockchain. During the first phase of our audit, we studied Harmony source code and ran our in-house static code analyzer through the codebase, focused on the Harmony VM and crypto libraries. Next, we audited the general token transfer, staking, and consensus logics. The purpose here is to statically identify known coding bugs, and then manually verify (reject or confirm) issues reported by our tools. We further manually review business logics, examine system operations, and place operation specific aspects under scrutiny to uncover possible pitfalls and/or bugs. We have so far identified a list of potential issues: some of them involve subtle corner cases that might not be previously thought of, while others refer to unusual interactions among multiple modules.

For each uncovered issue, we have therefore developed test cases for reasoning, reproduction, and/or verification. After further analysis and internal discussion, as summarized in table 2.1, we determined 15 issues of that need to be brought up and pay more attention to, which are categorized in the table 2.2. More information can be found in the next subsection.

Here we also include screenshots of the current status of fuzzing. Figure 2.1 is a screenshot of a running AFL fuzzer which is testing the `bls` library. And, Figure 2.4 is the screenshot of a running Go-fuzz fuzzer which is testing the Harmony VM. We examine these parameters regularly, and whenever the *uniq crashes* increases, we look into the input which triggers the new unique crash. Once an

Severity	# of Findings	
Critical	10	■■■■■■■■■■
High	2	■■
Medium	2	■■
Low	0	
Informational	1	■
Total	15	

Table 2.1: The Severity of Our Findings

issue that triggers crash is determined to be valid, further investigation will follow to root-cause and formulate fix recommendation for it.

Table 2.2: Key Audit Findings

ID	Severity	Title	Category	Status
PVE-001	Medium	Missing Sanity Check When Adding Cross Shard Receipts	Coding Practices	Fixed
PVE-002	Informational	Missing Penalty When Leaders Not Processing Cross Shard Receipts	Behavioral Problems	Confirmed
PVE-003	Critical	Out-of-Bounds Access in the P2P Module - #1	Coding Practices	Fixed
PVE-004	Critical	Out-of-Bounds Access in the P2P Module - #2	Coding Practices	Fixed
PVE-005	Critical	Out-of-Bounds Access in the P2P Module - #3	Coding Practices	Fixed
PVE-006	Critical	DoS Vulnerability in the P2P Module - #1	Behavioral Problems	Fixed
PVE-007	Critical	DoS Vulnerability in the P2P Module - #2	Coding Practices	Fixed
PVE-008	Medium	Integer Overflow in the RPC module	Coding Practices	Fixed
PVE-009	Critical	Consensus Suspending in the Consensus Module - #1	Behavioral Problems	Fixed
PVE-010	Critical	Out-of-Memory in the Consensus Module - #1	Behavioral Problems	Fixed
PVE-011	Critical	Out-of-Memory in the Consensus Module - #2	Behavioral Problems	Fixed
PVE-012	Critical	Consensus Suspending in the Consensus Module - #2	Behavioral Problems	Fixed
PVE-013	High	Consensus suspending in the Consensus Module - #3	Input Validation Issues	Fixed
PVE-014	Critical	Missing Sanity Check on Slash Records - #1	Input Validation Issues	Fixed
PVE-015	High	Missing Sanity Check on Slash Records - #2	Behavioral Problems	Fixed

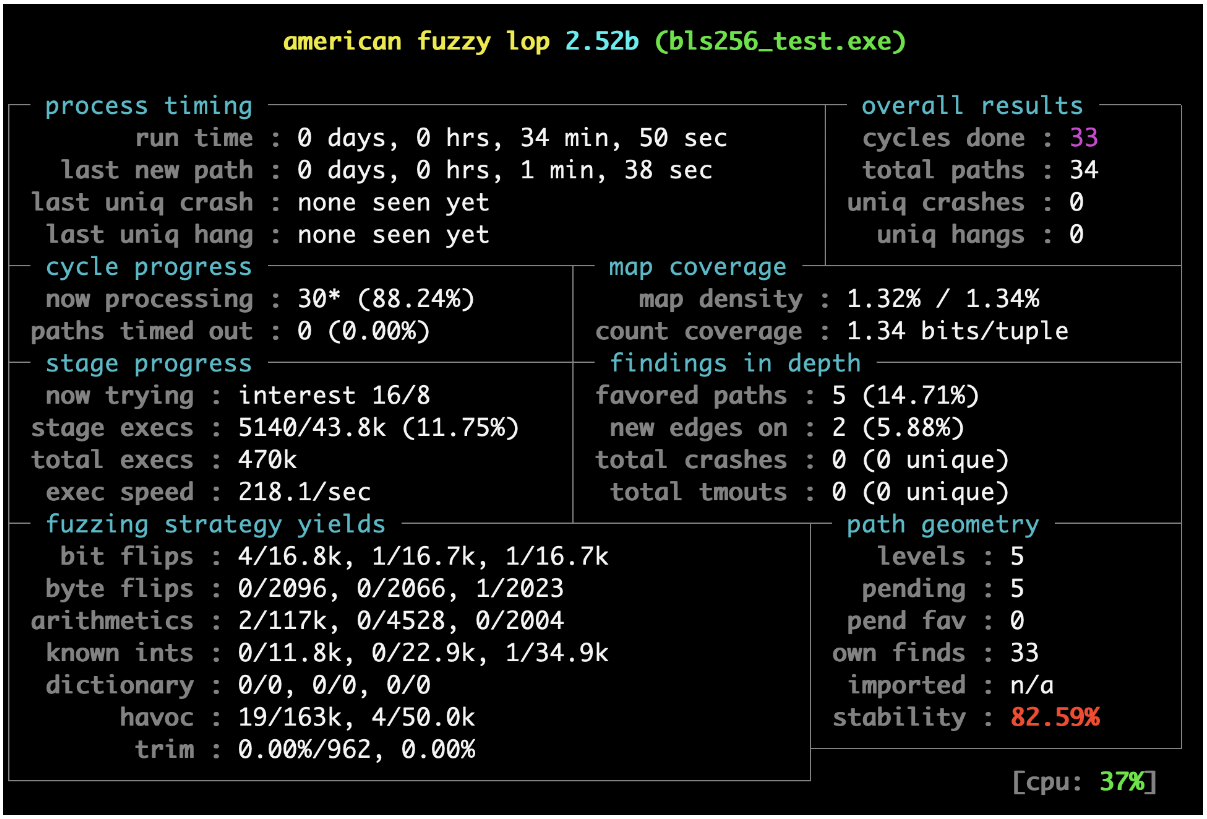
2.2 Key Findings

We conducted our audit of the Harmony design and implementations, starting with Harmony VM and crypto libraries, after that we audited general token transfer, staking, and consensus logics. After analyzing all of the potential issues found during the audit, we determined that a number of them need to be brought up and pay more attention to, as shown in Table 2.2. Please refer to Section 3 for detailed discussion of each vulnerability.

Harmony's VM is fully compatible with Ethereum VM (Constantinople), and they plan to support Wasm after mainnet launch. We worked through the Harmony VM code, and didn't find any fix missing for known Ethereum VM issues. We fed the Harmony VM through the go-fuzz tool, found two crashes and later determined to be caused by timeout. Further investigation found that they were timing issues related to go-fuzz, and there was no similar issue running Harmony VM directly. Therefore, we marked them as false warnings. The total coverage is pretty high, as shown in Figure 2.3, and the current status of the go-fuzz result is shown in Figure 2.4.

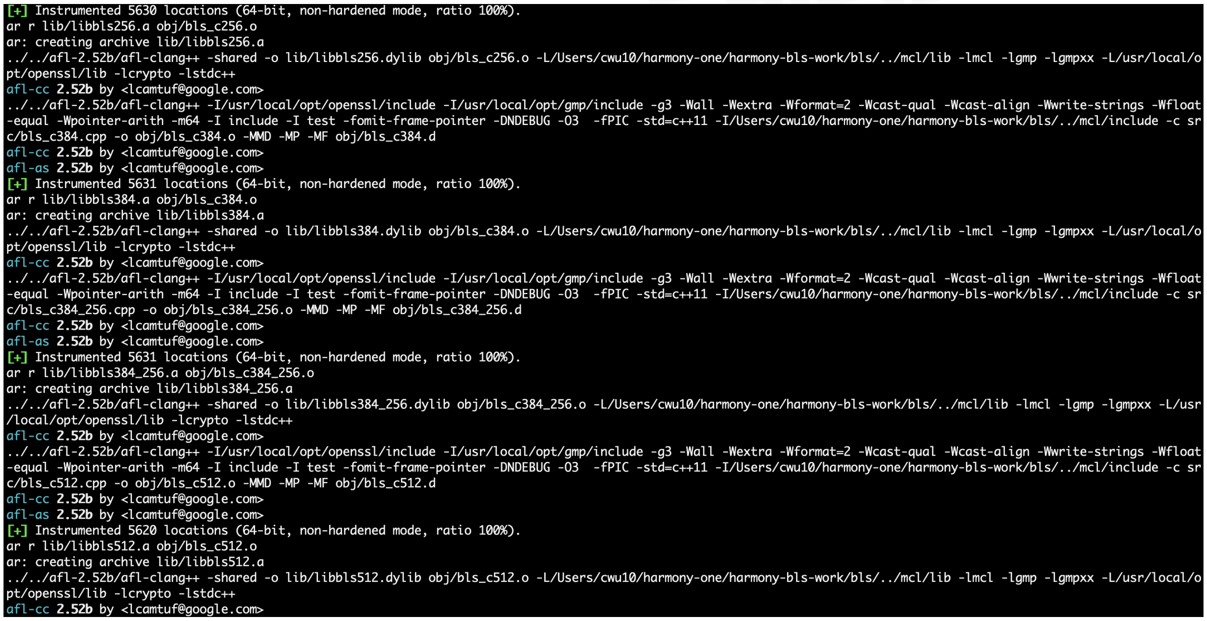
BLS signature scheme [7] is an excellent multisig solution which has some good properties compared to ECDSA [8] and Schnorr [9]. Harmony adopted the open source C++ BLS implementation [10] which has a harness that enables the integration with Golang software. We started our audit work with AFL fuzzing. Specifically, we used `afl-clang++` to compile the `bls` source code, which instruments the library as shown in Figure 2.2. Then, with a simple seed input, we started fuzzing the instrumented BLS as shown in Figure 2.1. During the first phase of our audit, we did not find any issue in the BLS library through AFL fuzzing. In the next phase, we will firstly try to improve the code coverage of fuzzing. Later, we will manually test and review the BLS implementation.

The other part of crypto libraries included in our first phase audit is the implementation of VDF, which is an essential component to provide trustworthy randomness on Harmony blockchain. With the trustworthy on-chain randomness, the blockchain would be able to safely support numerous applications such as dice dapps without an oracle mechanism. This is not a guaranteed feature on most blockchains. In many cases, the wrong implementations of on-chain mechanism caused tremendous financial damages [11, 12]. Our target here is a Golang implementation of Benjanmin Wesolowski's paper [13]. We started testing the library with the example `src/test/vdf_module_test.go` in this phase. In the next phase, we will apply go-fuzz on it as well.



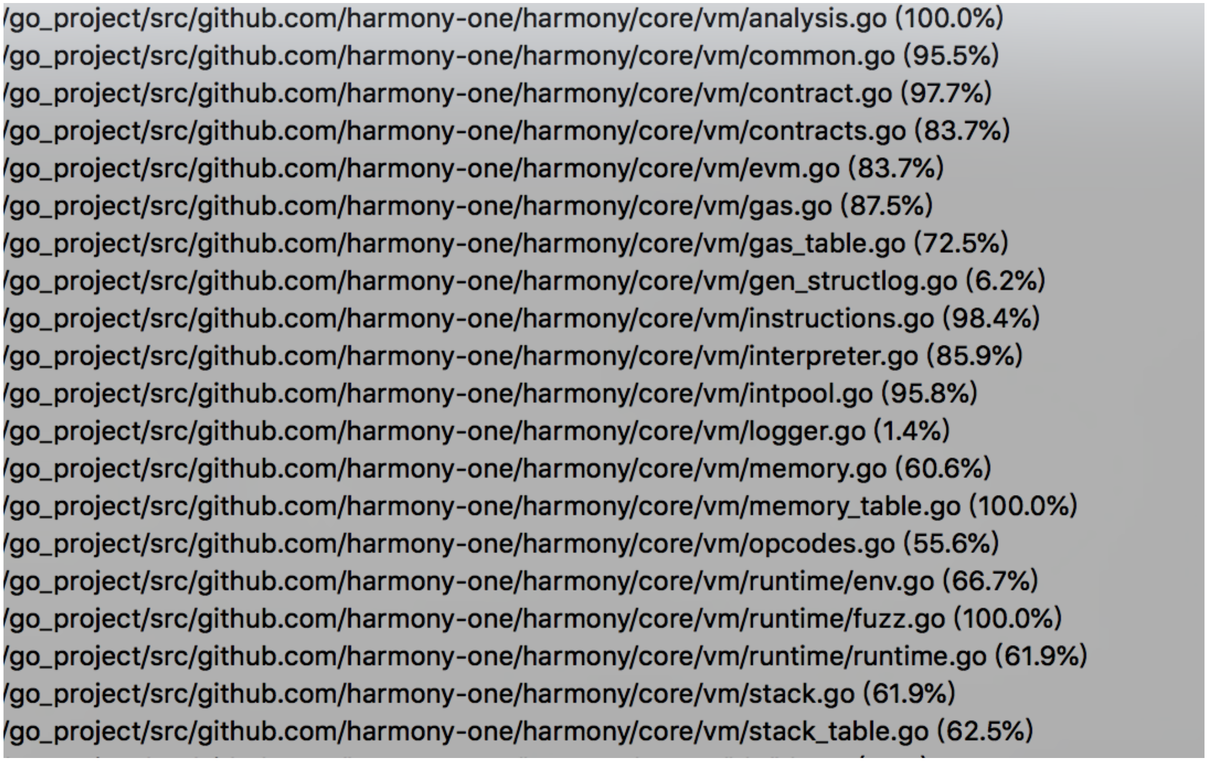
```
                american fuzzy lop 2.52b (bls256_test.exe)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 0 hrs, 34 min, 50 sec      │  cycles done : 33     │
│   last new path : 0 days, 0 hrs, 1 min, 38 sec       │  total paths : 34     │
│ last uniq crash : none seen yet                      │ uniq crashes : 0      │
│  last uniq hang : none seen yet                      │   uniq hangs : 0      │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 30* (88.24%)      │    map density : 1.32% / 1.34%         │
│ paths timed out : 0 (0.00%)         │ count coverage : 1.34 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : interest 16/8         │ favored paths : 5 (14.71%)             │
│ stage execs : 5140/43.8k (11.75%)   │  new edges on : 2 (5.88%)              │
│ total execs : 470k                  │ total crashes : 0 (0 unique)           │
│  exec speed : 218.1/sec             │  total tmouts : 0 (0 unique)           │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 4/16.8k, 1/16.7k, 1/16.7k             │    levels : 5          │
│  byte flips : 0/2096, 0/2066, 1/2023                │   pending : 5          │
│ arithmetics : 2/117k, 0/4528, 0/2004                │  pend fav : 0          │
│  known ints : 0/11.8k, 0/22.9k, 1/34.9k             │ own finds : 33         │
│  dictionary : 0/0, 0/0, 0/0                         │  imported : n/a        │
│       havoc : 19/163k, 4/50.0k                      │ stability : 82.59%     │
│        trim : 0.00%/962, 0.00%                      ├────────────────────────┘
└─────────────────────────────────────────────────────┘          [cpu: 37%]
```

