BEOSIN
Blockchain Security

Ankr-staking

Smart Contract Security Audit

V1.0

No. 202212061649

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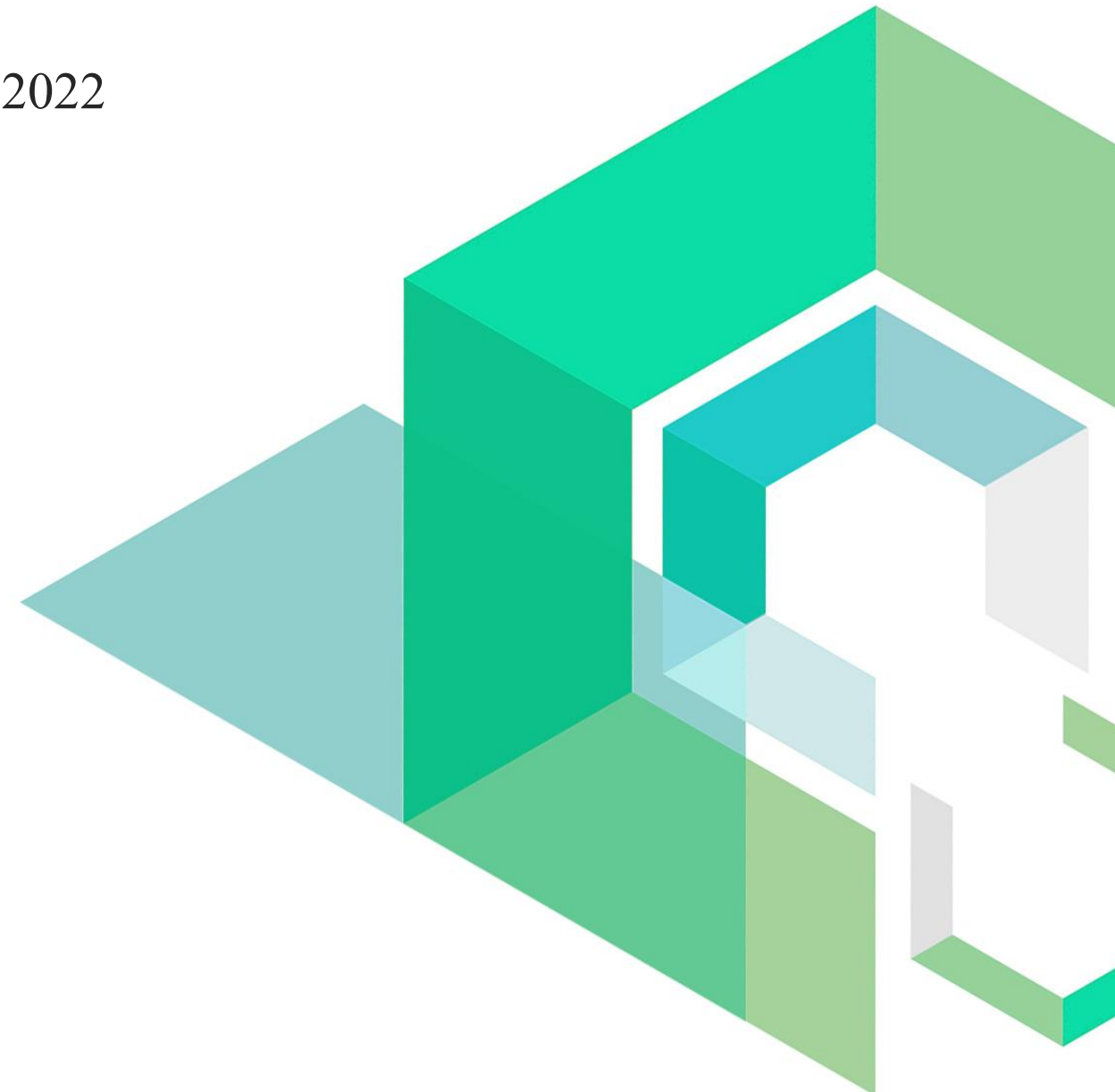
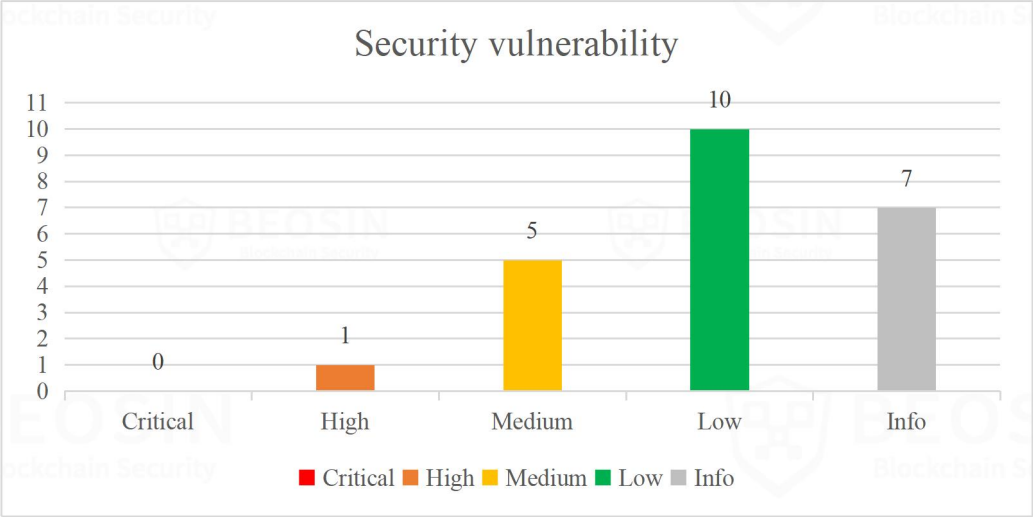


Contents

Summary of Audit Results

After auditing, 1 High-risk item, 5 Medium-risk items, 9 Low-risk items and 7 Info items were identified in the Ankr-staking project. Specific audit details will be presented in the **Findings section**. Users should pay attention to the following aspects when interacting with this project：



*Notes:

- **Risk Description:**

1. The AnkrProtocol contract does not implement the extraction function, the contract does not support users to withdraw staked assets.

2. Governance has the authority to modify the stake amount corresponding to the level to any value, resulting in user increase stake may decrease level.

3. The userDeposit.expires is controlled by the user and the assets is locked once.

4. The PayAsYouGo contract implements the final withdrawal operation by Consensus, and the handling fee is arbitrarily controlled by Consensus.

- **Project Description:**

1. Business overview

Ankr is a stake-type project. Users can spend the BEP20 token specified in the contract to register the address as a validator, and can set the validator's reward commission between 0% and 30%. When the validator is successfully registered, other users can spend the specified BEP20 to stake the validator. The user's reward amount in a specific epoch is the validator's reward amount multiplied by the user's stake ratio after deducting the owner's commission fee. It should be noted that the rewards need to be actively transferred to the validator. If there is no reward transfer, even if there is a staked amount, the rewards cannot be obtained.

1 Overview

1.1 Project Overview

Project Name	Ankr-staking
Platform	BNB Chain
Audit scope	https://github.com/Ankr-network/ankr-contracts/tree/STAKAN-00-undelegation_process
Commit Hash	5bc1483497c2846edcad6978396240e603a24a34(Initial) 23469d9d83bcd39e2454324ec72a7d01d509f2fc(Latest)

1.2 Audit Overview

Audit work duration：Sep 14, 2022 – Nov 23, 2022

Audit methods: Formal Verification, Static Analysis, Typical Case Testing and Manual Review.

Audit team: Beosin Security Team.

