A CONSENSYS DILIGENCE AUDIT REPORT

Summary - Thesis: tBTC and Keep

Date	February 2020
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Co-auditors	Alexander Wade

1 Executive Summary

In January 2020, Thesis asked us to conduct a security assessment of tBTC: a trust-minimized, redeemable, Bitcoin-backed ERC20 token. tBTC utilizes and builds on functionality provided by Summa and the Keep Network.

This document is a standalone summary. The full report can be found here.

We performed this assessment from February 03 to March 27, 2020. The assessment primarily focused on tBTC alongside its associated components. The engagement was conducted by Martin Ortner and Alexander Wade over the course of twelve person-weeks.

In addition to the review of tBTC, a review was performed of the cryptographic constructions and algorithms used in the Keep Network. A

complete report of this portion of the engagement can be found here.

1.1 Scope

We analyzed code located in the following repositories at the provided commits:

Repository	Audit Revision
keep-network/tbtc	#dcb1148025d6a1238b49a80fd56d8ca0beb93781
summa-tx/bitcoin-spv	#f5e4da091a1c97e6432c2d70eba434edb189f919
keep-network/keep-tecdsa – keep-network/sortition-pools	#c69871d252378c63ab47ab3f652de0a63b09eea5 #32523a74bb5fa51345de05f756ca8a9ecf246282
keep-network/keep-core	#b76b418f04bc94030d10aff18220d8e560a2ab09

Third party dependencies not explicitly mentioned in the above list (e.g. `summa-tx/relay-sol`) were out of scope for the audit.

tBTC interacts with the Keep Network via customized interfaces from `keep-network/keep-tecdsa`, which itself uses `keep-network/sortition-pools`. The keep random beacon used for signer group election (`keep-network/keep-core`) builds on an implementation of BLS signatures on the altbn128 curve. The source code is located in five repositories with the following dependencies as seen from the tBTC solution:

- `keep-network/tbtc`
  - `summa-tx/bitcoin-spv`
  - `keep-network/keep-tecdsa`
    - `keep-network/sortition-pools`
  - `keep-network/keep-core`
- `keep-network/keep-core` (independent solution)

Together with the client, it was established that the main focus for the review would be the smart contracts in the listed repositories, with a secondary focus on reviewing the keep client (located in `keep-core`).

A complete list of files in scope can be found in the Appendix.

1.2 Objectives

Given the limited time available and ongoing development on some components in scope, we elected to begin with a top-down approach centered around tBTC as the focal point. We started by understanding the architecture and design of high-risk components first, before diving into various system components to verify security assumptions.

Our primary objectives were to:

1. Ensure that the system is implemented consistently with the intended functionality, and without unintended edge cases.
2. Identify known vulnerabilities particular to smart contract systems, as outlined in our Smart Contract Best Practices, and the Smart Contract Weakness Classification Registry.
3. Ensure that there is no way to break the TBTC-BTC peg and that it is as difficult as possible to abscond with deposited funds for the backing ECDSA keep.

We also sought opportunities to improve the quality of the code either by reducing the complexity, or improving clarity and readability.

1.3 Audit Log - Phase 1

The primary engagement (Feb 03 - Feb 28) was scheduled as follows:

Week 1	Week 2	Week 3	Week 4
- ramp up `tbtc` - review `bitcoin-spv`	- `bitcoin-spv` - tBTC Deposits	- tBTC Deposits - ramp up keep	- keep - `keep-tecdsa` - `sortition-pools`

Week 1

During the first week, our efforts were directed towards tBTC: understanding the intention of its design and how it uses `bitcoin-spv` to validate spv proofs and other Bitcoin transaction information. This involved defining key risk factors and potential vulnerabilities requiring further investigation. Key findings were shared with the client in an end-of-week sync meeting.

By the end of the first week, the tBTC codebase was modified from its initial audit commit to the revision v1-audit. The client also provided a frozen codebase for keep-network/keep-core. keep-network/keep-tecdsa was still undergoing changes.

Week 2

During the second week, we reviewed changes made to tBTC during the previous week. We also began a more detailed review of the tBTC codebase; in particular, tBTC Deposit flows and the investigation of potential vulnerabilities. Key findings were shared with the client in an end-of-week sync meeting and filed in the client repository where applicable. keep-network/keep-tecdsa was still undergoing changes by the end of week two.

The audit team informed the client that given the size and complexity of the audit there might not be enough time to cover all parts of the initial scope. Together with the client, it was determined that we would spend the next week finishing the review of tBTC Deposit flows before transitioning our review to `keep-core`.