Figure 2.1: AFL Screenshot



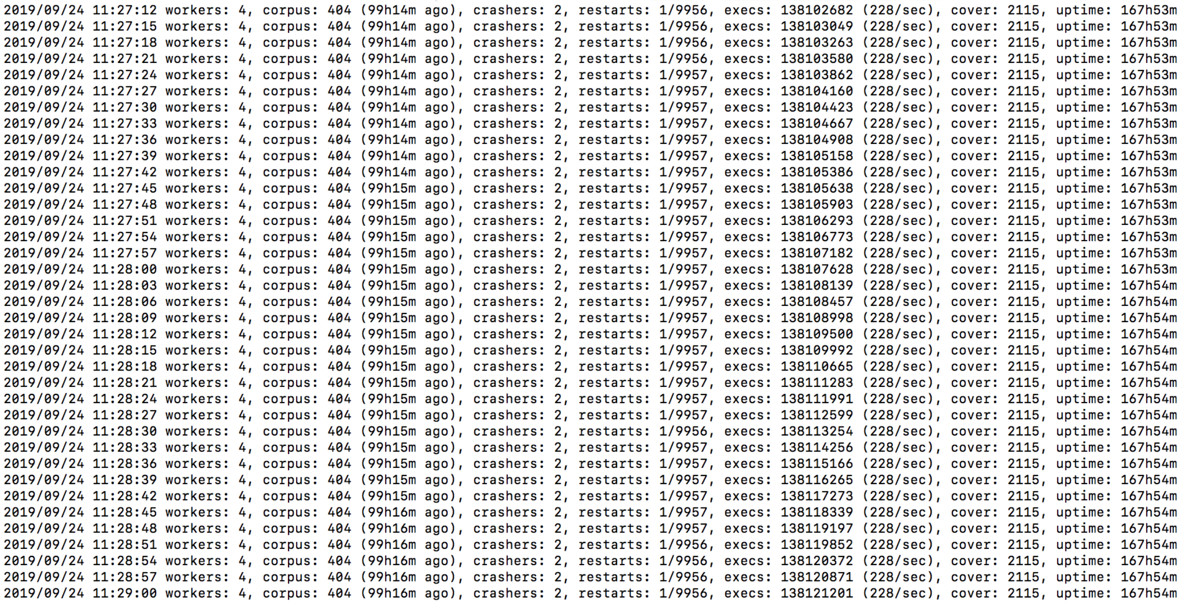
```
[+] Instrumented 5630 locations (64-bit, non-hardened mode, ratio 100%).
ar r lib/libbls256.a obj/bls_c256.o
ar: creating archive lib/libbls256.a
../../afl-2.52b/afl-clang++ -shared -o lib/libbls256.dylib obj/bls_c256.o -L/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/lib -lmcl -lgmp -lgmpxx -L/usr/local/o
pt/openssl/lib -lcrypto -lstdc++
afl-cc 2.52b by <lcamtuf@google.com>
../../afl-2.52b/afl-clang++ -I/usr/local/opt/openssl/include -I/usr/local/opt/gmp/include -g3 -Wall -Wextra -Wformat=2 -Wcast-qual -Wcast-align -Wwrite-strings -Wfloat
-equal -Wpointer-arith -m64 -I include -I test -fomit-frame-pointer -DNDEBUG -O3  -fPIC -std=c++11 -I/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/include -c sr
c/bls_c384.cpp -o obj/bls_c384.o -MMD -MP -MF obj/bls_c384.d
afl-cc 2.52b by <lcamtuf@google.com>
afl-as 2.52b by <lcamtuf@google.com>
[+] Instrumented 5631 locations (64-bit, non-hardened mode, ratio 100%).
ar r lib/libbls384.a obj/bls_c384.o
ar: creating archive lib/libbls384.a
../../afl-2.52b/afl-clang++ -shared -o lib/libbls384.dylib obj/bls_c384.o -L/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/lib -lmcl -lgmp -lgmpxx -L/usr/local/o
pt/openssl/lib -lcrypto -lstdc++
afl-cc 2.52b by <lcamtuf@google.com>
../../afl-2.52b/afl-clang++ -I/usr/local/opt/openssl/include -I/usr/local/opt/gmp/include -g3 -Wall -Wextra -Wformat=2 -Wcast-qual -Wcast-align -Wwrite-strings -Wfloat
-equal -Wpointer-arith -m64 -I include -I test -fomit-frame-pointer -DNDEBUG -O3  -fPIC -std=c++11 -I/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/include -c sr
c/bls_c384_256.cpp -o obj/bls_c384_256.o -MMD -MP -MF obj/bls_c384_256.d
afl-cc 2.52b by <lcamtuf@google.com>
afl-as 2.52b by <lcamtuf@google.com>
[+] Instrumented 5631 locations (64-bit, non-hardened mode, ratio 100%).
ar r lib/libbls384_256.a obj/bls_c384_256.o
ar: creating archive lib/libbls384_256.a
../../afl-2.52b/afl-clang++ -shared -o lib/libbls384_256.dylib obj/bls_c384_256.o -L/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/lib -lmcl -lgmp -lgmpxx -L/usr
/local/opt/openssl/lib -lcrypto -lstdc++
afl-cc 2.52b by <lcamtuf@google.com>
../../afl-2.52b/afl-clang++ -I/usr/local/opt/openssl/include -I/usr/local/opt/gmp/include -g3 -Wall -Wextra -Wformat=2 -Wcast-qual -Wcast-align -Wwrite-strings -Wfloat
-equal -Wpointer-arith -m64 -I include -I test -fomit-frame-pointer -DNDEBUG -O3  -fPIC -std=c++11 -I/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/include -c sr
c/bls_c512.cpp -o obj/bls_c512.o -MMD -MP -MF obj/bls_c512.d
afl-cc 2.52b by <lcamtuf@google.com>
afl-as 2.52b by <lcamtuf@google.com>
[+] Instrumented 5620 locations (64-bit, non-hardened mode, ratio 100%).
ar r lib/libbls512.a obj/bls_c512.o
ar: creating archive lib/libbls512.a
../../afl-2.52b/afl-clang++ -shared -o lib/libbls512.dylib obj/bls_c512.o -L/Users/cwu10/harmony-one/harmony-bls-work/bls/../mcl/lib -lmcl -lgmp -lgmpxx -L/usr/local/o
pt/openssl/lib -lcrypto -lstdc++
afl-cc 2.52b by <lcamtuf@google.com>
```

Figure 2.2: AFL Instrumentation



```
/go_project/src/github.com/harmony-one/harmony/core/vm/analysis.go (100.0%)
/go_project/src/github.com/harmony-one/harmony/core/vm/common.go (95.5%)
/go_project/src/github.com/harmony-one/harmony/core/vm/contract.go (97.7%)
/go_project/src/github.com/harmony-one/harmony/core/vm/contracts.go (83.7%)
/go_project/src/github.com/harmony-one/harmony/core/vm/evm.go (83.7%)
/go_project/src/github.com/harmony-one/harmony/core/vm/gas.go (87.5%)
/go_project/src/github.com/harmony-one/harmony/core/vm/gas_table.go (72.5%)
/go_project/src/github.com/harmony-one/harmony/core/vm/gen_structlog.go (6.2%)
/go_project/src/github.com/harmony-one/harmony/core/vm/instructions.go (98.4%)
/go_project/src/github.com/harmony-one/harmony/core/vm/interpreter.go (85.9%)
/go_project/src/github.com/harmony-one/harmony/core/vm/intpool.go (95.8%)
/go_project/src/github.com/harmony-one/harmony/core/vm/logger.go (1.4%)
/go_project/src/github.com/harmony-one/harmony/core/vm/memory.go (60.6%)
/go_project/src/github.com/harmony-one/harmony/core/vm/memory_table.go (100.0%)
/go_project/src/github.com/harmony-one/harmony/core/vm/opcodes.go (55.6%)
/go_project/src/github.com/harmony-one/harmony/core/vm/runtime/env.go (66.7%)
/go_project/src/github.com/harmony-one/harmony/core/vm/runtime/fuzz.go (100.0%)
/go_project/src/github.com/harmony-one/harmony/core/vm/runtime/runtime.go (61.9%)
/go_project/src/github.com/harmony-one/harmony/core/vm/stack.go (61.9%)
/go_project/src/github.com/harmony-one/harmony/core/vm/stack_table.go (62.5%)
```

Figure 2.3: Go-fuzz Coverage



```
2019/09/24 11:27:12 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9956, execs: 138102682 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:15 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9956, execs: 138103049 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:18 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9956, execs: 138103263 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:21 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9956, execs: 138103580 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:24 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138103862 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:27 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138104160 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:30 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138104423 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:33 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138104667 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:36 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138104908 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:39 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138105158 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:42 workers: 4, corpus: 404 (99h14m ago), crashers: 2, restarts: 1/9957, execs: 138105386 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:45 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138105638 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:48 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138105903 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:51 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138106293 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:54 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138106773 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:27:57 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138107182 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:28:00 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138107628 (228/sec), cover: 2115, uptime: 167h53m
2019/09/24 11:28:03 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138108139 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:06 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138108457 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:09 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138108998 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:12 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138109500 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:15 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138109992 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:18 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138110665 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:21 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138111283 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:24 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138111991 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:27 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138112599 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:30 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9956, execs: 138113254 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:33 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138114256 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:36 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138115166 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:39 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138116265 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:42 workers: 4, corpus: 404 (99h15m ago), crashers: 2, restarts: 1/9957, execs: 138117273 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:45 workers: 4, corpus: 404 (99h16m ago), crashers: 2, restarts: 1/9957, execs: 138118339 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:48 workers: 4, corpus: 404 (99h16m ago), crashers: 2, restarts: 1/9957, execs: 138119197 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:51 workers: 4, corpus: 404 (99h16m ago), crashers: 2, restarts: 1/9956, execs: 138119852 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:54 workers: 4, corpus: 404 (99h16m ago), crashers: 2, restarts: 1/9956, execs: 138120372 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:28:57 workers: 4, corpus: 404 (99h16m ago), crashers: 2, restarts: 1/9956, execs: 138120871 (228/sec), cover: 2115, uptime: 167h54m
2019/09/24 11:29:00 workers: 4, corpus: 404 (99h16m ago), crashers: 2, restarts: 1/9956, execs: 138121201 (228/sec), cover: 2115, uptime: 167h54m
```

Figure 2.4: Go-fuzz Screenshot

3 | Detailed Results

3.1 Missing Sanity Check When Adding Cross Shard Receipts

- ID: PVE-001
- Severity: Medium
- Likelihood: High
- Impact: Low

- Target: `node/node.go`
- Category: Coding Practices [14]
- CWE subcategory: CWE-20 [15]

Description

There is a vulnerability in the P2P module, which could be exploited by attackers to slow down the processing of cross shard transfers.

```
134 func (node *Node) ProcessReceiptMessage(msgPayload []byte) {
135     cxp := types.CXReceiptsProof{}
136     if err := rlp.DecodeBytes(msgPayload, &cxp); err != nil {
137         utils.Logger().Error().Err(err).Msg("[ProcessReceiptMessage] Unable to Decode
              message Payload")
138         return
139     }
140     utils.Logger().Debug().Interface("cxp", cxp).Msg("[ProcessReceiptMessage] Add
          CXReceiptsProof to pending Receipts")
141     // TODO: integrate with txpool
142     node.AddPendingReceipts(&cxp)
143 }
```

Listing 3.1: node/node_cross_shard.go

ProcessReceiptMessage will be called for receipts messages. It will decode the cross shard receipts and merkle proof encoded in RLP format, and pass them to AddPendingReceipts (line 142).

```
332 func (node *Node) AddPendingReceipts(receipts *types.CXReceiptsProof) {
333   node.pendingCXMutex.Lock()
334   defer node.pendingCXMutex.Unlock()
335 
336   if receipts.ContainsEmptyField() {
337     utils.Logger().Info().Int(... ...)
338     return
339   }
340
341   blockNum := receipts.Header.Number().Uint64()
342   shardID := receipts.Header.ShardID()
343   key := utils.GetPendingCXKey(shardID, blockNum)
344
345   if _, ok := node.pendingCXReceipts[key]; ok {
346     utils.Logger().Info().Int(... ...)
347     return
348   }
349   node.pendingCXReceipts[key] = receipts
350   utils.Logger().Info().Int(... ...)
351 }
```

Listing 3.2: node/node.go

```
// ContainsEmptyField checks whether the given CXReceiptsProof contains empty field
func (cxp *CXReceiptsProof) ContainsEmptyField() bool {
    return cxp == nil || cxp.Receipts == nil || cxp.MerkleProof == nil || cxp.Header == nil || len(cxp.CommitSig)+len(cxp.CommitBitmap) == 0
}
```

Listing 3.3: core/types/cx_receipt.go

AddPendingReceipts will first check whether the receipt contains empty fields (line 336) or had been recorded in the pendingCXReceipts map (line 345), and will save it if not (line 349).