2 Findings

Index	Risk description	Severity level	Status
Ankr-staking-1	No funds transferred when registering validator	High	Fixed
Ankr-staking-2	AdvanceStakingRewards execution order issue	Medium	Fixed
Ankr-staking-3	Deleted validator user cannot extract	Medium	Fixed
Ankr-staking-4	Asset types are not uniform	Medium	Fixed
Ankr-staking-5	Delete staking records without rewards	Low	Fixed
Ankr-staking-6	The dustRewards reward cannot be withdrawn	Low	Fixed
Ankr-staking-7	Inaccurate principal withdrawal amount	Low	Fixed
Ankr-staking-8	Unreasonable *stake* function	Low	Fixed
Ankr-staking-9	Not updating change.at to global variable	Info	Fixed
Ankr-staking-10	Inconsistent accuracy	Info	Fixed
Ankr-staking-11	Variable types are inconsistent	Info	Fixed
Ankr-staking-12	Meaningless payable keyword	Info	Fixed
AnkrProtocol-1	Missing asset extraction interface	Medium	Acknowledged
AnkrProtocol-2	Stake level setting issue	Low	Acknowledged
AnkrProtocol-3	Missing check for 0 address	Low	Fixed
AnkrProtocol-4	Code redundancy	Low	Fixed
AnkrProtocol-5	Lack of event triggering	Info	Fixed
AnkrProtocol-6	The stake lock issue	Info	Acknowledged
PayAsYouGo-1	Reward source not specified	Medium	Fixed
PayAsYouGo-2	User withdrawal issue	Low	Acknowledged
PayAsYouGo-3	Handling fee issue	Low	Fixed
PayAsYouGo-4	Variable does not implement the relevant function	Info	Acknowledged

Status Notes:

- AnkrProtocol-1 is unfixed and will cause no function to withdraw after the user stakes.
- AnkrProtocol-2 is unfixed and will cause after the governance modifies the stake amount of the corresponding level, the user's stake may not match the level.

- AnkrProtocol-6 is unfixed and will cause in the *_lockDeposit* function, the lockup time is only updated when it is judged that userDeposit.expires == 0. The user can control the lockup time and only lock the first stake.
- PayAsYouGo-2 is unfixed and will cause final lending operation is implemented by Consensus calling the *handleWithdraw* function. The user's withdrawal amount and Fee are not controlled by the user.
- PayAsYouGo-4 is unfixed and will not cause any issues.

Finding Details:

[Ankr-staking-1] No funds transferred when registering validator

Severity Level	**High**
Type	Business Security
Lines	TokenStaking.sol #L24-31
Description	When the validator is registered through the *registervalidator* function, it is not verified whether there is a token transfer corresponding to the amount. Then user can withdraw the assets in the contract by registering any number of stake records.

```
24    function registerValidator(address validatorAddress, uint16 commissionRate, uint256 amount) external payable
25        require(msg.value == 0, "TokenStaking: ERC20 expected");
26        // // initial stake amount should be greater than minimum validator staking amount
27        require(amount >= _stakingConfig.getMinValidatorStakeAmount(), "too low");
28        require(amount % BALANCE_COMPACT_PRECISION == 0, "no remainder");
29        // add new validator as pending
30        _addValidator(validatorAddress, msg.sender, ValidatorStatus.Pending, commissionRate, amount, nextEpoch());
31    }
```

Figure 1 The source code of *registervalidator* function

```
592   function _addValidator(address validatorAddress, address validatorOwner, ValidatorStatus status, uint16 commissionRate, uint256 initialStake, u
593       // validator commission rate
594       require(commissionRate >= COMMISSION_RATE_MIN_VALUE && commissionRate <= COMMISSION_RATE_MAX_VALUE, "bad commission");
595       // init validator default params
596       Validator memory validator = _validatorsMap[validatorAddress];
597       require(_validatorsMap[validatorAddress].status == ValidatorStatus.NotFound, "already exist");
598       validator.validatorAddress = validatorAddress;
599       validator.ownerAddress = validatorOwner;
600       validator.status = status;
601       validator.changedAt = sinceEpoch;
602       _validatorsMap[validatorAddress] = validator;
603       // save validator owner
604       require(_validatorOwners[validatorOwner] == address(0x00), "owner in use");
605       _validatorOwners[validatorOwner] = validatorAddress;
606       // add new validator to array
607       if (status == ValidatorStatus.Active) {
608           _activeValidatorsList.push(validatorAddress);
609       }
610       // push initial validator snapshot at zero epoch with default params
611       _validatorSnapshots[validatorAddress][sinceEpoch] = ValidatorSnapshot(0, uint112(initialStake / BALANCE_COMPACT_PRECISION), 0, commissionRat
612       // delegate initial stake to validator owner
613       ValidatorDelegation storage delegation = _validatorDelegations[validatorAddress][validatorOwner];
614       require(delegation.delegateQueue.length == 0);
615       delegation.delegateQueue.push(DelegationOpDelegate(uint112(initialStake / BALANCE_COMPACT_PRECISION), sinceEpoch, sinceEpoch));
616       emit Delegated(validatorAddress, validatorOwner, initialStake, sinceEpoch);
617       // emit event
618       emit ValidatorAdded(validatorAddress, validatorOwner, uint8(status), commissionRate);
619   }
```

Figure 2 The source code of *_addvalidator* function

Recommendations	It is recommended to verify whether there is a corresponding amount of tokens transferred in.
Status	Fixed.

```
function registerValidator(address validatorAddress, uint16 commissionRate, uint256 amount) external payable vir
    require(msg.value == 0, "TokenStaking: ERC20 expected");
    // initial stake amount should be greater than minimum validator staking amount
    require(amount >= _stakingConfig.getMinValidatorStakeAmount(), "too low");
    require(amount % BALANCE_COMPACT_PRECISION == 0, "no remainder");
    // transfer tokens
    require(_erc20Token.transferFrom(msg.sender, address(this), amount), "TokenStaking: failed to transfer");
    // add new validator as pending
    _addValidator(validatorAddress, msg.sender, ValidatorStatus.Pending, commissionRate, amount, nextEpoch());
}
```

Figure 3 The source code of *registervalidator* function(Fixed)

[Ankr-staking-2] AdvanceStakingRewards execution order issue

Severity Level	Medium
Type	Business Security
Lines	LiquidStakingPool.sol #L70-93
Description	The advanceStakingRewards modifier is called when staking and withdrawing, there is a issue with the order of execution. First calculate the stakeableDust through *_calcUnclaimedDelegatorFee* and *calcAvailableForDelegateAmount*. At this time, the contract has not yet received the dust reward and calls *_delegateTo* to stake. then the function will not be called successfully.

```
70  modifier advanceStakingRewards(address validator) {
71      {
72          ValidatorPool memory validatorPool = _getValidatorPool(validator);
73          // claim rewards from staking contract
74          (uint256 amountToStake, uint256 dustRewards) = _calcUnclaimedDelegatorFee(validatorPool);
75          // increase total accumulated rewards
76          validatorPool.totalStakedAmount += amountToStake;
77          validatorPool.dustRewards += dustRewards;
78
79          // might be some dust that can be stakeable
80          (uint256 stakeableDust, uint256 restDust) = _stakingContract.calcAvailableForDelegateAmount(validatorPool.dustReward
81          if (stakeableDust >= _stakingConfig.getMinValidatorStakeAmount()) {
82              validatorPool.dustRewards = restDust;
83              _delegateTo(validatorPool.validatorAddress, stakeableDust);
84          }
85          // save validator pool changes
86          _validatorPools[validator] = validatorPool;
87          // if we have something to redelegate then do this right now
88          if (amountToStake > 0) {
89              _stakingContract.redelegateDelegatorFee(validatorPool.validatorAddress);
90          }
91      }
92      _;
93  }
```

Figure 4 The source code of advanceStakingRewards modifier

Recommendations	It is recommended to change the calling order of the functions
Status	Fixed.

```
70  modifier advanceStakingRewards(address validator) {
71      {
72          ValidatorPool memory validatorPool = _getValidatorPool(validator);
73          // claim rewards from staking contract
74          (uint256 amountToStake, uint256 dustRewards) = _calcUnclaimedDelegatorFee(validatorPool);
75          // increase total accumulated rewards
76          validatorPool.totalStakedAmount += amountToStake;
77          validatorPool.dustRewards += dustRewards;
78          // if we have something to redelegate then do this right now
79          if (amountToStake > 0) {
80              _stakingContract.redelegateDelegatorFee(validatorPool.validatorAddress);
81          }
82          // might be some dust that can be stakeable
83          (uint256 stakeableDust, uint256 restDust) = _stakingContract.calcAvailableForDelegateAmount(validatorPool.dustRewards);
84          if (stakeableDust >= _stakingConfig.getMinValidatorStakeAmount()) {
85              validatorPool.dustRewards = restDust;
86              _delegateTo(validatorPool.validatorAddress, stakeableDust);
87          }
88          // save validator pool changes
89          _validatorPools[validator] = validatorPool;
90      }
91      _;
92  }
```

Figure 5 The source code of advanceStakingRewards modifier(Fixed)

[Ankr-staking-3] Deleted validator user cannot extract	
Severity Level	**Medium**
Type	Business Security
Lines	Staking.sol #L631-641
Description	When the Governance deletes the validator through the *removevalidator* function, the user will not be able to withdraw the staked principal through the *undelegate* function.

```
631    function removeValidator(address account) external onlyFromGovernance virtual override {
632        Validator memory validator = _validatorsMap[account];
633        require(validator.status != ValidatorStatus.NotFound, "not found");
634        // remove validator from active list if exists
635        _removeValidatorFromActiveList(account);
636        // remove from validators map
637        delete _validatorOwners[validator.ownerAddress];
638        delete _validatorsMap[account];
639        // emit event about it
640        emit ValidatorRemoved(account);
641    }
```

Figure 6 The source code of *removevalidator* function

Recommendations	It is recommended to add the extraction function for the deleted validator.
Status	Fixed. The project side deleted the *removevalidator* function.