Week 3

During the third week, we reviewed tBTC Deposit flows and started transitioning from tBTC to `keep-core`, maintaining a focus on the functionality of `keep-core` that was most relevant to tBTC.

The audit revision for the `keep-tecdsa` codebase was provided in the second half of the week and tagged as keep-tecdsa#v0.8.0. Additionally, the sortition-pools#v0.1.1 repository referenced by `keep-tecdsa` was added to the audit's scope.

The cryptographic review that was planned to start this week had to be delayed due to availability problems with our cryptographer. The review of the keep client was temporarily set out of scope to ensure sufficient attention was given to the smart contracts. Key findings and questions were shared

immediately via the client collaboration channel and discussed in an end-of-week sync meeting.

Week 4

During the fourth week, we focused on `keep-core` and the now frozen `keep-tecdsa` implementation. The week was kicked off by the client providing a walkthrough of the relevant code of `keep-tecdsa`. Key findings and questions were shared immediately via the client collaboration channel and discussed in an end-of-week sync meeting. The **preliminary report** outlining recommendations and findings was prepared towards the end of the week targeting delivery for the following Monday.

Two-week hiatus

A two-week hiatus allowing the client to address discussion points, recommendations, and issues found during the audit was planned from March 02 to March 13.

The engagement was scheduled to be continued for a final two-week review from March 16 to March 27.

1.4 Audit Log - Phase 2

The final phase of the engagement was scheduled as follows:

Week 1	Week 2
- review fixes made during hiatus - review `keep-core`	- surface-level review of `keep-core` client - finalize report

Week 1

During the first week after providing the initial report, we focused on continuing our efforts with `keep-core` and reviewing the feedback and fixes that were provided for the initial report. A secondary goal was to start reviewing the client implementations in `keep-core`. The client provided a high-level walkthrough of the keep client codebase and the audit team shared the sources for the tBTC state diagram (see Security - tBTC). The audit codebase was updated to the following revisions:

- `tbtc` : fbb2018c41456d19ec20eb28a17070ee2b10eb5d (noted above)
- `keep-tecdsa` : 2aab1f755e437d6e816c34a4fd354025cea5de3a (v0.10.0-rc)
- `keep-core` : 9f8b13fe54cc627548746d7e64b77d6aa50b94e1 (v0.11.0-rc) (provided on friday)
- `sortition-pools` : no update provided
- `bitcoin-spv` : no update provided

Week 2

During the second week, we continued with our focus on `keep-core` and started reviewing the client logic that is interacting with the smart contracts. The **final report** outlining recommendations and findings including client feedback and a review of provided fixes was prepared towards the end of the week targeting delivery for the following Monday. In addition to that the cryptographic review was finalized and prepared for the delivery on Monday.

Appendix 1 - Files in Scope

Our review covered the following files at the outset:

bitcoin-spv

File	SHA-1 hash
bitcoin-spv/solidity/contracts/BTCUtils.sol	c35c9ea329cc87ff74f1c5ce0c300a0d7db368e4
bitcoin-spv/solidity/contracts/BytesLib.sol	2178fa49f897c2afe236478a9f4559408ac8aa8a
bitcoin-spv/solidity/contracts/SafeMath.sol	7462e2ec469c36913b6fc47bafef1749f29b1c88
bitcoin-spv/solidity/contracts/BTCUtilsDelegate.sol	ea3bc8ef148ef4fb8daff8c4c260c24ff747e4b9
bitcoin-spv/solidity/contracts/CheckBitcoinSigs.sol	e9624d00af1fbd377229fe767032eceec856232d

File	SHA-1 hash
bitcoin-spv/solidity/contracts/CheckBitcoinSigsDelegate.sol	53c0a185f9c778df4c184921a3bec6f0c6c5f34b
bitcoin-spv/solidity/contracts/ValidateSPV.sol	1a5fcca4dfe7b2c6ec416030445226905633 01da
bitcoin-spv/solidity/contracts/ValidateSPVDelegate.sol	1c0bfe67ec7d9c20192e1e940a8101c0ac711511