However, there is no further sanity check enforced while adding new receipts into pendingCXReceipts. Specifically, a malicious attacker can craft a valid yet meaningless CXReceiptsProof and send it to the victims to occupy the pendingCXReceipts map with the key composed from shardID and blockNum, which will block the real CXReceiptsProof from normal nodes and slow down the cross shard transfer processing.

Recommendation Add sanity checks for the origin and validity of the cross shard receipts.

3.2 Missing Penalty When Leaders Not Processing Cross Shard Receipts

- ID: PVE-002
- Severity: Informational
- Likelihood: High
- Impact: None/Undetermined

- Target: `node/worker/worker.go`
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-841 [17]

Description

The cross shard transfer is supported on harmony blockchain. The process can be summarized as follows:

1) Source shards run the cross shard transactions, and broadcast cross shard receipts to destination shards.

2) Destination shards receive the receipts and put them in a pending map.

3) Destination shards leaders handle the cross shard receipts in the new blocks.

```go
79  func (node *Node) proposeNewBlock() (*types.Block, error) {
80    node.Worker.UpdateCurrent()
81  ... ...
```

Listing 3.4: node/node_newblock.go

```go
124   if err := node.Worker.CommitTransactions(
125     pending, pendingStakingTransactions, beneficiary,
126     func(payload staking.RPCTransactionError) {
127       const maxSize = 1024
128       node.errorSink.Lock()
129       if l := len(node.errorSink.failedTxns); l >= maxSize {
130         node.errorSink.failedTxns = append(node.errorSink.failedTxns[1:], payload)
131       } else {
132         node.errorSink.failedTxns = append(node.errorSink.failedTxns, payload)
133       }
134       node.errorSink.Unlock()
135     },
136   ); err != nil {
137     utils.Logger().Error().Err(err).Msg("cannot commit transactions")
138     return nil, err
139   }
140
141   // Prepare cross shard transaction receipts
142   receiptsList := node.proposeReceiptsProof()
143   if len(receiptsList) != 0 {
144     if err := node.Worker.CommitReceipts(receiptsList); err != nil {
145       utils.Logger().Error().Err(err).Msg("[proposeNewBlock] cannot commit receipts")
146     }
147   }
```

Listing 3.5: node/node_newblock.go

proposeNewBlock is called by shard leaders for proposing a new block. It will process the pending transactions / staking transactions (line 124 - 139), and handle the cross shard transaction receipts (line 142 - 147).

```
206 func (w *Worker) CommitReceipts(receiptsList []*types.CXReceiptsProof) error {
207   if w.current.gasPool == nil {
208     w.current.gasPool = new(core.GasPool).AddGas(w.current.header.GasLimit())
209   }
210
211   if len(receiptsList) == 0 {
212     w.current.header.SetIncomingReceiptHash(types.EmptyRootHash)
213   } else {
214     w.current.header.SetIncomingReceiptHash(types.DeriveSha(types.CXReceiptsProofs(
          receiptsList)))
215   }
216
217   for _, cx := range receiptsList {
218     err := core.ApplyIncomingReceipt(w.config, w.current.state, w.current.header, cx)
219     if err != nil {
220       return ctxerror.New("cannot apply receiptsList").WithCause(err)
221     }
222   }
223
224   for _, cx := range receiptsList {
225     w.current.incxs = append(w.current.incxs, cx)
226   }
227   return nil
228 }
```

Listing 3.6: node/worker/worker.go

`CommitReceipts` will apply the receipts and adjust the balance of the corresponding account (line 218). However, there is no penalty if shard leader intentionally ignore any specific receipts and let them stay pending forever. Specifically, a leader is free to choose any receipts in the `node.pendingCXReceipts` map, not by timestamp or any other specific rule, and there is no penalty if a malicious leader intentionally ignore some receipts. Ttechnically, a leader can skip some cross shard receipts on purpose and let them stay pending forever.

Recommendation Add penalty when leaders do not process cross shard receipts. According to Harmony, leader rotation and the mechanisms to detect transaction withholding and preempt a malicious leader will be added in the next phase of mainnet upgrade. In the current phase where Harmony controls the leader nodes, this is not an issue to the users.

3.3 Out-of-Bounds Access in the P2P Module - #1

- ID: PVE-003
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: `node/node_handler.go`
- Category: Coding Practices [14]
- CWE subcategory: CWE-129 [18]

Description

This is a vulnerability in the P2P module, which could be exploited by attackers to perform DoS attack against the harmony network.

Within the harmony network, a node can be one of the these roles: validator, leader, beacon validator, or beacon leader depending on its context. With each role, a node would run a certain set of services.

Furthermore, harmony network has enabled libp2p based gossiping using pubsub. Nodes no longer send messages to individual nodes, instead, they publish / subscribe to different topics.

```
39 // receiveGroupMessage use libp2p pubsub mechanism to receive broadcast messages
40 func (node *Node) receiveGroupMessage(
41     receiver p2p.GroupReceiver, rxQueue msgq.MessageAdder,
42 ) {
43     ctx := context.Background()
44     // TODO ek - infinite loop; add shutdown/cleanup logic
45     for {
46         msg, sender, err := receiver.Receive(ctx)
47         if err != nil {
48             utils.Logger().Warn().Err(err).
49                 Msg("cannot receive from group")
50             continue
51         }
52         if sender == node.host.GetID() {
53             continue
54         }
55         //utils.Logger().Info("[PUBSUB]", "received group msg", len(msg), "sender",
               sender)
56         // skip the first 5 bytes, 1 byte is p2p type, 4 bytes are message size
57         if err := rxQueue.AddMessage(msg[5:], sender); err != nil {
58             utils.Logger().Warn().Err(err).
59                 Str("sender", sender.Pretty()).
60                 Msg("cannot enqueue incoming message for processing")
61         }
62     }
63 }
```

Listing 3.7: node/node_handler.go

Specifically, each node will call `receiveGroupMessage` to receive broadcast messages, and distribute them to consumers. However, there is no sanity check for the length of the received messages. It simply passes the buffer start from offset 5 (line 57) to queues, which could cause out-of-bound access panic for nodes subscribe to the topic if the message length < 5.

Recommendation Add sanity checks for the length of the received messages.

3.4 Out-of-Bounds Access in the P2P Module - #2

- ID: PVE-004
- Severity: Critical
- Likelihood: High
- Impact: High
- Target: `node/node_handler.go`
- Category: Coding Practices [14]
- CWE subcategory: CWE-129 [18]

Description

This is a vulnerability in the P2P module, which could be exploited by attackers to perform DoS attack against the harmony network.

Within the harmony network, a node can be treated as one of the roles: validator, leader, beacon validator, or beacon leader depending on its context. With each role, a node can run a certain set of services.

Also, harmony has enabled libp2p based gossiping using pubsub. Nodes no longer send messages to individual nodes, instead, they publish / subscribe to different topics.

```go
// receiveGroupMessage use libp2p pubsub mechanism to receive broadcast messages
func (node *Node) receiveGroupMessage(
    receiver p2p.GroupReceiver, rxQueue msgq.MessageAdder,
) {
    ctx := context.Background()
    // TODO ek - infinite loop; add shutdown/cleanup logic
    for {
        msg, sender, err := receiver.Receive(ctx)
        if err != nil {
            utils.Logger().Warn().Err(err).
                Msg("cannot receive from group")
            continue
        }
        if sender == node.host.GetID() {
            continue
        }
        //utils.Logger().Info("[PUBSUB]", "received group msg", len(msg), "sender", sender)
        // skip the first 5 bytes, 1 byte is p2p type, 4 bytes are message size
        if err := rxQueue.AddMessage(msg[5:], sender); err != nil {
            utils.Logger().Warn().Err(err).
                Str("sender", sender.Pretty()).
                Msg("cannot enqueue incoming message for processing")
        }
    }
}
```

Listing 3.8: node/node_handler.go

Each node would call `receiveGroupMessage` to receive broadcast messages, and distribute them to consumers. Messages are encoded as the following format:

```
----  content start -----
1 byte          - message category
                  0x00: Consensus
                  0x01: Node...
1 byte          - message type
                  - for Consensus category
                    0x00: consensus
                    0x01: sharding ...
                  - for Node category
                    0x00: transaction ...
n - 2 bytes     - actual message payload
----   content end  -----
```

Every message has its category and type, and would be handled accordingly.

```
func (node *Node) HandleMessage(content []byte, sender libp2p_peer.ID) {
    msgCategory, err := proto.GetMessageCategory(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message category failed")
        return
    }

    msgType, err := proto.GetMessageType(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message type failed")
        return
    }

    msgPayload, err := proto.GetMessagePayload(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message payload failed")
        return
    }

    switch msgCategory {
    case proto.Consensus:
        msgPayload, _ := proto.GetConsensusMessagePayload(content)
        if node.NodeConfig.Role() == nodeconfig.ExplorerNode {
            node.ExplorerMessageHandler(msgPayload)
        } else {
            node.ConsensusMessageHandler(msgPayload)
        }
    case proto.DRand:
        msgPayload, _ := proto.GetDRandMessagePayload(content)
        if node.DRand != nil {
            if node.DRand.IsLeader {
                node.DRand.ProcessMessageLeader(msgPayload)
104             } else {
105                 node.DRand.ProcessMessageValidator(msgPayload)
106             }
107         }
108     case proto.Node:
109         actionType := proto_node.MessageType(msgType)
110         switch actionType {
111         case proto_node.Transaction:
112             utils.Logger().Debug().Msg("NET: received message: Node/Transaction")
113             node.transactionMessageHandler(msgPayload)
114         case proto_node.Staking:
115             utils.Logger().Debug().Msg("NET: received message: Node/Staking")
116             node.stakingMessageHandler(msgPayload)
117         case proto_node.Block:
118             utils.Logger().Debug().Msg("NET: received message: Node/Block")
119             blockMsgType := proto_node.BlockMessageType(msgPayload[0])
```

Listing 3.9: node/node_handler.go

`msgCategory`, `msgType`, `msgPayload` are extracted from the message (msg[0], msg[1], msg[2:]), and `HandleMessage` will take different actions according to them. However, there is no sanity check for `msgPayload` for proto_node.Block case (line 117).

Specifically, if a malicious attacker passed in a small buffer (length = 7) with msgCategory = proto.Node and msgType = proto_node.Block, msgPayload (line 83) will be a 0 length slice, and accessing to it (line 119) would cause out-of-bound access panic for nodes subscribe to the topic.

Recommendation Add sanity checks for the length of the received messages.

3.5 Out-of-Bounds Access in the P2P Module - #3

- ID: PVE-005
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: `node/node_handler.go`
- Category: Coding Practices [14]
- CWE subcategory: CWE-129 [18]

Description

This is a vulnerability in the P2P module, which could be exploited by attackers to perform DoS attack against the harmony network.

Within the harmony network, a node can be treated as one of the roles: validator, leader, beacon validator, or beacon leader depending on its context. With each role, a node can run a certain set of services.