[Ankr-staking-4] Asset types are not uniform

Severity Level	Medium
Type	Business Security
Lines	Staking.sol #L581-588
Description	When the user registers with the validator through *registervalidator* function, they use the BNB as the stake asset and create a corresponding number of stake records. However, the specified BEP20 tokens are used when receiving awards and withdrawing for settlement. Then when the registered user withdraws, the BEP20 tokens staked by other users will be withdrawn, and the BNB staked in the contract will not be able to be withdrawn.

```
581     function registerValidator(address validatorAddress, uint16 commissionRate) payable external virtual override {
582         uint256 initialStake = msg.value;
583         // // initial stake amount should be greater than minimum validator staking amount
584         require(initialStake >= _stakingConfig.getMinValidatorStakeAmount(), "too low");
585         require(initialStake % BALANCE_COMPACT_PRECISION == 0, "no remainder");
586         // add new validator as pending
587         _addValidator(validatorAddress, msg.sender, ValidatorStatus.Pending, commissionRate, initialStake, nextEpoch());
588     }
589
```

Figure 7 The source code of *registervalidator* function

```
38      function _safeTransferWithGasLimit(address payable recipient, uint256 amount) internal override {
39          require(_erc20Token.transfer(recipient, amount), "failed to safe transfer");
40      }
41
42      function _unsafeTransfer(address payable recipient, uint256 amount) internal override {
43          require(_erc20Token.transfer(recipient, amount), "failed to unsafe transfer");
44      }
45  }
```

Figure 8 The source code of *transfer* functions

Recommendations	It is recommended to unify the asset types used in the contract.
Status	Fixed.

```
24      function registerValidator(address validatorAddress, uint16 commissionRate, uint256 amount) external payable virtual override(Staking,
25          require(msg.value == 0, "TokenStaking: ERC20 expected");
26          // initial stake amount should be greater than minimum validator staking amount
27          require(amount >= _stakingConfig.getMinValidatorStakeAmount(), "too low");
28          require(amount % BALANCE_COMPACT_PRECISION == 0, "no remainder");
29          // transfer tokens
30          require(_erc20Token.transferFrom(msg.sender, address(this), amount), "TokenStaking: failed to transfer");
31          // add new validator as pending
32          _addValidator(validatorAddress, msg.sender, ValidatorStatus.Pending, commissionRate, amount, nextEpoch());
33      }
```

Figure 9 The source code of *registervalidator* function(Fixed)

[Ankr-staking-5] Delete staking records without rewards

Severity Level	**Low**
Type	Business Security
Lines	Staking.sol #L441-471
Description	When the user's gasleft meets the CLAIM_BEFORE_GAS of the first cycle, but not the CLAIM_BEFORE_GAS of the second cycle. There will be cases where users' staking records are deleted without rewards being issued.

```
61      uint32 internal constant CLAIM_BEFORE_GAS = 100_000;
```

Figure 10 The source code of CLAIM_BEFORE_GAS

```
function _processDelegateQueue(address validator, ValidatorDelegation storage delegation, uint64 beforeEpochExclude) internal returns (uint256 availableFunds) {
    uint64 lockPeriod = _stakingConfig.getLockPeriod();
    uint64 delegateGap = delegation.delegateGap;
    for (uint256 queueLength = delegation.delegateQueue.length; delegateGap < queueLength && gasleft() > CLAIM_BEFORE_GAS;) {
        DelegationOpDelegate memory delegateOp = delegation.delegateQueue[delegateGap];
        if (delegateOp.epoch >= beforeEpochExclude + lockPeriod) {
            break;
        }
        uint256 voteChangedAtEpoch = 0;
        if (delegateGap < queueLength - 1) {
            voteChangedAtEpoch = delegation.delegateQueue[delegateGap + 1].epoch;
        }
        for (; delegateOp.epoch < beforeEpochExclude && (voteChangedAtEpoch == 0 || delegateOp.epoch < voteChangedAtEpoch) && gasleft() > CLAIM_BEFORE_GAS; deleg
            ValidatorSnapshot memory validatorSnapshot = _validatorSnapshots[validator][delegateOp.epoch];
            if (validatorSnapshot.totalDelegated == 0) {
                continue;
            }
            (uint256 delegatorFee, /*uint256 ownerFee*/, /*uint256 systemFee*/) = _calcValidatorSnapshotEpochPayout(validatorSnapshot);
            availableFunds += delegatorFee * delegateOp.amount / validatorSnapshot.totalDelegated;
        }
        // if we have reached end of the delegation list then lets stay on the last item, but with updated latest processed epoch
        if (delegateGap >= queueLength - 1) {
            delegation.delegateQueue[delegateGap] = delegateOp;
            break;
        }
        delete delegation.delegateQueue[delegateGap];
        ++delegateGap;
    }
    delegation.delegateGap = delegateGap;
    return availableFunds;
}
```

Figure 11 The source code of *_processDelegateQueue* function

Recommendations	It is suggested that the gasleft judgment of the second cycle is smaller than the first reasonable value.
Status	Fixed. The project party modified the collection logic.

```
function _processDelegateQueue(address validator, ValidatorDelegation storage delegation, uint64 beforeEpochExclude) internal returns (uint256 availableFunds) {
    uint64 delegateGap = delegation.delegateGap;
    // lets iterate delegations from delegateGap to queueLength
    for (uint256 queueLength = delegation.delegateQueue.length; delegateGap < queueLength && gasleft() > CLAIM_BEFORE_GAS;) {
        // pull delegation
        DelegationOpDelegate memory delegateOp = delegation.delegateQueue[delegateGap];
        if (delegateOp.epoch >= beforeEpochExclude) {
            break;
        }
        uint256 voteChangedAtEpoch = 0;
        if (delegateGap < queueLength - 1) {
            voteChangedAtEpoch = delegation.delegateQueue[delegateGap + 1].epoch;
        }
        // if delegateOp was created before field claimEpoch added
        if (delegateOp.claimEpoch == 0) {
            delegateOp.claimEpoch = delegateOp.epoch;
        }
        // lets calculate unclaimed rewards from claimEpoch to beforeEpochExclude
        for (; delegateOp.claimEpoch < beforeEpochExclude && (voteChangedAtEpoch == 0 || delegateOp.claimEpoch < voteChangedAtEpoch) && gasleft() > CLAIM_BEFOR
            ValidatorSnapshot memory validatorSnapshot = _validatorSnapshots[validator][delegateOp.claimEpoch];
            if (validatorSnapshot.totalDelegated == 0) {
                continue;
            }
            (uint256 delegatorFee, /*uint256 ownerFee*/, /*uint256 systemFee*/) = _calcValidatorSnapshotEpochPayout(validatorSnapshot);
            availableFunds += delegatorFee * delegateOp.amount / validatorSnapshot.totalDelegated;
        }
        // update claimEpoch for delegation
        delegation.delegateQueue[delegateGap] = delegateOp;

        ++delegateGap;
    }
```

Figure 12 The source code of *_processDelegateQueue* function(Fixed)

