Extortionware: Exploiting Smart Contract Vulnerabilities for Fun and Profit

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Abstract—Smart Contracts (SCs) publicly deployed on blockchain have been shown to include multiple vulnerabilities, which can be maliciously exploited by users.

In this paper, we present extortionware, a novel attack exploiting the public nature of vulnerable SCs to gain control over the victim's SC assets. Thanks to the control gained over the SC, the attacker obliges the victim to pay a price to re-gain exclusive control of the SC.

Index Terms—Blockchain, smart contract, ransomware, zero-knowledge proof

I. INTRODUCTION

S
mart Contracts are the main enablers of new blockchain-based services and decentralized applications thanks to their self-verification, self-execution, and tamper resistance. Due to these features, they are used by multiple untrusted parties to stipulate agreements that are publicly verifiable. The impact of this technology is demonstrated by the number of actively deployed Smart Contracts (SCs), whose number increased by 100 times in the last couple of years. When deployed in permission-less blockchains, SCs’ code is publicly available. Therefore, anyone having access to the blockchain can investigate the SC’s code. This allows external actors to gain insights on the procedures and operations that SCs execute, both in terms of amount of assets transferred and in terms of parties involved. Such information can be exploited by an attacker to select a suitable target to maximize the reward associated with a possible attack. In particular, loopholes or vulnerabilities leading to recurrent SC behaviors, can be exploited by an attacker to steal assets from the account connected to the victim’s SC.

The vulnerabilities associated with backdoors or non-restricted access to systems are very well known these days. In particular, during the last years, a large number of systems and companies were subject to ransomware attacks. In these attacks, the accessibility to systems’ resources is compromised by an attacker gaining access to the network and encrypting all the accessible sensitive information. The attacker exploits the fact that attacks towards robust cryptographic protocols have no solution other than the brute-force exploration of all possible keys, which however requires an unfeasible amount of time to find the correct key. The victim has no choice other than paying the required ransom to the attacker to get the key and gaining back access to the encrypted sensitive information.

The number of ransomware attacks and the requested ransom amount significantly increased in 2021, with a last significant example from the U.S. department of justice that paid 2.3 Million Dollars in ransom in June 2021. Therefore, the presence of vulnerabilities might not only impact on the system’s functionalities, but also provide attackers means for economic attacks.

In this work, we present the extortionware, a novel attack methodology inspired by ransomware attacks and targeting SCs. The public nature of smart contracts together with the lack of a fully secure SC development framework, provide attackers with means for continuous exploitation of the identified vulnerability. Thanks to this, the attacker might be able to cause a continuous damage that allows for the request of a ransom to stop the exploitation. This concept is similar to a ransomware. However, instead of denying access to restricted data via encryption, the attacker is able to undermine the security of the SC and its related operations. We discuss throughout the paper some of the vulnerabilities that can be exploited and the damage they may cause. We also explain why there is no simple workaround at the victim’s side. Although several tools for designing secure SC are available for developers, a recent study showed that the majority of the currently deployed SCs exhibit some vulnerabilities. Therefore, our framework represents a serious threat and shall not be overlooked.

II. EXTORSIONWARE BASIC BLOCKS

The extortionware merges a technology, i.e., SC, with an attack methodology, i.e., ransomware. In this section we review both the technology and the attack methodology. In particular, we first provide an overview of the SC technology, explaining how it works and how it can be used. Then, we review the ransomware attack.

A. Smart Contract

SCs are low-level programs stored and running on a blockchain. They are usually part of an event driven program, i.e., a program whose actions depend on the stimuli received by other on-chain or off-chain actors. SCs can execute different set of actions, such as transfer of funds, issuing tickets, and registering vehicles. Thanks to their self-execution design, SCs do not need human monitoring. Rather, they autonomously execute actions including, among the others, the creation of other contracts. The terms of agreement between the involved parties determine the set of actions and actors that determine the design and coding of the SC. Compared
to other types of contracts, SCs provide advantages such as the immutability of the information and trust enforcement among untrusted parties thanks to the use of the blockchain technology. In fact, in order to revert a transaction or alter the information provided or shared by a SC, a malicious actor would need to revert the entire blockchain. This feature holds also for the SC itself, as it cannot be modified unless altering the information stored in the blockchain. Notice however that, as for all other software, a certain degree of freedom for modification after deployment is needed to fix possible bugs and upgrade the SC. SCs provide transparency to parties, as no third regulatory party is involved and the encrypted record of transactions is shared among all the participants. A further advantage of their decentralization is the time needed to execute transactions. In fact, there is no need to wait for the third party regulatory approval before execution, reducing hence the delays compared to other centralized systems.