The harmony network has also enabled libp2p based gossiping using pubsub. Nodes no longer send messages to individual nodes, instead, they publish / subscribe to different topics.

```go
// receiveGroupMessage use libp2p pubsub mechanism to receive broadcast messages
func (node *Node) receiveGroupMessage(
    receiver p2p.GroupReceiver, rxQueue msgq.MessageAdder,
) {
    ctx := context.Background()
    // TODO ek - infinite loop; add shutdown/cleanup logic
    for {
        msg, sender, err := receiver.Receive(ctx)
        if err != nil {
            utils.Logger().Warn().Err(err).
                Msg("cannot receive from group")
            continue
        }
        if sender == node.host.GetID() {
            continue
        }
        //utils.Logger().Info("[PUBSUB]", "received group msg", len(msg), "sender",
            sender)
        // skip the first 5 bytes, 1 byte is p2p type, 4 bytes are message size
        if err := rxQueue.AddMessage(msg[5:], sender); err != nil {
            utils.Logger().Warn().Err(err).
                Str("sender", sender.Pretty()).
                Msg("cannot enqueue incoming message for processing")
        }
    }
}
```

Listing 3.10: node/node_handler.go

Each node would call `receiveGroupMessage` to receive broadcast messages, and distribute them to consumers. Messages are encoded as the following format:

```
----  content start -----
1 byte              - message category
                      0x00: Consensus
                      0x01: Node...
1 byte              - message type
                      - for Consensus category
                        0x00: consensus
                        0x01: sharding ...
                      - for Node category
                        0x00: transaction ...
n - 2 bytes         - actual message payload
----   content end  -----
```

Every message has its category and type, and would be handled accordingly.

```go
func (node *Node) HandleMessage(content []byte, sender libp2p_peer.ID) {
    msgCategory, err := proto.GetMessageCategory(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message category failed")
        return
    }

    msgType, err := proto.GetMessageType(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message type failed")
        return
    }

    msgPayload, err := proto.GetMessagePayload(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message payload failed")
        return
    }

    switch msgCategory {
    case proto.Consensus:
        msgPayload, _ := proto.GetConsensusMessagePayload(content)
        if node.NodeConfig.Role() == nodeconfig.ExplorerNode {
            node.ExplorerMessageHandler(msgPayload)
        } else {
            node.ConsensusMessageHandler(msgPayload)
        }
    case proto.DRand:
        msgPayload, _ := proto.GetDRandMessagePayload(content)
        if node.DRand != nil {
            if node.DRand.IsLeader {
                node.DRand.ProcessMessageLeader(msgPayload)
            } else {
                node.DRand.ProcessMessageValidator(msgPayload)
            }
        }
    case proto.Node:
        actionType := proto_node.MessageType(msgType)
        switch actionType {
        case proto_node.Transaction:
            utils.Logger().Debug().Msg("NET: received message: Node/Transaction")
            node.transactionMessageHandler(msgPayload)
        case proto_node.Staking:
            utils.Logger().Debug().Msg("NET: received message: Node/Staking")
            node.stakingMessageHandler(msgPayload)
        case proto_node.Block:
            utils.Logger().Debug().Msg("NET: received message: Node/Block")
            blockMsgType := proto_node.BlockMessageType(msgPayload[0])
```

Listing 3.11: node/node_handler.go

msgCategory, msgType, msgPayload are extracted from the message (msg[0], msg[1], msg[2:]), and HandleMessage would take different actions according to them.

```go
173 func (node *Node) transactionMessageHandler(msgPayload []byte) {
174     txMessageType := proto_node.TransactionMessageType(msgPayload[0])
175 
176     switch txMessageType {
177     case proto_node.Send:
178         txs := types.Transactions{}
179         err := rlp.Decode(bytes.NewReader(msgPayload[1:]), &txs) // skip the Send messge
             type
180         if err != nil {
181             utils.Logger().Error().
182                 Err(err).
183                 Msg("Failed to deserialize transaction list")
184             return
185         }
186         node.addPendingTransactions(txs)
187     }
188 }
```

Listing 3.12: node/node_handler.go

transactionMessageHandler would be called for transaction messages. However, there is no sanity check for msgPayload (line 174).

To be exact, if a malicious attacker passed in a small buffer (length = 7) with msgCategory = proto.Node and msgType = proto_node.Transaction, msgPayload will be a 0 length slice, and accessing to it (line 174) could cause OOB access panic for nodes subscribe to the topic.

Recommendation Add sanity checks for the length of the received messages.

3.6 DoS Vulnerability in the P2P Module - #1

- ID: PVE-006
- Severity: Critical
- Likelihood: High
- Impact: High
- Target: node/node.go
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-696 [19]

Description

This is a vulnerability in the P2P module, which could be exploited by attackers to perform DoS attack against the harmony network.

Within the harmony network, a node can be one of the these roles: validator, leader, beacon validator, or beacon leader depending on its context. With each role, a node would run a certain set of services.

Furthermore, harmony network has enabled libp2p based gossiping using pubsub. Nodes no longer send messages to individual nodes, instead, they publish / subscribe to different topics.

```go
func (node *Node) HandleMessage(content []byte, sender libp2p_peer.ID) {
    msgCategory, err := proto.GetMessageCategory(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message category failed")
        return
    }

    msgType, err := proto.GetMessageType(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message type failed")
        return
    }

    msgPayload, err := proto.GetMessagePayload(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message payload failed")
        return
    }

    switch msgCategory {
    case proto.Consensus:
        msgPayload, _ := proto.GetConsensusMessagePayload(content)
        if node.NodeConfig.Role() == nodeconfig.ExplorerNode {
            node.ExplorerMessageHandler(msgPayload)
        } else {
            node.ConsensusMessageHandler(msgPayload)
        }
    case proto.DRand:
        msgPayload, _ := proto.GetDRandMessagePayload(content)
        if node.DRand != nil {
            if node.DRand.IsLeader {
                node.DRand.ProcessMessageLeader(msgPayload)
            } else {
                node.DRand.ProcessMessageValidator(msgPayload)
            }
        }
    case proto.Node:
        actionType := proto_node.MessageType(msgType)
        switch actionType {
        case proto_node.Transaction:
            utils.Logger().Debug().Msg("NET: received message: Node/Transaction")
            node.transactionMessageHandler(msgPayload)
        case proto_node.Staking:
            utils.Logger().Debug().Msg("NET: received message: Node/Staking")
            node.stakingMessageHandler(msgPayload)
        case proto_node.Block:
            utils.Logger().Debug().Msg("NET: received message: Node/Block")
            blockMsgType := proto_node.BlockMessageType(msgPayload[0])
```

Listing 3.13: node/node_handler.go

msgCategory, msgType, msgPayload are extracted from the message (msg[0], msg[1], msg[2:]), and HandleMessage will take different actions according to them.

```
190 func (node *Node) stakingMessageHandler(msgPayload []byte) {
191     txs := staking.StakingTransactions{}
192     err := rlp.Decode(bytes.NewReader(msgPayload[:]), &txs)
193     if err != nil {
194         utils.Logger().Error().
195             Err(err).
196             Msg("Failed to deserialize staking transaction list")
197         return
198     }
199     node.addPendingStakingTransactions(txs)
200 }
```

Listing 3.14: node/node_handler.go

stakingMessageHandler will be called for staking transaction messages. It will decode the staking transactions encoded in RLP format, and pass them to addPendingStakingTransactions (line 199).

```
295 func (node *Node) addPendingStakingTransactions(newStakingTxs staking.
        StakingTransactions) {
296     txPoolLimit := core.ShardingSchedule.MaxTxPoolSizeLimit()
297     node.pendingStakingTxMutex.Lock()
298     for _, tx := range newStakingTxs {
299         if _, ok := node.pendingStakingTransactions[tx.Hash()]; !ok {
300             node.pendingStakingTransactions[tx.Hash()] = tx
301         }
302         if len(node.pendingStakingTransactions) > txPoolLimit {
303             break
304         }
305     }
306     node.pendingStakingTxMutex.Unlock()
307 ...  ...
308 }
```

Listing 3.15: node/node.go

addPendingStakingTransactions will check whether the staking transaction had been recorded in the pendingStakingTransactions map (line 299), and will stop storing new transactions if the map size > txPoolLimit (8,000 in mainnet).

However, the length check is misplaced, it should be executed before storing the staking transaction into pendingStakingTransactions.

Specifically, a malicious attacker can flood the victims with many different staking transactions and gradually increase the memory usage of the `pendingStakingTransactions` map, which eventually could lead to resource exhausting and hang or crash the remote nodes in the end.

Recommendation Put the length check in the right place.

3.7 DoS Vulnerability in the P2P Module - #2

- ID: PVE-007
- Severity: Critical
- Likelihood: High
- Impact: High
- Target: `node/node.go`
- Category: Coding Practices [14]
- CWE subcategory: CWE-20 [15]

Description

This is a vulnerability in the P2P module, which could be exploited by attackers to perform DoS attack against the harmony network.

Within the harmony network, a node can be one of the these roles: validator, leader, beacon validator, or beacon leader depending on its context. With each role, a node would run a certain set of services.

Furthermore, harmony network has enabled libp2p based gossiping using pubsub. Nodes no longer send messages to individual nodes, instead, they publish / subscribe to different topics.

```go
func (node *Node) HandleMessage(content []byte, sender libp2p_peer.ID) {
    msgCategory, err := proto.GetMessageCategory(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message category failed")
        return
    }

    msgType, err := proto.GetMessageType(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message type failed")
        return
    }

    msgPayload, err := proto.GetMessagePayload(content)
    if err != nil {
        utils.Logger().Error().
            Err(err).
            Msg("HandleMessage get message payload failed")
        return
    }

    switch msgCategory {
    case proto.Consensus:
        msgPayload, _ := proto.GetConsensusMessagePayload(content)
        if node.NodeConfig.Role() == nodeconfig.ExplorerNode {
            node.ExplorerMessageHandler(msgPayload)
        } else {
            node.ConsensusMessageHandler(msgPayload)
        }
    case proto.DRand:
        msgPayload, _ := proto.GetDRandMessagePayload(content)
        if node.DRand != nil {
            if node.DRand.IsLeader {
                node.DRand.ProcessMessageLeader(msgPayload)
            } else {
                node.DRand.ProcessMessageValidator(msgPayload)
            }
        }
    case proto.Node:
        actionType := proto_node.MessageType(msgType)
        switch actionType {
        case proto_node.Transaction:
            utils.Logger().Debug().Msg("NET: received message: Node/Transaction")
            node.transactionMessageHandler(msgPayload)
        case proto_node.Staking:
            utils.Logger().Debug().Msg("NET: received message: Node/Staking")
            node.stakingMessageHandler(msgPayload)
        case proto_node.Block:
            utils.Logger().Debug().Msg("NET: received message: Node/Block")
            blockMsgType := proto_node.BlockMessageType(msgPayload[0])
            switch blockMsgType {
            case proto_node.Sync:
                utils.Logger().Debug().Msg("NET: received message: Node/Sync")
                var blocks []*types.Block
                err := rlp.DecodeBytes(msgPayload[1:], &blocks)
                if err != nil {
                    utils.Logger().Error().
                        Err(err).
                        Msg("block sync")
                } else {
                    // for non-beaconchain node, subscribe to beacon block broadcast
                    if node.Blockchain().ShardID() != 0 {
                        for _, block := range blocks {
                            if block.ShardID() == 0 {
                                utils.Logger().Info().
                                    Uint64("block", blocks[0].NumberU64()).
                                    Msgf("Block being handled by block channel %d %d",
                                        block.NumberU64(), block.ShardID())
                                node.BeaconBlockChannel <- block
                            }
                        }
                    }
                    if node.Client != nil && node.Client.UpdateBlocks != nil && blocks != nil {
                        utils.Logger().Info().Msg("Block being handled by client")
                        node.Client.UpdateBlocks(blocks)
                    }
                }

            case proto_node.Header:
                // only beacon chain will accept the header from other shards
                utils.Logger().Debug().Uint32("shardID", node.NodeConfig.ShardID).Msg("NET: received message: Node/Header")
                if node.NodeConfig.ShardID != 0 {
                    return
                }
                node.ProcessHeaderMessage(msgPayload[1:]) // skip first byte which is blockMsgType

            case proto_node.Receipt:
                utils.Logger().Debug().Msg("NET: received message: Node/Receipt")
                node.ProcessReceiptMessage(msgPayload[1:]) // skip first byte which is blockMsgType

            }
```

Listing 3.16: node/node_handler.go

msgCategory, msgType, msgPayload are extracted from the message (msg[0], msg[1], msg[2:]), and HandleMessage will take different actions according to them.

```
406 func (node *Node) ProcessReceiptMessage(msgPayload []byte) {
407     cxp := types.CXReceiptsProof{}
408     if err := rlp.DecodeBytes(msgPayload, &cxp); err != nil {
409         utils.Logger().Error().Err(err).Msg("[ProcessReceiptMessage] Unable to Decode message Payload")
410         return
411     }
412     utils.Logger().Debug().Interface("cxp", cxp).Msg("[ProcessReceiptMessage] Add CXReceiptsProof to pending Receipts")
413     // TODO: integrate with txpool
414     node.AddPendingReceipts(&cxp)
415 }
```

Listing 3.17: node/node_cross_shard.go

ProcessReceiptMessage would be called for receipts messages. It would decode the cross shard receipts and merkle proof encoded in RLP format, and pass them to AddPendingReceipts (line 414).

```
func (node *Node) AddPendingReceipts(receipts *types.CXReceiptsProof) {
    node.pendingCXMutex.Lock()
    defer node.pendingCXMutex.Unlock()
332
333     if receipts.ContainsEmptyField() {
334         utils.Logger().Info().Int("totalPendingReceipts", len(node.pendingCXReceipts)).
                Msg("CXReceiptsProof contains empty field")
335         return
336     }
337
338     blockNum := receipts.Header.Number().Uint64()
339     shardID := receipts.Header.ShardID()
340     key := utils.GetPendingCXKey(shardID, blockNum)
341
342     if _, ok := node.pendingCXReceipts[key]; ok {
343         utils.Logger().Info().Int("totalPendingReceipts", len(node.pendingCXReceipts)).
                Msg("Already Got Same Receipt message")
344         return
345     }
346     node.pendingCXReceipts[key] = receipts
347     utils.Logger().Info().Int("totalPendingReceipts", len(node.pendingCXReceipts)).Msg("
            Got ONE more receipt message")
348 }
```

Listing 3.18: node/node.go

`AddPendingReceipts` would check whether the receipt had been recorded in the `pendingCXReceipts` map (line 342), and would save it if not (line 346).

However, there is no limitation enforced while adding new receipts into `pendingCXReceipts`.