[Ankr-staking-6] The dustRewards reward cannot be withdrawn

Severity Level	**Low**
Type	Business Security
Lines	LiquidStakingPool.sol #L70-86
Description	When the advanceStakingRewards modifier calls the *redelegateDelegatorFee* function, the rewardsDust transferred to the LiquidStakingPool contract is not processed, resulting in rewardsDust being locked in the contract and unable to be withdrawn.

```
70    modifier advanceStakingRewards(address validator) {
71        {
72            ValidatorPool memory validatorPool = _getValidatorPool(validator);
73            // claim rewards from staking contract
74            (uint256 amountToStake, uint256 dustRewards) = _calcUnclaimedDelegatorFee(validatorPool);
75            // increase total accumulated rewards
76            validatorPool.totalStakedAmount += amountToStake;
77            validatorPool.dustRewards += dustRewards;
78            // save validator pool changes
79            _validatorPools[validator] = validatorPool;
80            // if we have something to redelegate then do this right now
81            if (amountToStake > 0) {
82                _stakingContract.redelegateDelegatorFee(validatorPool.validatorAddress);
83            }
84        }
85        _;
86    }
```

Figure 13 The source code of advanceStakingRewards modifier

```
420    function _redelegateDelegatorRewards(address validator, address delegator, uint64 beforeEpochExclude, bool withRewards, bool withUndel
421        ValidatorDelegation storage delegation = _validatorDelegations[validator][delegator];
422        // claim rewards and undelegates
423        uint256 availableFunds = 0;
424        if (withRewards) {
425            availableFunds += _processDelegateQueue(validator, delegation, beforeEpochExclude);
426        }
427        if (withUndelegates) {
428            availableFunds += _processUndelegateQueue(delegation, beforeEpochExclude);
429        }
430        (uint256 amountToStake, uint256 rewardsDust) = calcAvailableForDelegateAmount(availableFunds);
431        // if we have something to re-stake then delegate it to the validator
432        if (amountToStake > 0) {
433            _delegateTo(delegator, validator, amountToStake, false);
434        }
435        // if we have dust from staking then send it to user (we can't keep them in the contract)
436        if (rewardsDust > 0) {
437            _safeTransferWithGasLimit(payable(delegator), rewardsDust);
438        }
439        // emit event
440        emit Redelegated(validator, delegator, amountToStake, rewardsDust, beforeEpochExclude);
441    }
```

Figure 14 The source code of _redelegateDelegatorRewards function

Recommendations	It is recommended to increase the extraction function of rewardsDust.
Status	Fixed.

```
70      modifier advanceStakingRewards(address validator) {
71          {
72              ValidatorPool memory validatorPool = _getValidatorPool(validator);
73              // claim rewards from staking contract
74              (uint256 amountToStake, uint256 dustRewards) = _calcUnclaimedDelegatorFee(validatorPool);
75              // increase total accumulated rewards
76              validatorPool.totalStakedAmount += amountToStake;
77              validatorPool.dustRewards += dustRewards;
78              // if we have something to redelegate then do this right now
79              if (amountToStake > 0) {
80                  _stakingContract.redelegateDelegatorFee(validatorPool.validatorAddress);
81              }
82              // might be some dust that can be stakeable
83              (uint256 stakeableDust, uint256 restDust) = _stakingContract.calcAvailableForDelegateAmount(validatorPool.dustRewards);
84              if (stakeableDust >= _stakingConfig.getMinValidatorStakeAmount()) {
85                  validatorPool.dustRewards = restDust;
86                  _delegateTo(validatorPool.validatorAddress, stakeableDust);
87              }
88              // save validator pool changes
89              _validatorPools[validator] = validatorPool;
90          }
91          _;
92      }
```

Figure 15 The source code of advanceStakingRewards modifier(Fixed)

[Ankr-staking-7] Inaccurate principal withdrawal amount

Severity Level	Low
Type	Business Security
Lines	Staking.sol #L441-471, L338-360
Description	The sequence of receiving prizes and principal withdrawals will affect the next principal withdrawal amount. If the reward is claimed first, the next principal withdrawal amount will be reduced.

```
441  function _processDelegateQueue(address validator, ValidatorDelegation storage delegation, uint64 beforeEpochExclude) internal returns (uin
442      uint64 lockPeriod = _stakingConfig.getLockPeriod();
443      uint64 delegateGap = delegation.delegateGap;
444      for (uint256 queueLength = delegation.delegateQueue.length; delegateGap < queueLength && gasleft() > CLAIM_BEFORE_GAS;) {
445          DelegationOpDelegate memory delegateOp = delegation.delegateQueue[delegateGap];
446          if (delegateOp.epoch >= beforeEpochExclude) {
447              break;
448          }
449          uint256 voteChangedAtEpoch = 0;
450          if (delegateGap < queueLength - 1) {
451              voteChangedAtEpoch = delegation.delegateQueue[delegateGap + 1].epoch;
452          }
453          for (; delegateOp.epoch < beforeEpochExclude && (voteChangedAtEpoch == 0 || delegateOp.epoch < voteChangedAtEpoch) && gasleft() >
454              ValidatorSnapshot memory validatorSnapshot = _validatorSnapshots[validator][delegateOp.epoch];
455              if (validatorSnapshot.totalDelegated == 0) {
456                  continue;
457              }
458              (uint256 delegatorFee, /*uint256 ownerFee*/, /*uint256 systemFee*/) = _calcValidatorSnapshotEpochPayout(validatorSnapshot);
459              availableFunds += delegatorFee * delegateOp.amount / validatorSnapshot.totalDelegated;
460          }
461          // if we have reached end of the delegation list then lets stay on the last item, but with updated latest processed epoch
462          if (delegateGap >= queueLength - 1) {
463              delegation.delegateQueue[delegateGap] = delegateOp;
464              break;
465          }
466          delete delegation.delegateQueue[delegateGap];
467          ++delegateGap;
468      }
469      delegation.delegateGap = delegateGap;
470      return availableFunds;
471  }
```

Figure 16 The source code of *_processDelegateQueue* function

```
338  function _calcUnlockedDelegatedAmount(ValidatorDelegation storage delegation) internal view returns (uint256 unlockedAmount) {
339      uint64 beforeEpochExclude = nextEpoch();
340      // if lock period is zero than this feature is disabled
341      uint64 lockPeriod = _stakingConfig.getLockPeriod();
342      if (lockPeriod == 0) return type(uint256).max;
343      // calc last unlocked amount
344      for (uint256 i = delegation.delegateGap; i < delegation.delegateQueue.length; i++) {
345          DelegationOpDelegate memory delegateOp = delegation.delegateQueue[i];
346          if (delegateOp.epoch + lockPeriod < beforeEpochExclude) {
347              unlockedAmount = uint256(delegateOp.amount) * BALANCE_COMPACT_PRECISION;
348          }
349      }
350      uint256 pendingWithdrawals = 0;
351      for (uint256 i = delegation.undelegateGap; i < delegation.undelegateQueue.length; i++) {
352          DelegationOpUndelegate memory undelegateOp = delegation.undelegateQueue[i];
353          pendingWithdrawals += uint256(undelegateOp.amount) * BALANCE_COMPACT_PRECISION;
354      }
355      // if user still have pending withdrawals then disallow to unstake
356      if (pendingWithdrawals >= unlockedAmount) {
357          return 0;
358      }
359      return unlockedAmount - pendingWithdrawals;
360  }
```

Figure 17 The source code of *_calcUnlockedDelegatedAmount* function

Recommendations	It is recommended to keep stake records.
Status	Fixed.