SCs can actively issue transactions and make external calls to other SCs to delegate the transaction execution [7]. SC can also perform internal calls, i.e., calls generated within a contract that are not recorded on chain. SCs are also allowed to receive input parameters and values to use in the function execution. To execute a SC, the sender needs to pay a fee associated to the contract’s computational cost. In Ethereum-based SCs, the fee is associated to units of gas, and this value is agreed upon before the instruction execution. The gas is used to reward the miner of the block containing the transaction, and any remaining gas is refunded to the issuer. To avoid loopholes where transaction are never terminated due to infinite cycles, each SC defines a gas limit that can be used for contract execution. An out of gas exception is thrown whenever the gas limit is reached.

SCs’ code can be stored in plaintext in the blockchain [8]. Therefore, SCs stored in permissionless blockchains are publicly available, and can be read by anyone accessing the network. A similar concept holds for permissioned blockchain, where access to code is provided upon authorization. However, in both cases, the set of actions and triggering conditions of the SC can be accessed by simply accessing to the block where it is stored. This feature is exploited to provide transparency to the involved parties. However, as we will later discuss, this also allows attackers to identify and exploit SC vulnerabilities.

B. Ransomware Attack

In a ransomware attack, a malicious user finds and exploits a vulnerability that allow accessing to resources of a victim’s system. In particular, the attacker renders inaccessible such resources to the victim, and demands for a ransom to return the stolen assets. The ransomware attack can be divided in five phases [9], as depicted in Figure 1. The five phases can be described as follows:

1) **Exploitation and Infection.** In this phase, the attacker either discovers a vulnerability in a target system, or injects malicious software in the victim’s systems via social engineering attack (e.g., phishing). Exploitation can be performed also via exploit kit, which explore and identify common system’s vulnerabilities. More

uncommon (although likely) cases include leaking of the victim’s sensitive information such as passwords for accessing the system.

2) **Delivery and Execution.** In this phase, the attacker sends the actual ransomware executable and runs it on the victim’s system. The attacker usually exploits strong encryption to prevent the identification of the executable. Most of these malware are equipped with persistence mechanisms, such that in case of reboot during the encryption process, the malware can pick up from where it has been interrupted.

3) **Back-up Spoliation.** This phase is peculiar of ransomware attacks. The malware, after few seconds from its execution, removes all back-up files or folders, as well as shadow copies to prevent the victim to recover the encrypted data without paying the ransom. The ransomware malware is usually able to remove eventual lockers on such files.

4) **Encryption.** After deleting all back-up copies, the ransomware malware starts encrypting files on the victim’s system. Depending on the malware implementation, the encryption keys are either agreed with the command and control server, or without reaching the internet. Encryption is performed via strong mechanisms, such as AES 256, such that the victim is not able to break the encryption without knowing the keys. Depending on the type of system and its connection with other network components, the malware may be able to encrypt files distributed over multiple network nodes.

5) **User Notification and Clean-Up.** After successfully delivering the attack, the ransomware software usually presents to the victim instructions on how to recover files. The victim is given a couple of days, after which the ransom amount progressively increases. Finally, the malware removes itself from the system to avoid the collection of forensics information.

III. SMART CONTRACT VULNERABILITIES

Similar to classical contracts written on paper, SCs need to be written by humans. The main difference is that, in the case of SC, the writer is a programmer that translates the set of instructions and obligations stipulated by the involved
parties into executable code. Statistics show that, due to human fallibility, codes contain a large number of bugs. An estimate reports an average number of 15 - 50 errors per 1000 lines of delivered code [10]. Being SCs computer programs, they are hence susceptible to human mistakes in code design or writing. In this section we review some of the common coding mistakes resulting from the lack of expertise in the best SC coding practices. All these vulnerabilities could be potentially exploited either singularly or simultaneously by attacker to perform extorsionware. The full list of known SC vulnerabilities is provided by the Smart Contract Weakness registry [11]. The gist of the SC vulnerabilities are described as follows.

a) Arithmetic Under/Overflow: The range of numbers that can be represented by a SC depends on its code definition and is completely handled at compilation time. Therefore, in case of lack of a proper verification mechanism, an attacker can input data values that go beyond the range of the supported type.

b) Public Default Visibility: In Solidity, SCs’ functions can be called by other contracts or users both internal and external to the blockchain depending on the visibility type. The default option is to set functions as public. Therefore, if visibility types are not properly handled, a malicious actor could call functions to trigger transactions execution.

c) Lack of True Randomness: The random number generation function is not present in solidity, as achieving decentralized randomness is a current research problem. Therefore, SC programmers create their own random function. However, the lack of a properly design randomness source may lead to leakage of information that an attacker can exploit for predictions.