Therefore, a malicious attacker can flood the victims with many crafted receipts and gradually increase the memory usage of the `pendingCXReceipts` map, which eventually could lead to resource exhausting and hang or crash the remote nodes in the end.

Recommendation Add length limitation on the cross shard receipts.

3.8 Integer Overflow in the RPC Module

- ID: PVE-008
- Severity: Medium
- Likelihood: High
- Impact: Low

- Target: `internal/hmyapi/transactionpool.go`
- Category: Coding Practices [14]
- CWE subcategory: CWE-190 [20]

Description

This is a vulnerability in the RPC api `GetTransactionsHistory`, which could be exploited by attackers to perform DoS attack against RPC thread.

```
45 // GetTransactionsHistory returns the list of transactions hashes that involve a
       particular address.
46 func (s *PublicTransactionPoolAPI) GetTransactionsHistory(ctx context.Context, args
       TxHistoryArgs) (map[string]interface{}, error) {
47     address := args.Address
48     result := []common.Hash{}
49     var err error
50    if strings.HasPrefix(args.Address, "one1") {
51      address = args.Address
52    } else {
53      addr := internal_common.ParseAddr(args.Address)
54      address, err = internal_common.AddressToBech32(addr)
55      if err != nil {
56        return nil, err
57      }
58    }
59     hashes, err := s.b.GetTransactionsHistory(address, args.TxType, args.Order)
60     if err != nil {
61       return nil, err
62     }
63     result = ReturnWithPagination(hashes, args)
```

Listing 3.19: internal/hmyapi/transactionpool.go

When analyzing the above code snippet, we noticed that harmony network allows a user to request transactions hashes history (line 59) by passing parameters of `TxHistoryArgs` struct:

```
// TxHistoryArgs is struct to make GetTransactionsHistory request
type TxHistoryArgs struct {
  Address   string ‘json:"address"‘
   PageIndex int    ‘json:"pageIndex"‘
   PageSize  int    ‘json:"pageSize"‘
   FullTx    bool   ‘json:"fullTx"‘
   TxType    string ‘json:"txType"‘
   Order     string ‘json:"order"‘
}
```

Listing 3.20: internal/hmyapi/transactionpool.go

The `ReturnWithPagination` routine use two parameters PageIndex/pageSize to return transactions history with pagination:

```
// ReturnWithPagination returns result with tran (offset, page in TxHistoryArgs).
   func ReturnWithPagination(hashes []common.Hash, args TxHistoryArgs) []common.Hash {
   pageSize := defaultPageSize
   pageIndex := args.PageIndex
   if args.PageSize > 0 {
     pageSize = args.PageSize
   }
   if pageSize*pageIndex >= len(hashes) {
     return make([]common.Hash, 0)
   }
   if pageSize*pageIndex+pageSize > len(hashes) {
```

```
30      return hashes[pageSize*pageIndex:]
31    }
32    return hashes[pageSize*pageIndex : pageSize*pageIndex+pageSize]
33  }
```

Listing 3.21: internal/hmyapi/util.go

However, these parameters are directly passed from a user-controlled transaction and thus they should be validated before usage. Although in current implementation, such validation is insufficient and malicious parameters, i.e., pageIndex and pageSize, can cause an array OOB Panic (lines 32).

Recommendation Add sanity checks for these parameters.

3.9 Consensus Suspending in the Consensus Module - #1

- ID: PVE-009
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: `consensus/checks.go`
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-841 [17]

Description

This is a vulnerability in the consensus module, which could be exploited by attackers to compromise the harmony network consensus. As an improvement on PBFT, Harmony's consensus protocol is linearly scalable in terms of communication complexity, and thus it is called Fast Byzantine Fault Tolerance (FBFT). Specifically, Harmony's FBFT consensus involves the following steps as shown in Figure 3.1:

The first phase is announce, the leader broadcasts announce message (e.g. the proposal block) to validators. When a validator receives announce message, it enters prepare phase.

```
  func (consensus *Consensus) onAnnounce(msg *msg_pb.Message) {
    recvMsg, err := ParseFBFTMessage(msg)
    if err != nil {
    consensus.getLogger().Error().
      Err(err).
      Uint64("MsgBlockNum", recvMsg.BlockNum).
      Msg("[OnAnnounce] Unparseable leader message")
      return
    }

    // NOTE let it handle its own logs
    if !consensus.onAnnounceSanityChecks(recvMsg) {
      return
```

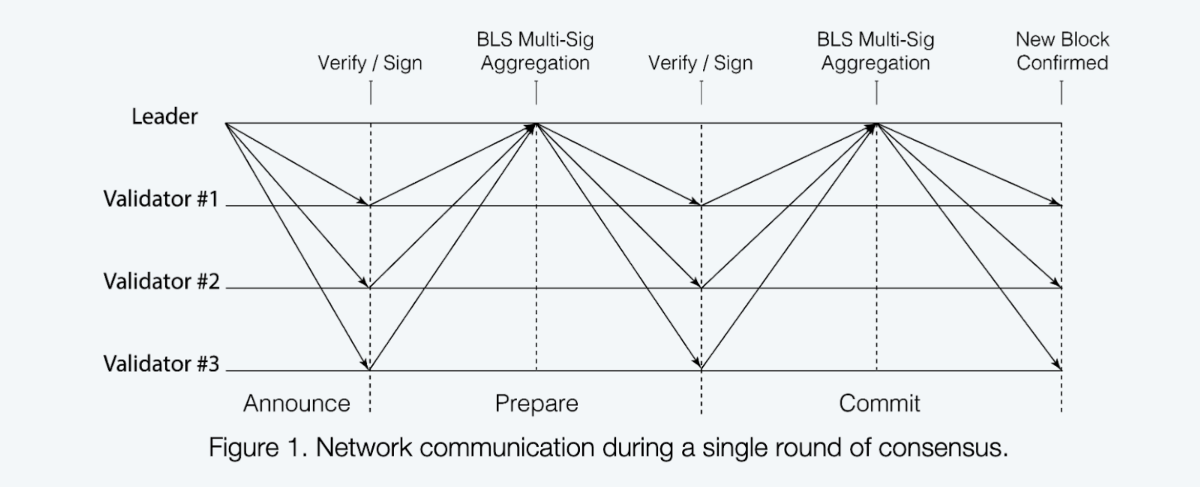


Figure 1. Network communication during a single round of consensus.

Figure 3.1: FBFT Consensus

```
      }
```

Listing 3.22: consensus/validator.go

`onAnnounce` is called when validators receives announce message from the leader. It performs lots of sanity check to make sure the message is valid.

```
func (consensus *Consensus) onAnnounceSanityChecks(recvMsg *FBFTMessage) bool {
   logMsgs := consensus.FBFTLog.GetMessagesByTypeSeqView(
      msg_pb.MessageType_ANNOUNCE, recvMsg.BlockNum, recvMsg.ViewID,
   )
   if len(logMsgs) > 0 {
      if logMsgs[0].BlockHash != recvMsg.BlockHash &&
         logMsgs[0].SenderPubkey.IsEqual(recvMsg.SenderPubkey) {
         consensus.getLogger().Debug().
        Str("logMsgSenderKey", logMsgs[0].SenderPubkey.SerializeToHexStr()).
        Str("logMsgBlockHash", logMsgs[0].BlockHash.Hex()).
        Str("recvMsg.SenderPubkey", recvMsg.SenderPubkey.SerializeToHexStr()).
        Uint64("recvMsg.BlockNum", recvMsg.BlockNum).
        Uint64("recvMsg.ViewID", recvMsg.ViewID).
        Str("recvMsgBlockHash", recvMsg.BlockHash.Hex()).
        Str("LeaderKey", consensus.LeaderPubKey.SerializeToHexStr()).
        Msg("[OnAnnounce] Leader is malicious")
         if consensus.current.Mode() == ViewChanging {
            viewID := consensus.current.ViewID()
            consensus.startViewChange(viewID + 1)
         } else {
            consensus.startViewChange(consensus.viewID + 1)
         }
```

Listing 3.23: consensus/checks.go

When a validator detects the leader proposed two different announce messages in one view, it would immediately start view change (line 107-112). However, the sanity check in `onAnnounce` can't guarantee the message is from the current leader.

```
 9 func (consensus *Consensus) validatorSanityChecks(msg *msg_pb.Message) bool {
10     senderKey, err := consensus.verifySenderKey(msg)
11     if err != nil {
12         if err == errValidNotInCommittee {
13             consensus.getLogger().Info().
14             Msg("sender key not in this slot's subcommittee")
15         } else {
16             consensus.getLogger().Error().Err(err).Msg("VerifySenderKey failed")
17         }
18         return false
19     }
20 
21     if !senderKey.IsEqual(consensus.LeaderPubKey) &&
22         consensus.current.Mode() == Normal && !consensus.ignoreViewIDCheck {
23         consensus.getLogger().Warn().Msg("[OnPrepared] SenderKey not match leader PubKey")
24         return false
25     }
26 
27     if err := verifyMessageSig(senderKey, msg); err != nil {
28         consensus.getLogger().Error().Err(err).Msg(
29             "Failed to verify sender's signature",
30         )
31         return false
32     }
33 
34     return true
35 }
```

Listing 3.24: consensus/checks.go

Specifically, a malicious leader can intentionally propose two different announce messages in one view to trigger validators' view change and make them all transit to ViewChanging mode. Once validators are in ViewChanging mode, the sanity checks (line 21-23) are ignored, thus the leader can constantly trigger view change by sending different announce messages with the same block number and view id, eventually compromise the whole harmony network.

Recommendation Add sanity checks for the legality of the announce messages.

3.10 Out-of-Memory in the Consensus Module - #1

- ID: PVE-010
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: `consensus/checks.go`
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-115 [21]

Description

Under harmony's PBFT consensus protocol, the first phase is announce, the leader would broadcast announce message (e.g. the proposal block) to validators. When a validator receives announce message, it enters prepare phase.

```
17    func (consensus *Consensus) onAnnounce(msg *msg_pb.Message) {
18       recvMsg, err := ParseFBFTMessage(msg)
19       if err != nil {
20       consensus.getLogger().Error().
21          Err(err).
22          Uint64("MsgBlockNum", recvMsg.BlockNum).
23          Msg("[OnAnnounce] Unparseable leader message")
24          return
25       }
26
27       // NOTE let it handle its own logs
28       if !consensus.onAnnounceSanityChecks(recvMsg) {
29          return
30       }
31
32       consensus.getLogger().Debug().
33        Uint64("MsgViewID", recvMsg.ViewID).
34        Uint64("MsgBlockNum", recvMsg.BlockNum).
35        Msg("[OnAnnounce] Announce message Added")
36       consensus.FBFTLog.AddMessage(recvMsg)
```

Listing 3.25: consensus/validator.go

onAnnounce is called when validators receives announce message from the leader. It performs lots of sanity check to make sure the message is valid. It would store the message for future validation (line 36).

```
func (consensus *Consensus) onAnnounceSanityChecks(recvMsg *FBFTMessage) bool {
   logMsgs := consensus.FBFTLog.GetMessagesByTypeSeqView(
      msg_pb.MessageType_ANNOUNCE, recvMsg.BlockNum, recvMsg.ViewID,
   )
   if len(logMsgs) > 0 {
      if logMsgs[0].BlockHash != recvMsg.BlockHash &&
         logMsgs[0].SenderPubkey.IsEqual(recvMsg.SenderPubkey) {
         consensus.getLogger().Debug().
        Str("logMsgSenderKey", logMsgs[0].SenderPubkey.SerializeToHexStr()).
        Str("logMsgBlockHash", logMsgs[0].BlockHash.Hex()).
        Str("recvMsg.SenderPubkey", recvMsg.SenderPubkey.SerializeToHexStr()).
        Uint64("recvMsg.BlockNum", recvMsg.BlockNum).
        Uint64("recvMsg.ViewID", recvMsg.ViewID).
        Str("recvMsgBlockHash", recvMsg.BlockHash.Hex()).
        Str("LeaderKey", consensus.LeaderPubKey.SerializeToHexStr()).
        Msg("[OnAnnounce] Leader is malicious")
         if consensus.current.Mode() == ViewChanging {
            viewID := consensus.current.ViewID()
            consensus.startViewChange(viewID + 1)
110             } else {
111                 consensus.startViewChange(consensus.viewID + 1)
112             }
113         }
114         consensus.getLogger().Debug().
115             Str("leaderKey", consensus.LeaderPubKey.SerializeToHexStr()).
116             Msg("[OnAnnounce] Announce message received again")
117     }
118     return consensus.isRightBlockNumCheck(recvMsg)
119 }
120
121 func (consensus *Consensus) isRightBlockNumCheck(recvMsg *FBFTMessage) bool {
122     if recvMsg.BlockNum < consensus.blockNum {
123         consensus.getLogger().Debug().
124             Uint64("MsgBlockNum", recvMsg.BlockNum).
125             Msg("Wrong BlockNum Received, ignoring!")
126         return false
127     }
128     return true
129 }
```

Listing 3.26: consensus/checks.go

When a validator detects the leader proposed two different announce messages in one view, it would immediately start view change (line 107-112). However, the sanity check in `onAnnounce` can't guarantee the message is from the current leader.

```
func (consensus *Consensus) validatorSanityChecks(msg *msg_pb.Message) bool {
    senderKey, err := consensus.verifySenderKey(msg)
    if err != nil {
        if err == errValidNotInCommittee {
            consensus.getLogger().Info().
                Msg("sender key not in this slot's subcommittee")
        } else {
            consensus.getLogger().Error().Err(err).Msg("VerifySenderKey failed")
        }
        return false
    }

    if !senderKey.IsEqual(consensus.LeaderPubKey) &&
        consensus.current.Mode() == Normal && !consensus.ignoreViewIDCheck {
        consensus.getLogger().Warn().Msg("[OnPrepared] SenderKey not match leader PubKey")
        return false
    }

    if err := verifyMessageSig(senderKey, msg); err != nil {
        consensus.getLogger().Error().Err(err).Msg(
            "Failed to verify sender's signature",
        )
        return false
    }

34     return true
35 }
```

Listing 3.27: consensus/checks.go

Therefore, a malicious leader could intentionally propose two different announce messages in one view to trigger validators' view change (line 107-112) and make them all transit to ViewChanging mode. Once validators are in ViewChanging mode, the sanity checks (line 21-25) are ignored, and the leader can flood these validators by sending lots of announce messages with large block number (line 122) so the validators would keep storing these messages and eventually cause them out of memory.