[Ankr-staking-8] Unreasonable *stake* function

Severity Level	**Low**
Type	Business Security
Lines	LiquidStakingPool.sol #L108-111
Description	The LiquidStakingPool contract has redundant *stake* functions, and the staked assets are platform tokens. TokenLiquidStakingPool will inherit this function and the call will fail.

```
108    function stake(address validator, uint256 amount) external payable advanceStakingRewards(validator) virtual override {
109        require(amount == msg.value, "StakingPool: bad amount");
110        _stake(msg.sender, validator, amount);
111    }
```

Figure 18 The source code of *stake* function

Recommendations	It is recommended to remove this function.
Status	Fixed.

```
31    function stake(address validator, uint256 amount) external payable advanceStakingRewards(validator) override(LiquidStakingPool) {
32        require(msg.value == 0, "StakingPool: ERC20 expected");
33        IERC20 token = _erc20Token();
34        require(token.transferFrom(msg.sender, address(this), amount), "StakingPool: failed to transfer");
35        _stake(msg.sender, validator, amount);
36    }
```

Figure 19 The source code of *stake* function(Fixed)

[Ankr-staking-9] Not updating change.at to global variable

Severity Level	Info
Type	Business Security
Lines	Staking.sol #L741-751
Description	After validator updates change.at as memory, it does not assign a value to the global variable. Causes the recorded data to be incorrect.

```
741     function _depositFee(address validatorAddress, uint256 amount) internal {
742         // make sure validator is active
743         Validator memory validator = _validatorsMap[validatorAddress];
744         require(validator.status != ValidatorStatus.NotFound, "not found");
745         uint64 epoch = currentEpoch();
746         // increase total pending rewards for validator for current epoch
747         ValidatorSnapshot storage currentSnapshot = _touchValidatorSnapshot(validator, epoch);
748         currentSnapshot.totalRewards += uint96(amount);
749         // emit event
750         emit ValidatorDeposited(validatorAddress, amount, epoch);
751     }
```

Figure 20 The source code of *_depositFee* function

Recommendations	It is recommended to update global variables.
Status	Fixed.

```
740     function _depositFee(address validatorAddress, uint256 amount) internal {
741         // make sure validator is active
742         Validator memory validator = _validatorsMap[validatorAddress];
743         require(validator.status != ValidatorStatus.NotFound, "not found");
744         uint64 epoch = currentEpoch();
745         // increase total pending rewards for validator for current epoch
746         ValidatorSnapshot storage currentSnapshot = _touchValidatorSnapshot(validator, epoch);
747         currentSnapshot.totalRewards += uint96(amount);
748         // validator data might be changed during _touchValidatorSnapshot()
749         _validatorsMap[validatorAddress] = validator;
750         // emit event
751         emit ValidatorDeposited(validatorAddress, amount, epoch);
752     }
```

Figure 21 The source code of *_depositFee* function(Fixed)

[Ankr-staking-10] Inconsistent accuracy

Severity Level	Info
Type	Business Security
Lines	Staking.sol #L328-360
Description	The latestDelegate used by the *calcUnlockedDelegatedAmount* function returned without restoring precision, resulting in a reduced drawable amount for the user.

```
328     function calcUnlockedDelegatedAmount(address validator, address delegator) public view returns (uint256) {
329         ValidatorDelegation storage delegation = _validatorDelegations[validator][delegator];
330         uint256 unlockedAmount = _calcUnlockedDelegatedAmount(delegation);
331         if (unlockedAmount < type(uint256).max || delegation.delegateQueue.length == 0) {
332             return unlockedAmount;
333         }
334         DelegationOpDelegate memory latestDelegate = delegation.delegateQueue[delegation.delegateQueue.length - 1];
335         return latestDelegate.amount;
336     }
```

Figure 22 The source code of *calcUnlockedDelegatedAmount* function

```
338     function _calcUnlockedDelegatedAmount(ValidatorDelegation storage delegation) internal view returns (uint256 unlockedAmount) {
339         uint64 beforeEpochExclude = nextEpoch();
340         // if lock period is zero than this feature is disabled
341         uint64 lockPeriod = _stakingConfig.getLockPeriod();
342         if (lockPeriod == 0) return type(uint256).max;
343         // calc last unlocked amount
344         for (uint256 i = delegation.delegateGap; i < delegation.delegateQueue.length; i++) {
345             DelegationOpDelegate memory delegateOp = delegation.delegateQueue[i];
346             if (delegateOp.epoch + lockPeriod < beforeEpochExclude) {
347                 unlockedAmount = uint256(delegateOp.amount) * BALANCE_COMPACT_PRECISION;
348             }
349         }
350         uint256 pendingWithdrawals = 0;
351         for (uint256 i = delegation.undelegateGap; i < delegation.undelegateQueue.length; i++) {
352             DelegationOpUndelegate memory undelegateOp = delegation.undelegateQueue[i];
353             pendingWithdrawals += uint256(undelegateOp.amount) * BALANCE_COMPACT_PRECISION;
354         }
355         // if user still have pending withdrawals then disallow to unstake
356         if (pendingWithdrawals >= unlockedAmount) {
357             return 0;
358         }
359         return unlockedAmount - pendingWithdrawals;
360     }
```

Figure 23 The source code of *_calcUnlockedDelegatedAmount* function

Recommendations	It is recommended to restore the accuracy to the same.
Status	Fixed.

```
330     function calcUnlockedDelegatedAmount(address validator, address delegator) public view returns (uint256) {
331         ValidatorDelegation storage delegation = _validatorDelegations[validator][delegator];
332         uint256 unlockedAmount = _calcUnlockedDelegatedAmount(delegation);
333         if (unlockedAmount < type(uint256).max || delegation.delegateQueue.length == 0) {
334             return unlockedAmount;
335         }
336         DelegationOpDelegate memory latestDelegate = delegation.delegateQueue[delegation.delegateQueue.length - 1];
337         return uint256(latestDelegate.amount) * BALANCE_COMPACT_PRECISION;
338     }
```

Figure 24 The source code of *calcUnlockedDelegatedAmount* function(Fixed)

[Ankr-staking-11] Variable types are inconsistent

Severity Level	Info
Type	Business Security
Lines	Staking.sol #L102-110
Description	The uint64 type used by the *_undelegateFrom* function is inconsistent with the definition.

```
102     struct DelegationOpDelegate {
103         uint112 amount;
104         uint64 epoch;
105     }
106
107     struct DelegationOpUndelegate {
108         uint112 amount;
109         uint64 epoch;
110     }
```

Figure 25 The source code of DelegationOp

```
362 function _undelegateFrom(address toDelegator, address fromValidator, uint256 amount) internal {
363     // check minimum delegate amount
364     require(amount >= _stakingConfig.getMinStakingAmount() && amount != 0, "too low");
365     require(amount % BALANCE_COMPACT_PRECISION == 0, "no remainder");
366     // make sure validator exists at least
367     Validator memory validator = _validatorsMap[fromValidator];
368     uint64 beforeEpoch = nextEpoch();
369     // Lets upgrade next snapshot parameters:
370     // + find snapshot for the next epoch after current block
371     // + increase total delegated amount in the next epoch for this validator
372     // + re-save validator because last affected epoch might change
373     ValidatorSnapshot storage validatorSnapshot = _touchValidatorSnapshot(validator, beforeEpoch);
374     require(validatorSnapshot.totalDelegated >= uint112(amount / BALANCE_COMPACT_PRECISION), "insufficient balance");
375     validatorSnapshot.totalDelegated -= uint112(amount / BALANCE_COMPACT_PRECISION);
376     _validatorsMap[fromValidator] = validator;
377     // if last pending delegate has the same next epoch then its safe to just increase total
378     // staked amount because it can't affect current validator set, but otherwise we must create
379     // new record in delegation queue with the last epoch (delegations are ordered by epoch)
380     ValidatorDelegation storage delegation = _validatorDelegations[fromValidator][toDelegator];
381     require(delegation.delegateQueue.length > 0, "insufficient balance");
382     DelegationOpDelegate storage recentDelegateOp = delegation.delegateQueue[delegation.delegateQueue.length - 1];
383     require(recentDelegateOp.amount >= uint64(amount / BALANCE_COMPACT_PRECISION), "insufficient balance");
384     // disallow to undelegate if lock period is not reached yet (make sure we don't have pending undelegates)
385     //_transferDelegatorRewards(fromValidator, toDelegator, beforeEpoch, false, true);
386     require(amount <= _calcUnlockedDelegatedAmount(delegation), "still locked");
387     // calc next delegated amount
388     uint112 nextDelegatedAmount = recentDelegateOp.amount - uint112(amount / BALANCE_COMPACT_PRECISION);
389     if (recentDelegateOp.epoch >= beforeEpoch) {
390         // decrease total delegated amount for the next epoch
391         recentDelegateOp.amount = nextDelegatedAmount;
392     } else {
393         // there is no pending delegations, so lets create the new one with the new amount
394         delegation.delegateQueue.push(DelegationOpDelegate({epoch : beforeEpoch, amount : nextDelegatedAmount}));
395     }
```