tBTC

File	SHA-1 Hash
tbtc/implementation/contracts/DepositLog.sol	0b4097f3400f2b6bfd1783fa9e31696beb23d1fe
tbtc/implementation/contracts/deposit/DepositFunding.sol	c77af1cd7eb7422bc1365e20dca246a4ab3d0fcf
tbtc/implementation/contracts/system/TBTCToken.sol	91a9c9663212800c7b1fbdb96868d3966ad65fe3
tbtc/implementation/contracts/system/VendingMachineAuthority.sol	5e63aae00f82cd5c6c7823149fc71196091f86f6
tbtc/implementation/contracts/system/TBTCSystem.sol	2171736428af6abd9c31fde64fe1c6accc5f86e1
tbtc/implementation/contracts/system/VendingMachine.sol	17f16b793f5c0378f88680ff1268a129b3e453e1
tbtc/implementation/contracts/system/TBTCDepositToken.sol	2e926a39620647d72dbfd8530e6d0324d6b8a0d3
tbtc/implementation/contracts/system/DepositFactoryAuthority.sol	188311a48e8b7e4491d2b3b2b7807a8ceaf2fa06
tbtc/implementation/contracts/system/FeeRebateToken.sol	0e977f37fca62daeed737e3db1a755a192ca7390

File	SHA-1 Hash
tbtc/implementation/contracts/deposit/TBTCConstants.sol	5b0fc693173bd612cba1cbbaa9d6f87101a5f9d5
tbtc/implementation/contracts/deposit/DepositUtils.sol	7308079022c02b2e146466ffe2acefdcf5e4afa8
tbtc/implementation/contracts/deposit/DepositStates.sol	5ebaa3a0c9f708a98f65363401a97408f0c06054
tbtc/implementation/contracts/interfaces/ITBTCSystem.sol	97a6241eea43fd6f319def22589499111d2e3678
tbtc/implementation/contracts/deposit/Deposit.sol	0449315750be89b5a74a02ce11ec8c02cf9e8127
tbtc/implementation/contracts/deposit/DepositLiquidation.sol	613be100e9f79a8964746511717fc43f8f6b8333
tbtc/implementation/contracts/deposit/OutsourceDepositLogging.sol	790c605150564a8963be57c25730392a4877d8ce
tbtc/implementation/contracts/deposit/DepositRedemption.sol	7ee02dd144011e257f2462fb8d69a99f866753f1
tbtc/implementation/contracts/system/TBTCSystemAuthority.sol	7924969f054ee6740de374eb1ef1368f08f8c1c9
tbtc/implementation/contracts/proxy/DepositFactory.sol	26a280871b518490022b52763d3c83f4d12770ad
tbtc/implementation/contracts/proxy/CloneFactory.sol	9044bc020f1d0132f5d408f95e645d6986074a18
tbtc/implementation/contracts/interfaces/IBTCETHPriceFeed.sol	d9d24818569427dbc4d644a05a980d4df68adc14
tbtc/implementation/contracts/external/IMedianizer.sol	957d66ee5fc768bf9ff7c47362050e532b3ae367
tbtc/implementation/contracts/price-feed/BTCETHPriceFeed.sol	3658670d0d66b155cdf56e46ea0a9556c9b7ad0b

keep-tecdsa

File Name	SHA-1 Hash
contracts/BondedECDSAKeep.sol	bc89cc51280d6c424fa76ac70afaca59794bf8ce
contracts/BondedECDSAKeepFactory.sol	23d428253b1f70f12e98e791ff39547edac898ad
contracts/BondedECDSAKeepVendor.sol	6397c7bac818add006ec5add72f72f8ca77dee0d
contracts/BondedECDSAKeepVendorImplV1.sol	4314a3c1f5aff333db73426d35da9b545e468347
contracts/CloneFactory.sol	7408e755f2f9eb6699c04b45a8c28446041a3f73
contracts/KeepBonding.sol	a3b01f99c4fde8652f050a45fe2b4a30c6fa4b9e
contracts/api/IBondedECDSAKeep.sol	02624cb967aade2c5290cb13c9740825e905b4de
contracts/api/IBondedECDSAKeepFactory.sol	30d55d502d4ef0f5aadb812ab553c6221cc1d633
contracts/api/IBondedECDSAKeepVendor.sol	764019742ba132a75ddf1272cdeb0e8a7ccb7f17

sortition-pools

File Name	SHA-1 Hash
contracts/AbstractSortitionPool.sol	7a4b163dcf5fd3ea8a9c74c5c219aadfc6c007b9
contracts/BondedSortitionPool.sol	3cde74fa4b63e4e9979dafc6418aa57ac90ec798
contracts/BondedSortitionPoolFactory.sol	49706b318ace886b3b8bd0725d546ece329958b9
contracts/Branch.sol	2571e8c19fe3f4764aa9feac8b37808f595bb407