Recommendation Add sanity checks for the legality of the announce messages.

3.11 Out-of-Memory in the Consensus Module - #2

- ID: PVE-011
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: `consensus/view_change.go`
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-115 [21]

Description

Under harmony's PBFT consensus protocol, there are two causes for validators to start view change process. One is when a validator detects the leader proposed two different announce messages in one view, it would immediately start view change. The other is a validator doesn't make any progress after timeout. There are two kinds of timeouts: timeout in normal consensus mode and timeout in view change mode.

```
112 func (consensus *Consensus) startViewChange(viewID uint64) {
113     if consensus.disableViewChange {
114         return
115     }
116     consensus.consensusTimeout[timeoutConsensus].Stop()
117     consensus.consensusTimeout[timeoutBootstrap].Stop()
118     consensus.current.SetMode(ViewChanging)
119     consensus.current.SetViewID(viewID)
120     consensus.LeaderPubKey = consensus.GetNextLeaderKey()
121 
122     diff := viewID - consensus.viewID
123     duration := time.Duration(int64(diff) * int64(viewChangeDuration))
124     consensus.getLogger().Info().
125         Uint64("ViewChangingID", viewID).
126         Dur("timeoutDuration", duration).
127         Str("NextLeader", consensus.LeaderPubKey.SerializeToHexStr()).
128         Msg("[startViewChange]")
129
130     msgToSend := consensus.constructViewChangeMessage()
131     consensus.host.SendMessageToGroups([]nodeconfig.GroupID{
132         nodeconfig.NewGroupIDByShardID(nodeconfig.ShardID(consensus.ShardID)),
133     },
134         host.ConstructP2pMessage(byte(17), msgToSend),
135     )
136
137     consensus.consensusTimeout[timeoutViewChange].SetDuration(duration)
138     consensus.consensusTimeout[timeoutViewChange].Start()
139     consensus.getLogger().Debug().
140         Uint64("ViewChangingID", consensus.current.ViewID()).
141         Msg("[startViewChange] start view change timer")
142 }
```

Listing 3.28: consensus/view_change.go

startViewChange is called when a validator want to start a view change process. It would stop the consensus timer (line 116), set current mode to ViewChanging (line 118), construct and send out the view change message (line 130-135), and lastly, start the view change timer (line 137-138)

```
144 func (consensus *Consensus) onViewChange(msg *msg_pb.Message) {
145   recvMsg, err := ParseViewChangeMessage(msg)
146   if err != nil {
147     consensus.getLogger().Warn().Msg("[onViewChange] Unable To Parse Viewchange Message"
        )
148     return
149   }
150   newLeaderKey := recvMsg.LeaderPubkey
151   if !consensus.PubKey.IsEqual(newLeaderKey) {
152     return
153   }
154
155   if consensus.Decider.IsQuorumAchieved(quorum.ViewChange) {
156     consensus.getLogger().Debug().
157       Int64("have", consensus.Decider.SignersCount(quorum.ViewChange)).
158       Int64("need", consensus.Decider.TwoThirdsSignersCount()).
159       Str("validatorPubKey", recvMsg.SenderPubkey.SerializeToHexStr()).
160       Msg("[onViewChange] Received Enough View Change Messages")
161     return
162   }
163
164   senderKey, err := consensus.verifyViewChangeSenderKey(msg)
165   if err != nil {
166     consensus.getLogger().Debug().Err(err).Msg("[onViewChange] VerifySenderKey Failed")
167     return
168   }
169
170   // TODO: if difference is only one, new leader can still propose the same committed
        block to avoid another view change
```

```go
// TODO: new leader catchup without ignore view change message
if consensus.blockNum > recvMsg.BlockNum {
    consensus.getLogger().Debug().
        Uint64("MsgBlockNum", recvMsg.BlockNum).
        Msg("[onViewChange] Message BlockNum Is Low")
    return
}

if consensus.blockNum < recvMsg.BlockNum {
    consensus.getLogger().Warn().
        Uint64("MsgBlockNum", recvMsg.BlockNum).
        Msg("[onViewChange] New Leader Has Lower Blocknum")
    return
}

if consensus.current.Mode() == ViewChanging &&
    consensus.current.ViewID() > recvMsg.ViewID {
    consensus.getLogger().Warn().
        Uint64("MyViewChangingID", consensus.current.ViewID()).
        Uint64("MsgViewChangingID", recvMsg.ViewID).
        Msg("[onViewChange] ViewChanging ID Is Low")
    return
}
if err = verifyMessageSig(senderKey, msg); err != nil {
    consensus.getLogger().Debug().Err(err).Msg("[onViewChange] Failed To Verify Sender's Signature")
    return
}

consensus.vcLock.Lock()
defer consensus.vcLock.Unlock()

// update the dictionary key if the viewID is first time received
consensus.addViewIDKeyIfNotExist(recvMsg.ViewID)
```

Listing 3.29: consensus/view_change.go

```go
// received enough view change messages, change state to normal consensus
if consensus.Decider.IsQuorumAchievedByMask(consensus.viewIDBitmap[recvMsg.ViewID], true) {
    consensus.current.SetMode(Normal)
    consensus.LeaderPubKey = consensus.PubKey
    consensus.ResetState()
    if len(consensus.m1Payload) == 0 {
        // TODO(Chao): explain why ReadySignal is sent only in this case but not the other case.
        go func() {
            consensus.ReadySignal <- struct{}{}
        }()
    } else {
```

Listing 3.30: consensus/view_change.go

```
395         consensus.current.setviewid(recvmsg.viewid)
396         msgtosend := consensus.constructnewviewmessage(recvmsg.viewid)
397 
398         consensus.getLogger().Warn().
399       Int("payloadSize", len(consensus.m1Payload)).
400       Hex("M1Payload", consensus.m1Payload).
401       Msg("[onViewChange] Sent NewView Message")
402     consensus.msgSender.SendWithRetry(consensus.blockNum, msg_pb.MessageType_NEWVIEW, []
        nodeconfig.GroupID{nodeconfig.NewGroupIDByShardID(nodeconfig.ShardID(consensus.
        ShardID))}, host.ConstructP2pMessage(byte(17), msgToSend))
403 
404         consensus.viewid = recvmsg.viewid
405         consensus.resetviewchangestate()
406         consensus.consensustimeout[timeoutviewchange].stop()
407         consensus.consensustimeout[timeoutconsensus].start()
```

Listing 3.31: consensus/view_change.go

`onViewChange` is responsible for view change handling for validators. First, make sure it's the next leader (line 151), then update the dictionary key if the viewID is received for the first time (line 203) Once new leader receives enough view change messages (line 350), it would change state to normal, and reset the consensus state (line 351-353). Finally, new leader will construct and send out a new view message to others (line 396-402), and reset its view change state (line 405). However, there is no constraint on updating the dictionary key.

```
func (consensus *Consensus) addViewIDKeyIfNotExist(viewID uint64) {
    members := consensus.Decider.Participants()
    if _, ok := consensus.bhpSigs[viewID]; !ok {
        consensus.bhpSigs[viewID] = map[string]*bls.Sign{}
    }
    if _, ok := consensus.nilSigs[viewID]; !ok {
        consensus.nilSigs[viewID] = map[string]*bls.Sign{}
    }
    if _, ok := consensus.viewIDSigs[viewID]; !ok {
        consensus.viewIDSigs[viewID] = map[string]*bls.Sign{}
    }
    if _, ok := consensus.bhpBitmap[viewID]; !ok {
        bhpBitmap, _ := bls_cosi.NewMask(members, nil)
        consensus.bhpBitmap[viewID] = bhpBitmap
    }
    if _, ok := consensus.nilBitmap[viewID]; !ok {
        nilBitmap, _ := bls_cosi.NewMask(members, nil)
        consensus.nilBitmap[viewID] = nilBitmap
    }
    if _, ok := consensus.viewIDBitmap[viewID]; !ok {
        viewIDBitmap, _ := bls_cosi.NewMask(members, nil)
        consensus.viewIDBitmap[viewID] = viewIDBitmap
    }
}
```

Listing 3.32: consensus/consensus_service.go

A malicious validator could flood next leader by sending lots of view change messages with different viewID. `addViewIDKeyIfNotExist` would make new maps and masks for first time received new viewID. On the other hand, the crafted view change messages may never achieve quorum to trigger view change process and clear the view state, so in the end, the next leader would run out of memory.

Recommendation Add sanity checks for the viewID of view change messages.

3.12 Consensus Suspending in the Consensus Module - #2

- ID: PVE-012
- Severity: Critical
- Likelihood: High
- Impact: High
- Target: `consensus/view_change.go`
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-115 [21]

Description

Under harmony's PBFT consensus protocol, there are two causes for validators to start view change process. One is when a validator detects the leader proposed two different announce messages in one view, it would immediately start view change. The other is a validator doesn't make any progress after timeout. There are two kinds of timeouts: timeout in normal consensus mode and timeout in view change mode.

The view change process is as follows:

1) When the consensus timer timeouts, a node starts view change by sending view change message including viewID and prepared message (containing >=2f+1 aggregated signatures) to new leader. If it doesn't receive prepared message, it just sends view change message including signature on viewID but without prepared message.

2) When the new leader receives enough (>=2f+1) view change messages, it aggregates signatures of viewID and just pick one prepared message from view change messages. It broadcasts new view message including aggregated signatures as well as the picked prepared message. Then the new leader switches to normal consensus mode. A validator switches to normal consensus node when it receives new view message from the new leader, at the same time, it stops the view change timer and start the consensus timer. If the validator doesn't receive new view message before view change timeout, it would increase viewID by one and start another view change.

```
440  if recvMsg.M3AggSig == nil || recvMsg.M3Bitmap == nil {
441    consensus.getLogger().Error().Msg("[onNewView] M3AggSig or M3Bitmap is nil")
442    return
443  }
444  m3Sig := recvMsg.M3AggSig
445  m3Mask := recvMsg.M3Bitmap
446
447  viewIDBytes := make([]byte, 8)
448  binary.LittleEndian.PutUint64(viewIDBytes, recvMsg.ViewID)
449
450  if !consensus.Decider.IsQuorumAchievedByMask(m3Mask, true) {
451    consensus.getLogger().Warn().
452      Msgf("[onNewView] Quorum Not achieved")
453    return
454  }
455
456  if !m3Sig.VerifyHash(m3Mask.AggregatePublic, viewIDBytes) {
457    consensus.getLogger().Warn().
458      Str("m3Sig", m3Sig.SerializeToHexStr()).
459      Hex("m3Mask", m3Mask.Bitmap).
460      Uint64("MsgViewID", recvMsg.ViewID).
461      Msg("[onNewView] Unable to Verify Aggregated Signature of M3 (ViewID) payload")
462    return
463  }
```

Listing 3.33: consensus/view_change.go

```
515  // newView message verified success, override my state
516  consensus.viewID = recvMsg.ViewID
517  consensus.current.SetViewID(recvMsg.ViewID)
518  consensus.LeaderPubKey = senderKey
519  consensus.ResetViewChangeState()
520
521  // change view and leaderKey to keep in sync with network
522  if consensus.blockNum != recvMsg.BlockNum {
523    consensus.getLogger().Debug().
```

Listing 3.34: consensus/view_change.go

`onNewView` is called when a validator receives the new view message from new leader at step 2. It would check whether the signature of viewID is valid and achieved the quorum (line 440-463). If verified successly, the consensus state would be updated (line 516-519).

However, some sanity checks are missing:

1) recvMsg.ViewID should > consensus.current.ViewID()

2) new view message should only come from next leader

A malicious next leader could save the new view message, and broadcast out whenever it wants to become leader, thus break the harmony network consensus. On the other hand, any committee member can also send the new view message to other validators, though it may not become the leader, can still compromise the consensus.

Recommendation Add sanity checks for the viewID of new view messages.

3.13 Consensus Suspending in the Consensus Module - #3

- ID: PVE-013
- Severity: High
- Likelihood: Medium
- Impact: High
- Target: `consensus/checks.go`
- Category: Input Validation Issues [22]
- CWE subcategory: CWE-349 [23]

Description

This is a vulnerability in the consensus module, which could be exploited by attackers to compromise the harmony network consensus.

As an improvement on PBFT, Harmony's consensus protocol is linearly scalable in terms of communication complexity, and thus it is called Fast Byzantine Fault Tolerance (FBFT).