Figure 26 The source code of *_undelegateFrom* function

Recommendations	It is recommended to unify the uint112 type.
Status	Fixed.

```
364     function _undelegateFrom(address toDelegator, address fromValidator, uint256 amount) internal {
365         // check minimum delegate amount
366         require(amount >= _stakingConfig.getMinStakingAmount() && amount != 0, "too low");
367         require(amount % BALANCE_COMPACT_PRECISION == 0, "no remainder");
368         // make sure validator exists at least
369         Validator memory validator = _validatorsMap[fromValidator];
370         uint64 beforeEpoch = nextEpoch();
371         // Lets upgrade next snapshot parameters:
372         // + find snapshot for the next epoch after current block
373         // + decrease total delegated amount in the next epoch for this validator
374         // + re-save validator because last affected epoch might change
375         ValidatorSnapshot storage validatorSnapshot = _touchValidatorSnapshot(validator, beforeEpoch);
376         require(validatorSnapshot.totalDelegated >= uint112(amount / BALANCE_COMPACT_PRECISION), "insufficient balance");
377         validatorSnapshot.totalDelegated -= uint112(amount / BALANCE_COMPACT_PRECISION);
378         _validatorsMap[fromValidator] = validator;
379         // if last pending delegate has the same next epoch then its safe to just decrease total
380         // staked amount because it can't affect current validator set, but otherwise we must create
381         // new record in delegation queue with the last epoch (delegations are ordered by epoch)
382         ValidatorDelegation storage delegation = _validatorDelegations[fromValidator][toDelegator];
383         require(delegation.delegateQueue.length > 0, "insufficient balance");
384         DelegationOpDelegate storage recentDelegateOp = delegation.delegateQueue[delegation.delegateQueue.length - 1];
385         require(recentDelegateOp.amount >= uint112(amount / BALANCE_COMPACT_PRECISION), "insufficient balance");
386         // disallow to undelegate if lock period is not reached yet (make sure we don't have pending undelegates)
387         //_transferDelegatorRewards(fromValidator, toDelegator, beforeEpoch, false, true);
388         require(amount <= _calcUnlockedDelegatedAmount(delegation), "still locked");
389         // calc next delegated amount
```

Figure 27 The source code of *_undelegateFrom* function(Fixed)

[Ankr-staking-12] Meaningless payable keyword

Severity Level	Info
Type	Business Security
Lines	TokenLiquidStakingPool.sol #L31-37 TokenStaking.sol #L35-38
Description	The function has a payable type, and the user may mistakenly lock the BNB in the contract.

```
31  function stake(address validator, uint256 amount) external payable advanceStakingRewards(validator) override(LiquidStakingPool) {
32      require(msg.value == 0, "StakingPool: ERC20 expected");
33      IERC20 token = _erc20Token();
34      require(token.transferFrom(msg.sender, address(this), amount), "StakingPool: failed to transfer");
35      _stake(msg.sender, validator, amount);
36  }
```

Figure 28 The source code of *stake* function

```
34
35      function delegate(address validatorAddress, uint256 amount) payable external override {
36          require(_erc20Token.transferFrom(msg.sender, address(this), amount), "failed to transfer");
37          _delegateTo(msg.sender, validatorAddress, amount, true);
38      }
```

Figure 29 The source code of *delegate* function

Recommendations	It is recommended to delete the payable type.
Status	Fixed.

```
31  function stake(address validator, uint256 amount) external payable advanceStakingRewards(validator) override(LiquidStakingPool) {
32      require(msg.value == 0, "StakingPool: ERC20 expected");
33      IERC20 token = _erc20Token();
34      require(token.transferFrom(msg.sender, address(this), amount), "StakingPool: failed to transfer");
35      _stake(msg.sender, validator, amount);
36  }
37
```

Figure 30 The source code of *stake* function(Fixed)

```
35      function delegate(address validatorAddress, uint256 amount) payable external override {
36          require(msg.value == 0, "TokenStaking: ERC20 expected");
37          require(_erc20Token.transferFrom(msg.sender, address(this), amount), "failed to transfer");
38          _delegateTo(msg.sender, validatorAddress, amount, true);
39      }
40
```

Figure 31 The source code of *delegate* function(Fixed)

[AnkrProtocol-1] Missing asset extraction interface

Severity Level	**Low**
Type	Business Security
Lines	AnkrProtocol.sol #L191-194
Description	The function of user extraction is not implemented in the contract, which causes the user to stake in the contract. The staked tokens are locked in the contract. And the fee charged cannot be withdrawn.

```
190
191     function withdraw(uint256 /*amount*/, uint256 /*fee*/) external nonReentrant {
192         revert("not supported yet");
193     }
194
```

Figure 32 The source code of *withdraw* function

Recommendations	It is recommended to implement the extraction function.
Status	Acknowledged. According to the description of the project party, withdrawals are not possible for this smart contract. The project party added additional function called *transferCollectedFee* that allow to transfer locked funds to special contract that do fee distribution.

[AnkrProtocol-2] Stake level setting issue

Severity Level	**Low**
Type	Business Security
Lines	AnkrProtocol.sol #L112-117
Description	Governance has the authority to call the *changeTierLevel* function to arbitrarily change the threshold (staking level judgment amount) and fee (staking fee) of different levels. In the *createTierLevel* function, it is stipulated that only the larger the threshold, the higher the corresponding stake level, so that the threshold arbitrarily changed in the *changeTierLevel* function may not match the corresponding level. When Governance calls the *changeTierLevel* function to increase the threshold of the user's level, then when the user selects a stake, the level queried by the *_matchTierLevelOf* function will decrease. If there is no corresponding processing in *_lockDeposit*, it will lead to a loss of user level reduction.
Recommendations	It is recommended to check whether the value is within the threshold range of the front and back levels when setting a new threshold in the *changeTierLevel* function.
Status	Acknowledged. According to the description of the project party, governance processes are managed and audited, the project party is not planning to change existing tier plans or add new tier plans.

```
112     function changeTierLevel(uint8 level, uint256 threshold, uint256 fee) external onlyFromGovernance {
113         require(_tierLevels[level].tier > 0, "AnkrProtocol: level doesn't exist");
114         _tierLevels[level].threshold = threshold;
115         _tierLevels[level].fee = fee;
116         emit TierLevelChanged(level);
117     }
```

Figure 33 The source code of *changeTierLevel* function

[AnkrProtocol-3] Missing check for zero address

Severity Level	Low
Type	Business Security
Lines	AnkrProtocol.sol #L195-206
Description	When the following functions are called with corresponding permissions, there is a risk of transferring permissions to address zero.

```
195     function changeConsensus(address newConsensus) external onlyFromGovernance {
196         _consensus = newConsensus;
197     }
198
199     function changeGovernance(address newGovernance) external onlyFromGovernance {
200         _governance = newGovernance;
201     }
202
203     function changeEnterpriseAdmin(address newEnterpriseAdmin) external onlyFromGovernance {
204         _enterpriseAdmin = newEnterpriseAdmin;
205     }
206 }
```

Figure 34 The source code of unchecked functions

Recommendations	It is recommended to add 0 address check.
Status	Fixed.

```
212     function changeConsensus(address newValue) external onlyFromGovernance {
213         require(newValue != address(0x00), "AnkrProtocol: zero address");
214         address oldValue = _consensus;
215         _consensus = newValue;
216         emit ConsensusChanged(oldValue, newValue);
217     }
218
219     function changeGovernance(address newValue) external onlyFromGovernance {
220         require(newValue != address(0x00), "AnkrProtocol: zero address");
221         address oldValue = _governance;
222         _governance = newValue;
223         emit GovernanceChanged(oldValue, newValue);
224     }
225
226     function changeEnterpriseAdmin(address newValue) external onlyFromGovernance {
227         require(newValue != address(0x00), "AnkrProtocol: zero address");
228         address oldValue = newValue;
229         _enterpriseAdmin = newValue;
230         emit EnterpriseAdminChanged(oldValue, newValue);
231     }
232 }
```

Figure 35 The source code of unchecked functions(Fixed)

[AnkrProtocol-4] Code redundancy

Severity Level	Low
Type	Business Security
Lines	AnkrProtocol.sol #L195-206
Description	The permission of consensus is not reflected in the contract.

```
82    modifier onlyFromConsensus() virtual {
83        require(msg.sender == address(_consensus), "AnkrProtocol: not consensus");
84        _;
85    }
86
```

Figure 36 The source code of onlyFromGovernance modifier

Recommendations	It is recommended to remove this modifier.
Status	Fixed.