d) Re-Entrancy: Ethereum SC envision the possibility of calling and employing functionalities embedded in other SCs. A relevant example in this context, is the transfer of Ether from an address to another only via calls made to external SCs. A malicious user can exploit this feature to withdraw all the account’s Ether. In particular, the attacker can create a malicious SC that, upon receiving ETH, calls-back the victim’s SC to re-execute the transaction.

e) Locked Ether: This vulnerability exploits the fact that a SC can be designed to execute fund transfers only by exploiting calls to other SCs similar to the previous point. However, in this case the attacker exploits a vulnerability in the executing SC to delete it without permission [12]. The victim SC therefore is not able to execute transactions as it makes calls to a non-existing SC. Similar vulnerabilities that allow for the modification of data stored inside the SC can be exploited to alter the address of the executing SC. In this case, the attacker may change the address with that of a fictitious SC that does not execute the transaction upon request from the victim.

f) Unhandled Exceptions: This vulnerability is associated to pre-compiled SCs. Such contracts can return either zero or one as exit state, but may also report false-positives in case they generate an exception that is not properly handled by the SC’s code.

g) Denial of Service: This vulnerability exploits external contract calls to stop the contracts’ correct functioning. In particular, it exploits the fact that the victim’s SC may exploit multiple external calls but fails in properly handling exception during this operation. This may prevent the contract to continue its execution remaining in an idle state.

IV. EXTORSIONWARE LIFE-CYCLE

The fact that SCs’ code is publicly available provides malicious users unique opportunities to exploit possible vulnerabilities. In fact, it is reasonable to assume that a malicious users takes advantage of the identified vulnerability to attack the SC. In this work, we present the extorsionware, a novel form of ransomware attack that targets the vulnerability of a publicly available SC. Similarly to a ransomware, we assume that the attacker possesses an information that is essential to the victim, and that such information is returned to the victim only upon payment of a ransom. Differently from ransomware, we do not assume that the attacker is able to hide information at the victim’s side (e.g., via encryption). We instead assume that the attacker identifies a vulnerability in a publicly available SC, and exploits it and the fact that the victim is unaware of such vulnerability to request a ransom.

The extorsionware begins with an individual or company creating a SC used for the transfer of funds and goods. The attack then includes the following five phases.

1) Scouting for Vulnerable SCs. The attacker first crawls the blockchain to identify vulnerable SCs belonging to potential victims. As the SC is publicly available, the attacker is able to identify possible vulnerabilities within the SC code that allows her to transfer assets at will or to steal assets from the victim.

2) Zero-Knowledge Attack. In order for the attacker to show that she actually controls the victim’s SC, the ransom request comes with a certain operation executed from the victim’s SC. For instance, the attacker states that she will withdraw a specific amount from an account belonging to that SC at a specific future time instant. Once the attacker executes the transaction at the specified day and time, the victim knows that the attacker controls the SC. This scheme is similar to a zero-knowledge proof, where one of the parties discloses the knowledge of a certain information without actually disclosing the information itself.

3) Compensation Request and Ultimatum. The attacker then gives the company an ultimatum for paying a ransom, or the vulnerability will be continuously exploited for malicious purposes or sold to the black market.

4) Continuous Exploitation. The longer time goes on and the ransom remains unpaid, the amount transferred to others will continue to grow or the SC’s functionalities will remain blocked. This is similar to how a typical ransomware model works in that the victim is motivated by a timer to quickly pay the ransom to prevent greater consequences.

5) Final Threat and Ransom Payment. Finally, the attacker will threaten to sell the SC flaw to the black
market if the ransom is never received. Once the ransom is paid, the attacker can reveal the flaw to the company. The company is then be able to rewrite the SC code in order to stop future attacks from happening.

Figure 2 shows the steps of extorsionware attack. Notice that the attack, depending on its purposes, is either continuous in time or is periodically launched until the ransom payment.

Due to this, we divided the fourth step of extorsionware in 4.1) attack, and 4.2) continuous exploitation.

An example of this attack would be an insurance company creating a SC for paying customers. If an attacker found a vulnerability that allowed them to send money at will, they could create a devastating ransomware attack. The attacker could send $1000 to another person as proof of this flaw and demand a ransom from the company of $1 Million in order to reveal the flaw and stop sending out money. The insurance company may want to save its reputation early and pay the ransom. If the company does not think the financial loss of the $1000 payouts is great enough yet, the attacker can increase the money sent to $10,000 and keep increasing it until the ransom is paid. The attacker could also sell the flaw in the SC on the black market so others could also take advantage of the vulnerability. We notice that a company may want to remove the flawed SC and replace it with another one. However, deploying a new SC comes with design and deployment costs. Furthermore, the legal implications of deploying a novel contract after failure of the originally stipulated one might not ease a SC replacement. Lastly, depending on the service offered by the victim company, revealing that the contract has been attacked due to poor implementation might impact on the company’s reputation. Therefore, it might be convenient for the victim to pay the ransom and recover the originally deployed contract.