In prepare phase, the validator sends prepare message (e.g. signature on blockhash) to leader. When leader receives enough (i.e. >=2f+1) prepare messages, it aggregates signatures of prepare messages received from validators and sends out prepared message contains aggregated prepare signatures and the candidate block.

```
func (consensus *Consensus) onPrepared(msg *msg_pb.Message) {
  recvMsg, err := ParseFBFTMessage(msg)
  if err != nil {
    consensus.getLogger().Debug().Err(err).Msg("[OnPrepared] Unparseable validator
        message")
    return
  }
  consensus.getLogger().Info().
    Uint64("MsgBlockNum", recvMsg.BlockNum).
    Uint64("MsgViewID", recvMsg.ViewID).
    Msg("[OnPrepared] Received prepared message")

  if recvMsg.BlockNum < consensus.blockNum {
    consensus.getLogger().Debug().Uint64("MsgBlockNum", recvMsg.BlockNum).
      Msg("Wrong BlockNum Received, ignoring!")
    return
  }

  // check validity of prepared signature
  blockHash := recvMsg.BlockHash
  aggSig, mask, err := consensus.ReadSignatureBitmapPayload(recvMsg.Payload, 0)
```

```
114   if err != nil {
115     consensus.getLogger().Error().Err(err).Msg("ReadSignatureBitmapPayload failed!")
116     return
117   }
118
119   if !consensus.Decider.IsQuorumAchievedByMask(mask) {
120     consensus.getLogger().Warn().
121       Msgf("[OnPrepared] Quorum Not achieved")
122     return
123   }
124
125   if !aggSig.VerifyHash(mask.AggregatePublic, blockHash[:]) {
126     myBlockHash := common.Hash{}
127     myBlockHash.SetBytes(consensus.blockHash[:])
128     consensus.getLogger().Warn().
129       Uint64("MsgBlockNum", recvMsg.BlockNum).
130       Uint64("MsgViewID", recvMsg.ViewID).
131       Msg("[OnPrepared] failed to verify multi signature for prepare phase")
132     return
133   }
134
135   // check validity of block
136   var blockObj types.Block
137   if err := rlp.DecodeBytes(recvMsg.Block, &blockObj); err != nil {
138     consensus.getLogger().Warn().
139       Err(err).
140       Uint64("MsgBlockNum", recvMsg.BlockNum).
141       Msg("[OnPrepared] Unparseable block header data")
142     return
143   }
144   // let this handle it own logs
145   if !consensus.onPreparedSanityChecks(&blockObj, recvMsg) {
146     return
147   }
148   consensus.mutex.Lock()
149   defer consensus.mutex.Unlock()
150
151   consensus.FBFTLog.AddBlock(&blockObj)
152   ......
```

Listing 3.35: consensus/validator.go

onPrepared is called when validators receives prepared message from the leader. It would perform lots of sanity checks to make sure the message is valid. If it's legit, validators would store the attached block (line 151)

```
234 func (consensus *Consensus) onCommitted(msg *msg_pb.Message) {
235   recvMsg, err := ParseFBFTMessage(msg)
236   if err != nil {
237     consensus.getLogger().Warn().Msg("[OnCommitted] unable to parse msg")
238     return
239   }
```

```
// NOTE let it handle its own logs
if !consensus.isRightBlockNumCheck(recvMsg) {
  return
}

aggSig, mask, err := consensus.ReadSignatureBitmapPayload(recvMsg.Payload, 0)
if err != nil {
  consensus.getLogger().Error().Err(err).Msg("[OnCommitted] readSignatureBitmapPayload failed")
  return
}

if !consensus.Decider.IsQuorumAchievedByMask(mask) {
  consensus.getLogger().Warn().
    Msgf("[OnCommitted] Quorum Not achieved")
  return
}

// TODO(audit): verify signature on hash+blockNum+viewID (add a hard fork)
blockNumBytes := make([]byte, 8)
binary.LittleEndian.PutUint64(blockNumBytes, recvMsg.BlockNum)
commitPayload := append(blockNumBytes, recvMsg.BlockHash[:]...)
if !aggSig.VerifyHash(mask.AggregatePublic, commitPayload) {
  consensus.getLogger().Error().
    Uint64("MsgBlockNum", recvMsg.BlockNum).
    Msg("[OnCommitted] Failed to verify the multi signature for commit phase")
  return
}

consensus.FBFTLog.AddMessage(recvMsg)
consensus.ChainReader.WriteLastCommits(recvMsg.Payload)
consensus.getLogger().Debug().
  Uint64("MsgViewID", recvMsg.ViewID).
  Uint64("MsgBlockNum", recvMsg.BlockNum).
  Msg("[OnCommitted] Committed message added")

consensus.mutex.Lock()
defer consensus.mutex.Unlock()

consensus.aggregatedCommitSig = aggSig
consensus.commitBitmap = mask

if recvMsg.BlockNum-consensus.blockNum > consensusBlockNumBuffer {
  consensus.getLogger().Debug().Uint64("MsgBlockNum", recvMsg.BlockNum).Msg("[OnCommitted] out of sync")
  go func() {
    select {
    case consensus.BlockNumLowChan <- struct{}{}:
      consensus.current.SetMode(Syncing)
      for _, v := range consensus.consensusTimeout {
        v.Stop()
      }
290       case <-time.After(1 * time.Second):
291       }
292     }()
293     return
294   }
295 
296   consensus.tryCatchup()
297   if consensus.current.Mode() == ViewChanging {
298     consensus.getLogger().Debug().Msg("[OnCommitted] Still in ViewChanging mode, Exiting !!")
299     return
300   }
301 
302   if consensus.consensusTimeout[timeoutBootstrap].IsActive() {
303     consensus.consensusTimeout[timeoutBootstrap].Stop()
304     consensus.getLogger().Debug().Msg("[OnCommitted] Start consensus timer; stop bootstrap timer only once")
305   } else {
306     consensus.getLogger().Debug().Msg("[OnCommitted] Start consensus timer")
307   }
308   consensus.consensusTimeout[timeoutConsensus].Start()
309 }
```

Listing 3.36: consensus/validator.go

After all validators agreed on the prepared message and enough commit messages are collected by the leader (i.e. >=2f+1), it would send committed message. `onCommitted` is called to handle the message, it would also perform lots of sanity checks to make sure the message is valid. If all seem right, this round is finished and the consensus timer would be reset (line 308).

However, the sanity checks in `onPreparedSanityChecks` can't guarantee the block is valid.

```
func (consensus *Consensus) onPreparedSanityChecks(
  blockObj *types.Block, recvMsg *FBFTMessage,
) bool {
  if blockObj.NumberU64() != recvMsg.BlockNum ||
    recvMsg.BlockNum < consensus.blockNum {
    consensus.getLogger().Warn().
      Uint64("MsgBlockNum", recvMsg.BlockNum).
      Uint64("blockNum", blockObj.NumberU64()).
      Msg("[OnPrepared] BlockNum not match")
    return false
  }
  if blockObj.Header().Hash() != recvMsg.BlockHash {
    consensus.getLogger().Warn().
      Uint64("MsgBlockNum", recvMsg.BlockNum).
      Hex("MsgBlockHash", recvMsg.BlockHash[:]).
      Str("blockObjHash", blockObj.Header().Hash().Hex()).
      Msg("[OnPrepared] BlockHash not match")
    return false
  }
  if consensus.current.Mode() == Normal {
    err := chain.Engine.VerifyHeader(consensus.ChainReader, blockObj.Header(), true)
151     if err != nil {
152       consensus.getLogger().Error().
153         Err(err).
154         Str("inChain", consensus.ChainReader.CurrentHeader().Number().String()).
155         Str("MsgBlockNum", blockObj.Header().Number().String()).
156         Msg("[OnPrepared] Block header is not verified successfully")
157       return false
158     }
159     if consensus.BlockVerifier == nil {
160       // do nothing
161     } else if err := consensus.BlockVerifier(blockObj); err != nil {
162       consensus.getLogger().Error().Err(err).Msg("[OnPrepared] Block verification failed")
163       return false
164     }
165   }
166 
167   return true
168 }
```

Listing 3.37: consensus/checks.go

Specifically, a malicious leader can bypass the sanity checks (line 149-165) by making validators switch to Syncing mode.

```
205 func (node *Node) DoSyncing(bc *core.BlockChain, worker *worker.Worker, willJoinConsensus bool) {
206 
207   // TODO ek infinite loop; add shutdown/cleanup logic
208 SyncingLoop:
209   for {
210     if node.stateSync == nil {
211       node.stateSync = syncing.CreateStateSync(node.SelfPeer.IP, node.SelfPeer.Port, node.GetSyncID())
212       utils.Logger().Debug().Msg("[SYNC] initialized state sync")
213     }
214     if node.stateSync.GetActivePeerNumber() < MinConnectedPeers {
215       shardID := bc.ShardID()
216       peers, err := node.SyncingPeerProvider.SyncingPeers(shardID)
217       if err != nil {
218         utils.Logger().Warn().
219           Err(err).
220           Uint32("shard_id", shardID).
221           Msg("cannot retrieve syncing peers")
222         continue SyncingLoop
223       }
224       if err := node.stateSync.CreateSyncConfig(peers, false); err != nil {
225         utils.Logger().Warn().
226           Err(err).
227           Interface("peers", peers).
228           Msg("[SYNC] create peers error")
229         continue SyncingLoop
230       }
231       utils.Logger().Debug().Int("len", node.stateSync.GetActivePeerNumber()).Msg("[SYNC
              ] Get Active Peers")
232     }
233     // TODO: treat fake maximum height
234     if node.stateSync.IsOutOfSync(bc) {
235       node.stateMutex.Lock()
236       node.State = NodeNotInSync
237       node.stateMutex.Unlock()
238       if willJoinConsensus {
239         node.Consensus.BlocksNotSynchronized()
240       }
241       node.stateSync.SyncLoop(bc, worker, false, node.Consensus)
242       if willJoinConsensus {
243         node.stateMutex.Lock()
244         node.State = NodeReadyForConsensus
245         node.stateMutex.Unlock()
246         node.Consensus.BlocksSynchronized()
247       }
248     }
249     node.stateMutex.Lock()
250     node.State = NodeReadyForConsensus
251     node.stateMutex.Unlock()
252     // TODO on demand syncing
253     time.Sleep(time.Duration(node.syncFreq) * time.Second)
254   }
255 }
```

Listing 3.38: node/node_syncing.go

A node would switch to Syncing mode if the node thinks it's out of sync (line 234, 239). How a node decides whether it's out of sync is by asking other peers about their block height.

```
case downloader_pb.DownloaderRequest_BLOCKHEIGHT:
  response.BlockHeight = node.Blockchain().CurrentBlock().NumberU64()
}
```

Listing 3.39: node/node_syncing.go

Theoretically, the malicious leader could trick other committee into Syncing mode by returning a fake high block height. Once validators are in Syncing mode, they would skip the block sanity checks in `onPreparedSanityChecks`, store whatever kind of block the leader sent and reply with the corresponding commit message. Once leader has enough commit message, it would send committed message to validators, and start a new round.

```
func (consensus *Consensus) tryCatchup() {
  consensus.getLogger().Info().Msg("[TryCatchup] commit new blocks")
  currentBlockNum := consensus.blockNum
  for {
    msgs := consensus.FBFTLog.GetMessagesByTypeSeq(msg_pb.MessageType_COMMITTED,
        consensus.blockNum)
    if len(msgs) == 0 {
      break
    }
    if len(msgs) > 1 {
      consensus.getLogger().Error().
        Int("numMsgs", len(msgs)).
        Msg("[TryCatchup] DANGER!!! we should only get one committed message for a given blockNum")
    }
    consensus.getLogger().Info().Msg("[TryCatchup] committed message found")

    block := consensus.FBFTLog.GetBlockByHash(msgs[0].BlockHash)
    if block == nil {
      break
    }

    if consensus.BlockVerifier == nil {
      // do nothing
    } else if err := consensus.BlockVerifier(block); err != nil {
      consensus.getLogger().Info().Msg("[TryCatchup] block verification failed")
      return
    }

    if block.ParentHash() != consensus.ChainReader.CurrentHeader().Hash() {
      consensus.getLogger().Debug().Msg("[TryCatchup] parent block hash not match")
      break
    }
    consensus.getLogger().Info().Msg("[TryCatchup] block found to commit")

    preparedMsgs := consensus.FBFTLog.GetMessagesByTypeSeqHash(
      msg_pb.MessageType_PREPARED, msgs[0].BlockNum, msgs[0].BlockHash,
    )
    msg := consensus.FBFTLog.FindMessageByMaxViewID(preparedMsgs)
    if msg == nil {
      break
    }
    consensus.getLogger().Info().Msg("[TryCatchup] prepared message found to commit")

    // TODO(Chao): Explain the reasoning for these code
    consensus.blockHash = [32]byte{}
    consensus.blockNum = consensus.blockNum + 1
    consensus.viewID = msgs[0].ViewID + 1
    consensus.LeaderPubKey = msgs[0].SenderPubkey

    consensus.getLogger().Info().Msg("[TryCatchup] Adding block to chain")
    consensus.OnConsensusDone(block, msgs[0].Payload)
    consensus.ResetState()

    select {
    case consensus.VerifiedNewBlock <- block:
    default:
      consensus.getLogger().Info().
        Str("blockHash", block.Hash().String()).
        Msg("[TryCatchup] consensus verified block send to chan failed")
```

```
266       continue
267     }
268 
269     break
270   }
271   if currentBlockNum < consensus.blockNum {
272     consensus.getLogger().Info().
273       Uint64("From", currentBlockNum).
274       Uint64("To", consensus.blockNum).
275       Msg("[TryCatchup] Caught up!")
276     consensus.switchPhase(FBFTAnnounce, true)
277   }
278   // catup up and skip from view change trap
279   if currentBlockNum < consensus.blockNum &&
280     consensus.current.Mode() == ViewChanging {
281     consensus.current.SetMode(Normal)
282     consensus.consensusTimeout[timeoutViewChange].Stop()
283   }
284   // clean up old log
285   consensus.FBFTLog.DeleteBlocksLessThan(consensus.blockNum - 1)
286   consensus.FBFTLog.DeleteMessagesLessThan(consensus.blockNum - 1)
287 }
288 }
```

Listing 3.40: consensus/consensus_v2.go

However, this round may not be able to complete. Say, if the leader sends a malformed block within the prepared message and bypasses the block sanity checks as we explained above, then `tryCatchup` would not be able to proceed because the validity checks (line 240-248), thus validators would not go to next round(line 261-268). What even worse is `onCommitted` would reset the consensus timer in the end, so the malicious leader could use the same committed message to suspend the consensus process and eventually compromise the entire harmony network.