[AnkrProtocol-5] Lack of event triggering

Severity Level	Info
Type	Business Security
Lines	AnkrProtocol.sol #L195-206
Description	The following functions are missing event triggers.

```
194
195     function changeConsensus(address newConsensus) external onlyFromGovernance {
196         _consensus = newConsensus;
197     }
198
199     function changeGovernance(address newGovernance) external onlyFromGovernance {
200         _governance = newGovernance;
201     }
202
203     function changeEnterpriseAdmin(address newEnterpriseAdmin) external onlyFromGovernance {
204         _enterpriseAdmin = newEnterpriseAdmin;
205     }
206 }
```

Figure 37 The source code of untouched functions

Recommendations	It is recommended to remove this modifier.
Status	Fixed.

```
212     function changeConsensus(address newValue) external onlyFromGovernance {
213         require(newValue != address(0x00), "AnkrProtocol: zero address");
214         address oldValue = _consensus;
215         _consensus = newValue;
216         emit ConsensusChanged(oldValue, newValue);
217     }
218
219     function changeGovernance(address newValue) external onlyFromGovernance {
220         require(newValue != address(0x00), "AnkrProtocol: zero address");
221         address oldValue = _governance;
222         _governance = newValue;
223         emit GovernanceChanged(oldValue, newValue);
224     }
225
226     function changeEnterpriseAdmin(address newValue) external onlyFromGovernance {
227         require(newValue != address(0x00), "AnkrProtocol: zero address");
228         address oldValue = newValue;
229         _enterpriseAdmin = newValue;
230         emit EnterpriseAdminChanged(oldValue, newValue);
231     }
232 }
```

Figure 38 The source code of untouched functions(Fixed)

[AnkrProtocol-6] stake lock issue

Severity Level	Info
Type	Business Security
Lines	AnkrProtocol.sol #L163-189
Description	When the user stake, the timeout lock-up time is controlled by the user, and in the *_lockDeposit* function, the lock-up time is only updated when it is judged that userDeposit.expires == 0. Then the user can control the lock-up time and only lock the first stakes.

```
163  function _lockDeposit(address user, uint256 amount, uint64 timeout, bytes32 publicKey) internal {
164      // transfer ERC20 tokens when its required
165      if (amount > 0) {
166          require(_ankrToken.transferFrom(user, address(this), amount), "Ankr Protocol: can't transfer");
167      }
168      // obtain user's lock and match next tier level
169      UserDeposit memory userDeposit = _userDeposits[user];
170      TierLevel memory newLevel = _matchTierLevelOf(userDeposit.total + amount);
171      // check do we need to charge for level increase
172      if (newLevel.fee > 0 && (newLevel.tier > userDeposit.tier || userDeposit.expires > block.timestamp)) {
173          amount -= newLevel.fee;
174          _collectedFee += newLevel.fee;
175      }
176      // increase locked amount
177      userDeposit.total += amount;
178      userDeposit.available += amount;
179      // if we have no expires set then increase it
180      if (userDeposit.expires == 0) {
181          userDeposit.expires = uint64(block.timestamp) + timeout;
182      }
183      // save new tier
184      userDeposit.tier = newLevel.tier;
185      _userDeposits[user] = userDeposit;
186      // emit event
187      emit TierAssigned(user, amount, userDeposit.tier, newLevel.roles, userDeposit.expires, publicKey);
188      emit FundsLocked(user, amount, newLevel.fee);
189  }
```

Figure 39 The source code of *_lockDeposit* function

Recommendations	It is suggested that the lock-up period is fixed, and the lock-up start time is the user's stake time each time.
Status	Acknowledged.

[PayAsYouGo-1] Reward source not specified

Severity Level	Medium
Type	Business Security
Lines	PayAsYouGo.sol #L193-198
Description	Consensus can call the *deliverReward* function to issue ankr token rewards to the current epoch of the stakingContract contract. This does not specify the source of the amount issued. If the amount is too large, the user's stake principal will be issued as a reward, which will cause losses to the user. If the source of the amount is the collected _collectedFee, then should judge whether the amount is less than _collectedFee and subtract the value of collectedFee in each call.

```
193
194     function deliverReward(address stakingContract, address validatorAddress, uint256 amount) external onlyConsensus {
195         require(_ankrToken.approve(stakingContract, amount), "PayAsYouGo: can't increase allowance");
196         ITokenStaking(stakingContract).distributeRewards(validatorAddress, amount);
197     }
198 }
```

Figure 40 The source code of *deliverReward* function

Recommendations	It is recommended to distribute rewards from collectedFee and deduct the corresponding amount.
Status	Fixed.

```
217     function deliverReward(address stakingContract, address validatorAddress, uint256 amount) external onlyConsensus {
218         require(amount <= _collectedFee, "PayAsYouGo: insufficient fee");
219         _collectedFee -= amount;
220         require(_ankrToken.approve(stakingContract, amount), "PayAsYouGo: can't increase allowance");
221         ITokenStaking(stakingContract).distributeRewards(validatorAddress, amount);
222     }
223 }
```

Figure 41 The source code of *deliverReward* function(Fixed)

[PayAsYouGo-2] User withdrawal issue

Severity Level	Low
Type	Business Security
Lines	PayAsYouGo.sol #L150-175
Description	The user can only call the *withdraw* function to increase the pending amount to be withdrawn, and the final transfer operation is implemented by Consensus calling the *handleWithdraw* function. The user's withdrawal amount and fee are not controlled by the user.

```
150  function handleWithdraw(address[] calldata users, uint256[] calldata amounts, uint256[] calldata fees) external onlyConsensus override {
151      require(users.length == amounts.length && amounts.length == fees.length, "PayAsYouGo: corrupted data");
152      for (uint256 i = 0; i < users.length; i++) {
153          _doWithdraw(users[i], amounts[i], fees[i]);
154      }
155  }
156
157  function _doWithdraw(address user, uint256 amount, uint256 fee) internal {
158      uint80 amount80 = uint80(amount / BALANCE_COMPACT_PRECISION);
159      uint80 fee80 = uint80(fee / BALANCE_COMPACT_PRECISION);
160      // decrease user's balance
161      UserBalance memory userDeposit = _userDeposits[user];
162      require(userDeposit.pending >= amount80, "PayAsYouGo: wrong withdraw amount");
163      require((userDeposit.pending + userDeposit.available) >= (amount80 + fee80), "PayAsYouGo: insufficient balance");
164      userDeposit.available += userDeposit.pending - amount80;
165      userDeposit.pending = 0;
166      _userDeposits[user] = userDeposit;
167      // if we have specified fee then charge it from user's account
168      if (fee > 0) {
169          _chargeAnkrFor(user, fee);
170      }
171      // transfer funds to user
172      require(_ankrToken.transfer(user, amount), "PayAsYouGo: can't transfer");
173      // emit event
174      emit FundsUnlocked(user, amount);
175  }
```

Figure 42 The source code of *handleWithdraw* and *_doWithdraw* functions

Recommendations	It is recommended to limit the value of fee within a reasonable range.
Status	Acknowledged.

[PayAsYouGo-3] Handling fee issue

Severity Level	**Low**
Type	Business Security
Lines	PayAsYouGo.sol #L126-140
Description	When the contract charges the fee through the *_chargeAnkrFor* function, the _collectedFee in the contract only increases but does not decrease. Then, the fee will not be processed in the contract.

```
126  function handleChargeFee(address[] calldata users, uint256[] calldata fees) external onlyConsensus override {
127      require(users.length == fees.length);
128      for (uint256 i = 0; i < users.length; i++) {
129          _chargeAnkrFor(users[i], fees[i]);
130      }
131  }
132
133  function _chargeAnkrFor(address sender, uint256 fee) internal {
134      uint80 fee80 = uint80(fee / BALANCE_COMPACT_PRECISION);
135      UserBalance memory userDeposit = _userDeposits[sender];
136      userDeposit.available -= fee80;
137      _userDeposits[sender] = userDeposit;
138      _collectedFee += fee;
139      emit FeeCharged(sender, fee);
140  }
```

Figure 43 The source code of *handleChargeFee* and *_chargeAnkrFor* functions

Recommendations	It is recommended to increase the extraction method of _collectedFee.
Status	Acknowledged. According to the description of the project party, fee here means not withdrawal fee, its fee for services. the project party doesn't charge fee immediately the project party charge it on weekly basis or on withdrawal. Its also intended.