File Name	SHA-1 Hash
contracts/DynamicArray.sol	ab6b782ce938cf958cc56e2c6b2a0f2334715d18
contracts/GasStation.sol	790159120d85a0dbdbfe57f729b5ada572ebbaef
contracts/Interval.sol	1fab3c416d8261f42d35d53d37c77b644fa1e3c0
contracts/Leaf.sol	22b7bee520b77214b1f81b75e352f44ad059ffc8
contracts/Position.sol	36cf18478fae2c9e22124d3ac52b5a050c7fe78b
contracts/RNG.sol	dc7862e02c56b9b033cc1db67fe19153a1e38ba7
contracts/SortitionPool.sol	e889623764112859984 2d0951f8721632cfd061e
contracts/SortitionPoolFactory.sol	56bcc990f6a8cbfbd877b06ca0df43a7da21dd38
contracts/SortitionTree.sol	7d4d0fac5e8d8d1bea709280c442576751f18b33
contracts/StackLib.sol	e91cfb78f3b90ca8b3a18f701356c565a933e52e
contracts/api/IBondedSortitionPool.sol	d9fd422dc4a6ca6323a0ba536cb65f33e44c3e1b
contracts/api/IBonding.sol	71b96ff01a2efdb09e6d24b7432484b9a15a4a00
contracts/api/ISortitionPool.sol	709d56b46065c160042dcac8c2cb9a42a1ea201c
contracts/api/IStaking.sol	9412ade9ccf9f0672875d1c94b49d230dbbe4be1

keep-core

File Name	SHA-1 Hash
keep-core/contracts/solidity/contracts/cryptography/AltBn128.sol	0af848f5bdf3bc548160febd4e12ae735c11b8cc
keep-core/contracts/solidity/contracts/cryptography/BLS.sol	95f316615a6177e4f9f91fa528acf50b7e4bc490
keep-core/contracts/solidity/contracts/DelayedWithdrawal.sol	ad8109961339eaf5ca8c45dcac1e7def56da55ca
keep-core/contracts/solidity/contracts/KeepRandomBeaconOperator.sol	206cb9399c1d4c7c86583280c271996cc57bc2b0
keep-core/contracts/solidity/contracts/KeepRandomBeaconService.sol	280a810f174100a126db552d61f1ef01c5ae280d
keep-core/contracts/solidity/contracts/KeepRandomBeaconServiceImplV1.sol	8d23f4ef32aea55e5d83e16516fcee26b2dc7f68
keep-core/contracts/solidity/contracts/KeepToken.sol	91f2bb61583f741b42641e03471f068b4a12cd8f
keep-core/contracts/solidity/contracts/Registry.sol	e1b58dd981a5baa1233d799a4fa321bf8e7484c5
keep-core/contracts/solidity/contracts/StakeDelegatable.sol	0e469a07df4bb72e8806f92b9d415fea49444c2a
keep-core/contracts/solidity/contracts/TokenGrant.sol	cf6b6befe786cfc1d093718f59e7e8b80439a170

File Name	SHA-1 Hash
keep-core/contracts/solidity/contracts/TokenStaking.sol	02c0446475d84aaea7043bbab976e0cfd33cbde8
keep-core/contracts/solidity/contracts/libraries/operator/DKGResultVerification.sol	132d1a7aa9c6d6c958db2923936279986f643ac5
keep-core/contracts/solidity/contracts/libraries/operator/GroupSelection.sol	8812a2027044f6a193cf6af51a57fec7aed119be
keep-core/contracts/solidity/contracts/libraries/operator/Groups.sol	ba8c30b6340966b3bf96afd728c03193d858dd1e
keep-core/contracts/solidity/contracts/libraries/operator/Reimbursements.sol	285de769e1f56d8c94a8bae1c0274f2c6052df8c
keep-core/contracts/solidity/contracts/utils/AddressArrayUtils.sol	85d9bf08c8628ec5ee45328213a9c74cbdaf2b99
keep-core/contracts/solidity/contracts/utils/ModUtils.sol	ebf6ebc9647c6b699a06a03d0d2fd4b717e65fb2
keep-core/contracts/solidity/contracts/utils/ThrowProxy.sol	fa012ba7589dc8b935048b9b63978e6e3c244a61
keep-core/contracts/solidity/contracts/utils/UintArrayUtils.sol	5d1210befba8fc72a8d46f615bf9f3af510b3296

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