A further example on how an attacker can enforce the creation of weak SCs is provided by the large amount of information available online. It is indeed common that non-expert users are tricked into creating and deploying vulnerable SCs thanks to false promises of easy monetary reward. A further push through quick adoption of a technology without a proper understanding on its implications is the fear of missing out, a form of social anxiety that pushes individuals to stay continually connected with what others are doing [13]. This might be the case of companies adopting blockchain and all related technology in a rush towards a market share, relying on internal non-expert staff, or to external experts that might be malicious.

V. SHOWCASE IMPLEMENTATION OF THE EXTORSIONWARE

In this section we show how one of the above mentioned vulnerabilities can be used for the extorsionware. Notice that our scope is not to showcase a new attack towards a specific SC implementation. Rather, we use an already known vulnerability to demonstrate the validity of the extorsionware and shows how our framework can be exploited to demand a ransom. Furthermore, notice that an analysis of the vulnerabilities of currently publicly deployed SCs has already been provided [5]. We exploit these results to validate the concreteness of the threat imposed by extorsionware. We focus on the threat imposed by re-entrancy attacks together with public visibility. In particular, the attacker finds a vulnerability that allows to call the victim contract multiple times and withdraw a certain amount of Ether. We assume that the victim already agreed on the terms of the SC with the other involved parties and deployed the SC on the Ethereum blockchain.

Figure 3 shows the victim’s Solidity SC implementation. The victim’s SC is designed with a withdrawValues function that allows for extracting a certain amount of Ether from the user’s account after calling an external contract via the transferValues function. Notice that no visibility has been specified for this function, therefore it assumes the default public visibility and can be controlled by external contracts. The vulnerability in this contract resides in the fact that the transfer function hands over the control to the receiving SC. If the latter is controlled by a malicious user, it could call back the sender before the transaction is completed.

Figure 4 shows the Solidity implementation of the attacker’s SC. This SC exploit the aforementioned vulnerability, i.e., the call back to the sender’s SC. The attack starts with a call to the victim’s withdraw function. When the victim’s SC call the transfer function, this will trigger in any receiving contract a payable fallback. In the contract in Figure 4 the payable function calls back the victim’s withdraw function. The victim hence repeatedly triggers call to the attacker’s contract until all Ethers are drown in.

In extorsionware, the attacker may stop this loop to prevent all assets to be withdrawn, or may start the process again if the ransom is not paid. This represents a form of zero-knowledge proof, where the attacker proves the knowledge of a secret to the victim without sharing the secret. We stress the fact that, although the ransom may imply a monetary loss higher than the amount of Ether withdrawn by the SC, a company may still want to pay the ransom to avoid a customer being deprived of her or his assets with a consequent loss of reputation by the company itself.

1In this work we refer to the Ethereum blockchain as it is the most commonly used for SC deployment. However, our attack framework does not depend on the underlying blockchain implementation.

2https://soliditylang.org/
In this work we presented the extorsionware, a novel attack framework inspired by ransomware attacks that exploits SC vulnerabilities to demand for ransoms. With our framework, an attacker is able to both show the knowledge of a weakness by programming attacks with specific effects, and to enforce victims to pay ransoms instead of removing publicly deployed contract. Due to the legal implications of SCs, a victim could not simply remove the SC and create a new one without incurring in economic or credibility losses. We believe that the threat imposed by extorsionware should be considered to enforce the design of secure SCs to avoid companies and privates exploiting this technology incurring in uncomfortable and risky situations.

In future works we will assess the impact that different types of vulnerability have when exploited by extorsionware. In particular, we will focus on the controllability provided to the attacker. Furthermore, we plan to develop a countermeasure for extorsionware. An idea might be to build a shield SC able to detect whether an exploitation is occurring. The shield SC will also serve to block the exploitation point and exclude the attacker from the network.

VI. CONCLUSIONS AND FUTURE WORKS

Although the public availability of SCs’ code enforces trust among non-trusted parties, it also opens up possibilities for attackers to exploit potential SC implementation weaknesses. In this work we presented the extorsionware, a novel attack framework inspired by ransomware attacks that exploits SC vulnerabilities to demand for ransoms. With our framework, an attacker is able to both show the knowledge of a weakness by programming attacks with specific effects, and to enforce victims to pay ransoms instead of removing publicly deployed contract. Due to the legal implications of SCs, a victim could not simply remove the SC and create a new one without incurring in economic or credibility losses. We believe that the threat imposed by extorsionware should be considered to enforce the design of secure SCs to avoid companies and privates exploiting this technology incurring in uncomfortable and risky situations.

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