[PayAsYouGo-4] Variable does not implement the relevant function

Severity Level	Info
Type	Business Security
Lines	PayAsYouGo.sol #L68-73, L93-103, L169-182
Description	The timeout and publicKey variables are passed in when the user stake s, but the contract is only used to trigger events and has no actual impact. When the user extracts, it just adds _requestNonce as a record and does not use it.

```
68    function deposit(uint256 amount, uint64 timeout, bytes32 publicKey) external nonReentrant override {
69        require(amount % BALANCE_COMPACT_PRECISION == 0, "PayAsYouGo: remainder is not allowed");
70        require(amount % DEPOSIT_WITHDRAW_PRECISION == 0, "PayAsYouGo: too high precision");
71        _lockDepositForUser(msg.sender, amount, timeout, msg.sender, publicKey);
72    }
73
```

Figure 44 The source code of *deposit* function

```
93    function _lockDepositForUser(address sender, uint256 amount, uint64 timeout, address user, bytes32 publicKey) internal {
94        if (amount > 0) {
95            require(_ankrToken.transferFrom(sender, address(this), amount), "PayAsYouGo: can't transfer");
96        }
97        // obtain user's lock and match next tier level
98        UserBalance memory userDeposit = _userDeposits[user];
99        userDeposit.available += uint80(amount / BALANCE_COMPACT_PRECISION);
100       _userDeposits[user] = userDeposit;
101       emit FundsLocked(user, amount);
102       // emit event for JWT token
103       emit TierAssigned(user, amount, 0, 0, uint64(block.timestamp + timeout), publicKey);
104   }
```

Figure 45 The source code of *_lockDepositForUser* function

```
169   function _triggerRequestEvent(address sender, uint64 lifetime, bytes memory input) internal {
170       // increase nonce
171       uint64 nonce = _requestNonce[sender];
172       _requestNonce[sender]++;
173       // calc request id
174       bytes32 id = keccak256(abi.encodePacked(sender, nonce, block.chainid, input));
175       // request expiration time (default lifetime is 1 week)
176       if (lifetime == 0) {
177           lifetime = 604800;
178       }
179       uint64 expires = uint64(block.timestamp) + lifetime;
180       // emit as event to provider
181       emit ProviderRequest(id, sender, 0, address(this), input, expires);
182   }
```

Figure 46 The source code of *_triggerRequestEvent* function

Recommendations	It is recommended to add related implementation.
Status	Acknowledged. According to the description of the project party, nonce is used to calculate request id. This event is used only to verify consensus of pending withdrawal to ask to process it.

3 Appendix

3.1 Vulnerability Assessment Metrics and Status in Smart Contracts

3.1.1 Metrics

In order to objectively assess the severity level of vulnerabilities in blockchain systems, this report provides detailed assessment metrics for security vulnerabilities in smart contracts with reference to CVSS 3.1 (Common Vulnerability Scoring System Ver 3.1).

According to the severity level of vulnerability, the vulnerabilities are classified into four levels: "critical", "high", "medium" and "low". It mainly relies on the degree of impact and likelihood of exploitation of the vulnerability, supplemented by other comprehensive factors to determine of the severity level.

Impact / Likelihood	Severe	High	Medium	Low
Probable	Critical	High	Medium	Low
Possible	High	High	Medium	Low
Unlikely	Medium	Medium	Low	Info
Rare	Low	Low	Info	Info

3.1.2 Degree of impact

- **Severe**

Severe impact generally refers to the vulnerability can have a serious impact on the confidentiality, integrity, availability of smart contracts or their economic model, which can cause substantial economic losses to the contract business system, large-scale data disruption, loss of authority management, failure of key functions, loss of credibility, or indirectly affect the operation of other smart contracts associated with it and cause substantial losses, as well as other severe and mostly irreversible harm.

- **High**

High impact generally refers to the vulnerability can have a relatively serious impact on the confidentiality, integrity, availability of the smart contract or its economic model, which can cause a greater economic loss, local functional unavailability, loss of credibility and other impact to the contract business system.

- **Medium**

Medium impact generally refers to the vulnerability can have a relatively minor impact on the confidentiality, integrity, availability of the smart contract or its economic model, which can cause a small amount of economic loss to the contract business system, individual business unavailability and other impact.

- **Low**

Low impact generally refers to the vulnerability can have a minor impact on the smart contract, which can pose certain security threat to the contract business system and needs to be improved.

3.1.4 Likelihood of Exploitation

- **Probable**

Probable likelihood generally means that the cost required to exploit the vulnerability is low, with no special exploitation threshold, and the vulnerability can be triggered consistently.

- **Possible**

Possible likelihood generally means that exploiting such vulnerability requires a certain cost, or there are certain conditions for exploitation, and the vulnerability is not easily and consistently triggered.

- **Unlikely**

Unlikely likelihood generally means that the vulnerability requires a high cost, or the exploitation conditions are very demanding and the vulnerability is highly difficult to trigger.

- **Rare**

Rare likelihood generally means that the vulnerability requires an extremely high cost or the conditions for exploitation are extremely difficult to achieve.

3.1.5 Fix Results Status

Status	Description
Fixed	The project party fully fixes a vulnerability.
Partially Fixed	The project party did not fully fix the issue, but only mitigated the issue.
Acknowledged	The project party confirms and chooses to ignore the issue.

3.2 Audit Categories

No.	Categories	Subitems
1	Coding Conventions	Compiler Version Security
		Deprecated Items
		Redundant Code
		require/assert Usage
		Gas Consumption
2	General Vulnerability	Integer Overflow/Underflow
		Reentrancy
		Pseudo-random Number Generator (PRNG)
		Transaction-Ordering Dependence
		DoS (Denial of Service)
		Function Call Permissions
		call/delegatecall Security
		Returned Value Security
		tx.origin Usage
		Replay Attack
		Overriding Variables
		Third-party Protocol Interface Consistency
3	Business Security	Business Logics
		Business Implementations
		Manipulable Token Price
		Centralized Asset Control
		Asset Tradability
		Arbitrage Attack

Beosin classified the security issues of smart contracts into three categories: Coding Conventions, General Vulnerability, Business Security. Their specific definitions are as follows:

- **Coding Conventions**

Audit whether smart contracts follow recommended language security coding practices. For example, smart contracts developed in Solidity language should fix the compiler version and do not use deprecated keywords.

- **General Vulnerability**

General Vulnerability include some common vulnerabilities that may appear in smart contract projects. These vulnerabilities are mainly related to the characteristics of the smart contract itself, such as integer overflow/underflow and denial of service attacks.

- **Business Security**

Business security is mainly related to some issues related to the business realized by each project, and has a relatively strong pertinence. For example, whether the lock-up plan in the code match the white paper, or the flash loan attack caused by the incorrect setting of the price acquisition oracle.

*Note that the project may suffer stake losses due to the integrated third-party protocol. This is not something Beosin can control. Business security requires the participation of the project party. The project party and users need to stay vigilant at all times.

3.3 Disclaimer

The Audit Report issued by Beosin is related to the services agreed in the relevant service agreement. The Project Party or the Served Party (hereinafter referred to as the "Served Party") can only be used within the conditions and scope agreed in the service agreement. Other third parties shall not transmit, disclose, quote, rely on or tamper with the Audit Report issued for any purpose.

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The Audit Report issued by Beosin in no way provides investment advice on any project, nor should it be utilized as investment suggestions of any type. This report represents an extensive evaluation process designed to help our customers improve code quality while mitigating the high risks in Blockchain.

3.4 About BEOSIN

BEOSIN is the first institution in the world specializing in the construction of blockchain security ecosystem. The core team members are all professors, postdocs, PhDs, and Internet elites from world-renowned academic institutions.BEOSIN has more than 20 years of research in formal verification technology, trusted computing, mobile security and kernel security, with overseas experience in studying and collaborating in project research at well-known universities. Through the security audit and defense deployment of more than 2,000 smart contracts, over 50 public blockchains and wallets, and nearly 100 exchanges worldwide, BEOSIN has accumulated rich experience in security attack and defense of the blockchain field, and has developed several security products specifically for blockchain.

BEOSIN
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