Also, consensus module uses `mapset.Set` to store received blocks / messages, but they are stored by their addresses, not contents (fields). So this vulnerability could also be exploited to attack committee members by flooding and make them Out-of-Memory.

Recommendation Add check when receiving peer's block height.

3.14 Missing Sanity Check on Slash Records - #1

- ID: PVE-014
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: `staking/slash/double-sign.go`
- Category: Input Validation Issues [22]
- CWE subcategory: CWE-349 [23]

Description

This is a vulnerability in the slashing module, which could be exploited by attackers to compromise the harmony network consensus. Harmony network introduces Effective Proof-of-Stake, an efficient staking mechanism that avoids stake centralization while still supporting stake compounding and delegation.

In addition to the block rewards used to incentivize good behavior, the slashing mechanism is equally important as it can deter misbehavior and potential attacks. In EPoS, there are slashing rules for misbehaviors like double-signing or unavailability.

```go
196 func (consensus *Consensus) onCommit(msg *msg_pb.Message) {
197   recvMsg, err := ParseFBFTMessage(msg)
198   log := consensus.getLogger()
199   if err != nil {
200     consensus.getLogger().Debug().Err(err).Msg("[OnCommit] Parse pbft message failed")
201     return
202   }
203 
204   // NOTE let it handle its own log
205   if !consensus.isRightBlockNumAndViewID(recvMsg) {
206     return
207   }
208 
209   consensus.mutex.Lock()
210   defer consensus.mutex.Unlock()
211 
212   // TODO(audit): refactor into a new func
213   if key := (bls.PublicKey{}); consensus.couldThisBeADoubleSigner(recvMsg) {
214     if alreadyCastBallot := consensus.Decider.ReadBallot(
215       quorum.Commit, recvMsg.SenderPubkey,
216     ); alreadyCastBallot != nil {
217       for _, blk := range consensus.FBFTLog.GetBlocksByNumber(recvMsg.BlockNum) {
218         alreadyCastBallot.SignerPubKey.ToLibBLSPublicKey(&key)
219         if recvMsg.SenderPubkey.IsEqual(&key) {
220           signed := blk.Header()
221           areHeightsEqual := signed.Number().Uint64() == recvMsg.BlockNum
222           areViewIDsEqual := signed.ViewID().Uint64() == recvMsg.ViewID
223           areHeadersEqual := bytes.Compare(
224             signed.Hash().Bytes(), recvMsg.BlockHash.Bytes(),
225           ) == 0
```

Listing 3.41: consensus/leader.go

`onCommit` is called when leader receives commit messages from validators. It would perform lots of sanity checks to make sure the message is valid, also the submitter is not a double-signer (line 213-225).

```go
func (w *Worker) CollectVerifiedSlashes() error {
  pending, failures :=
    w.chain.ReadPendingSlashingCandidates(), slash.Records{}
  if d := pending; len(d) > 0 {
    pending, failures = w.verifySlashes(d)
  }

  if f := failures; len(f) > 0 {
    if err := w.chain.DeleteFromPendingSlashingCandidates(f); err != nil {
      return err
    }
  }
  w.current.slashes = pending
  return nil
}
```

Listing 3.42: node/worker/worker.go

`CollectVerifiedSlashes` is responsible for collecting slashing evidences for double-signer which would be used later in block producing. However, the sanity check in `CollectVerifiedSlashes` could be bypassed and cause serious damages to the harmony network consensus.

```
func Verify(
  chain CommitteeReader,
  state *state.DB,
  candidate *Record,
) error {
  wrapper, err := state.ValidatorWrapper(candidate.Offender)
  if err != nil {
    return err
  }

  if wrapper.EPOSStatus == effective.Banned {
    return errAlreadyBannedValidator
  }

  if candidate.Offender == candidate.Reporter {
    return errReporterAndOffenderSame
  }

  first, second :=
    candidate.Evidence.AlreadyCastBallot,
    candidate.Evidence.DoubleSignedBallot
  k1, k2 := len(first.SignerPubKey), len(second.SignerPubKey)
  if k1 != shard.PublicKeySizeInBytes ||
    k2 != shard.PublicKeySizeInBytes {
    return errors.Wrapf(
      errSignerKeyNotRightSize, "cast key %d double-signed key %d", k1, k2,
    )
  }

  if shard.CompareBlsPublicKey(first.SignerPubKey, second.SignerPubKey) != 0 {
    k1, k2 := first.SignerPubKey.Hex(), second.SignerPubKey.Hex()
    return errors.Wrapf(
      errBallotSignerKeysNotSame, "%s %s", k1, k2,
    )
  }
  currentEpoch := chain.CurrentBlock().Epoch()
  // the slash can't come from the future (shard chain's epoch can't be larger than beacon chain's)
  if candidate.Evidence.Epoch.Cmp(currentEpoch) == 1 {
    return errors.Wrapf(
      errSlashFromFutureEpoch, "current-epoch %v", currentEpoch,
    )
  }

  superCommittee, err := chain.ReadShardState(candidate.Evidence.Epoch)

  if err != nil {
    return err
  }

  subCommittee, err := superCommittee.FindCommitteeByID(
    candidate.Evidence.ShardID,
  )

  if err != nil {
    return errors.Wrapf(
      err, "given shardID %d", candidate.Evidence.ShardID,
    )
  }

  if addr, err := subCommittee.AddressForBLSKey(
    second.SignerPubKey,
  ); err != nil || *addr != candidate.Offender {
    return err
  }

  for _, ballot := range [...]votepower.Ballot{
    candidate.Evidence.AlreadyCastBallot,
    candidate.Evidence.DoubleSignedBallot,
  } {
    // now the only real assurance, cryptography
    signature := &bls.Sign{}
    publicKey := &bls.PublicKey{}

    if err := signature.Deserialize(ballot.Signature); err != nil {
      return err
    }
    if err := first.SignerPubKey.ToLibBLSPublicKey(publicKey); err != nil {
      return err
    }

    blockNumBytes := make([]byte, 8)
    // TODO(audit): add view ID into signature payload
    binary.LittleEndian.PutUint64(blockNumBytes, ballot.Height)
    commitPayload := append(blockNumBytes, ballot.BlockHeaderHash[:]...)
```

```
237       if !signature.VerifyHash(publicKey, commitPayload) {
238         return errFailVerifySlash
239       }
240     }
241
242     return nil
243   }
```

Listing 3.43: staking/slash/double-sign.go

However, the sanity check could be bypassed by providing two identical `votepower.ballot` since the loop (line 218-240) doesn't verify whether the two records are exactly the same. So an attacker could broadcast some crafted slash records, and the leader would take these records into account while producing new blocks, slash innocent validators and delegators, eventually compromise the whole harmony network.

Recommendation Add more checks when receiving slash records.

3.15 Missing Sanity Check on Slash Records - #2

- ID: PVE-015
- Severity: High
- Likelihood: High
- Impact: Medium
- Target: `core/blockchain.go`
- Category: Behavioral Problems [16]
- CWE subcategory: CWE-115 [21]

Description

This is a vulnerability in the slashing module, which could be exploited by attackers to compromise the harmony network consensus. Harmony introduces Effective Proof-of-Stake, an efficient staking mechanism that avoids stake centralization while still supporting stake compounding and delegation. In addition to the block rewards used to incentivize good behavior, the slashing mechanism is equally important as it can deter misbehavior and potential attacks. In EPoS, there are slashing rules for misbehavior like double-signing or unavailability.

```
func (consensus *Consensus) onCommit(msg *msg_pb.Message) {
  recvMsg, err := ParseFBFTMessage(msg)
  log := consensus.getLogger()
  if err != nil {
    consensus.getLogger().Debug().Err(err).Msg("[OnCommit] Parse pbft message failed")
    return
  }

  // NOTE let it handle its own log
  if !consensus.isRightBlockNumAndViewID(recvMsg) {
```

```
206      return
207    }
208
209    consensus.mutex.Lock()
210    defer consensus.mutex.Unlock()
211
212    // TODO(audit): refactor into a new func
213    if key := (bls.PublicKey{}); consensus.couldThisBeADoubleSigner(recvMsg) {
214      if alreadyCastBallot := consensus.Decider.ReadBallot(
215        quorum.Commit, recvMsg.SenderPubkey,
216      ); alreadyCastBallot != nil {
217        for _, blk := range consensus.FBFTLog.GetBlocksByNumber(recvMsg.BlockNum) {
218          alreadyCastBallot.SignerPubKey.ToLibBLSPublicKey(&key)
219          if recvMsg.SenderPubkey.IsEqual(&key) {
220            signed := blk.Header()
221            areHeightsEqual := signed.Number().Uint64() == recvMsg.BlockNum
222            areViewIDsEqual := signed.ViewID().Uint64() == recvMsg.ViewID
223            areHeadersEqual := bytes.Compare(
224              signed.Hash().Bytes(), recvMsg.BlockHash.Bytes(),
225            ) == 0
```

Listing 3.44: consensus/leader.go

`onCommit` is called when leader receives commit messages from validators. It would perform lots of sanity checks to make sure the message is valid, and the submitter is not a double-signer(line 213-225).

```
case doubleSign := <-node.Consensus.SlashChan:
  utils.Logger().Info().
    RawJSON("double-sign-candidate", []byte(doubleSign.String())).
    Msg("double sign notified by consensus leader")
  // no point to broadcast the slash if we aren't even in the right epoch yet
  if !node.Blockchain().Config().IsStaking(
    node.Blockchain().CurrentHeader().Epoch(),
  ) {
    return
  }
  if hooks := node.NodeConfig.WebHooks.Hooks; hooks != nil {
    if s := hooks.Slashing; s != nil {
      url := s.OnNoticeDoubleSign
      go func() { webhooks.DoPost(url, &doubleSign) }()
    }
  }
  if node.NodeConfig.ShardID != shard.BeaconChainShardID {
    go node.BroadcastSlash(&doubleSign)
  } else {
    records := slash.Records{doubleSign}
    if err := node.Blockchain().AddPendingSlashingCandidates(
      records,
    ); err != nil {
      utils.Logger().Err(err).Msg("could not add new slash to ending slashes")
    }
618   }
619 }
```

Listing 3.45: node/node.go

When double-signer is detected, beacon chain leader would call `AddPendingSlashingCandidates` to store the record (line 613); leaders of other shards would broadcast it to beacon chain through P2P message (line 610) .

```
39 func (bc *BlockChain) AddPendingSlashingCandidates(
40   candidates slash.Records,
41 ) error {
42   bc.pendingSlashingCandidatesMU.Lock()
43   defer bc.pendingSlashingCandidatesMU.Unlock()
44   current := bc.ReadPendingSlashingCandidates()
45   pendingSlashes := append(
46     bc.pendingSlashes, current.SetDifference(candidates)...,
47   )
48   if l, c := len(pendingSlashes), len(current); l > maxPendingSlashes {
49     return errors.Wrapf(
50       errExceedMaxPendingSlashes, "current %d with-additional %d", c, l,
51     )
52   }
53   bc.pendingSlashes = pendingSlashes
54   return bc.writeSlashes(bc.pendingSlashes)
55 }
```

Listing 3.46: core/blockchain.go

`AddPendingSlashingCandidates` would make sure each slash record is unique (line 2038) and the length won't go beyond `maxPendingSlashes`. However, there is no sanity check to guarantee the slash records are valid, nor a limitation on how many records a node can send to others. So theoretically, a malicious node can flood a leader to stuff `bc.pendingSlashes` with lots of slash records, which could prevent legit slash records from being inserted into the slice and disable the slashing mechanism in a way. On the other hand, the uniqueness check can also be easily bypassed by adjusting some fields in the record, e.g., `TimeUnixNano`.

Recommendation Add more checks when adding slashing candidates.

4 | Conclusion

For this security audit, we have analyzed the Harmony Blockchain. During the first phase of our audit, we studied the source code and ran our in-house analyzing tools through the codebase, including areas such as Harmony VM and crypto libraries. Next, we audited the general token transfer, staking, and consensus logics, after that, we examined the slash logics. A list of potential issues were found, and some of them involve unusual interactions among multiple modules, therefore we developed test cases to reproduce and verify each of them. After further analysis and internal discussion, we determined that a number of issues need to be brought up and pay more attention to, which are reported in Sections 2 and 3. Given that the reported issues have been confirmed and fixed, we do feel that the Harmony blockchain code has been thoroughly inspected, therefore they can be deployed on the blockchain with confidence.

Our impression through this audit is that the Harmony Blockchain software is neatly organized and elegantly implemented and those identified issues are promptly confirmed and fixed. We'd like to commend Harmony for a well-done software project, and for quickly fixing issues found during the audit process. Also, as expressed in Section 1.4, we appreciate any constructive feedback or suggestions about this report.

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