Empowering Citizens by a Blockchain-Based Robinson List

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ABSTRACT

A Robinson list protects phone subscribers against commercial spam calls. Its least basic functionality is to collect the denial of the subscribers to be contacted by market operators. Nowadays, Robinson lists run as centralised services, which implies that citizens should trust third parties for the management of their choices.

In this paper, we show a design that allows us to realise a Robinson list as a decentralised service. Our work leverages the experience developed by Fondazione Ugo Bordoni as the manager of the Italian Robinson list. We present a general solution and a proof-of-concept (PoC) adopting the Algorand technology. We evaluate the performances of our PoC in terms of its scalability and of the latency perceived by the involved actors. We also discuss aspects related to identity management and privacy.

1 INTRODUCTION

User contact information is precious gold to marketing strategists. For this reason, users are now exposed to an unprecedented number of unwanted calls on their phones (spam calls) for marketing purposes, or even to attempts to defraud them by gaining their confidence (scam calls). To better understand the dimension of this problem, we focus on some of the figures reported in [2] that collects statistics from several sources:

- In 2019, roughly 40 percent of all calls in the US were scams.
  (Source: First Orion)
- Americans lost nearly $19.7 billion from phone scams in 2020 — more than double the amount lost in 2019.
  (Source: Truecaller)
- 44% of Americans received spam calls related to COVID-19 in Q1 of 2020.
  (Source: Truecaller)
- The number of spam calls jumped over 300 percent worldwide between 2017 and 2018.

One way to tackle the problem of unwanted calls is to block calls on our mobile phone [3]. Call blockers have also been recommended by governments in the recent pandemic emergency regarding COVID19 [4], to prevent scams or other threats for citizens. However, such apps will often not distinguish legitimate

survey research calls from telemarketing [5]. Moreover, call blockers are often eluded by spammers, as they usually have a large set of caller IDs to reach the customer, so blocking a single ID is not effective, most of the times.

We need a system capable to protect users and, at the same time, allow marketing operators to reach legitimately a vast audience of informed and aware consumers. Robinson Lists are the standard answer to this need. It is an opt-out list of people who do not wish to receive marketing communications. Nowadays, Robinson lists are centralised services existing in a number of countries, such as UK, Canada, Australia, and Italy, just to mention a few.

The Italian Robinson list is called Registro Pubblico delle Oppositioni (RPO) [6] and it is managed, since 2011, by Fondazione Ugo Bordoni (FUB). Today RPO manages 1.5 millions records, but, with the next introduction, in the near future, of the management of mobile phone numbers, it is expected to be required to handle at least 100 millions records. In the work described by this paper, the experience of FUB was fundamental for the identification of the requirements of a typical Robinson list and of realistic workloads.

Motivations. Nowadays, Robinson lists are managed as centralised services. The purpose of this work is to design and evaluate a decentralised Robinson list on top of blockchain technologies. The main positive effect of this approach is to empower citizens providing them with direct control of their options. Moreover, institutions that operate Robinson lists should aim to reduce their involvement in management of user options as much as possible, in order to lower their risks and costs. Indeed, cryptographic techniques adopted by blockchains natively provide tools that easily solve possible controversy between subscribers and operators. In this perspective, in this work we focus on the most critical and urgent function to decentralise, namely the ability of citizen to autonomously opt-in/out.

Structure of the paper. In this paper, we present a solution for a decentralised Robinson list. We first formally describe requirements on the basis of the experience on the Italian RPO (Section 3). Then, we describe our solution of blockchain-based Robinson list in abstract terms and identify the features that we require from the underlying blockchain technology (Section 4). We recognise that the Algorand technology complies with the identified requirements and base on it our PoC realisation. We describe the architecture of
our PoC and some of the most interesting technical details (Section 5). We exploit our PoC to perform an experimental evaluation of our approach that shows results that are comparable with the centralised solution currently deployed for the Italian RPO (Section 6). We also discuss privacy and identity management aspects (Section 7) and future work (Section 8).

2 STATE OF THE ART

Robinson lists are traditionally realised by a centralised authority that is trusted by subjects and operators [7]. The scientific literature regarding systems supporting Robinson lists is very limited. Indeed, the technical aspects of a centralised Robinson list are not particularly challenging.

Blockchain applications for managing user consents have been already considered for other application scenarios (e.g., medical, banking, IoT stream data).

The Dwarna system described in [8] stores research partners’ consent for bio-banking process in a blockchain to create an immutable audit trail of research partners’ consent changes. The work described in [9] describes the design and implementation of a smart contract for consent-driven data sharing. In this context, service providers can share data about costumers among each other and validate each other’s permissions to share it according to customers’ preferences. Both works are realised on Hyperledger [10], a permissioned blockchain solution. The work described in [11] proposes, a user-centric solution that allows data subjects to easily control consents regarding access to their personal data in an IoT ecosystem and exercise their rights in accordance with the GDPR regulation. However, a data subject and a data controller cannot publish their digital consents with the corresponding signatures directly on a blockchain but a centralised platform takes care of this task. In our solution, we aim to let each subscriber managing its own consent, autonomously.

Essentially, Robinson lists allow a subject to associate an attribute (the option) to an identifier (a telephone number). This problem is strictly related to the one faced by identity management systems (IdM). The main purpose of an IdM is to bind an identifier of a subject (usually a public key) with attributes, claims, entitlements, or properties of that subject. IdMs are standardized by ISO [12] and there regulations about them (e.g., eIDAS [13]). The idea of realising IdM on top of blockchains is a step toward making IdMs independent from a specific organisation. The Self-Sovereign Identity (SSI) approach, surveyed here [14], envisions solutions in which subjects should be able to create and control their own identity, without relying on any centralised authority. In this context, public/permissionless blockchains are fundamental tools. W3C has ongoing efforts to standardize the building blocks of SSI Decentralised Identifiers (DIDs) [15] are controlled by subjects and possibly securely stored in blockchains. DIDs are linked with DID documents where attributes are listed. Certain attributes are associated to Verifiable Claims/Credentials (VC) [16] which allow the binding between the identifier and the attributes.

3 MODELLING A ROBINSON LIST: ACTORS, USE CASES, AND REQUIREMENTS

In this section, we briefly outline the main actors and functions of the current centralised RPO that we consider as a common accepted practice for a Robinson list. Then, we define the main requirements to support a decentralised Robinson list focusing on the decentralisation of the most critic functions for citizens empowerment and disintermediation.

We model a Robinson list as a collection of records \(⟨\text{tel}, \text{opt}⟩\), where \text{tel} is the telephone number of the \text{subscriber} and \text{opt} can assume the values \text{IN}, if the subscriber opts-in to receive unsolicited calls on \text{tel} from \text{direct marketing operators}, and \text{OUT}, vice-versa.

The actors interacting with the Robinson list are the following:

- **Subscribers** A subscriber is the owner of one or more telephone numbers and consequently the owner of some records in the Robinson list, where options associated with telephone numbers are recorded.
- **Attestator** The attestator is a single actor that is responsible for the creation of the Robinson list, for binding subscribers to their telephone numbers, and for pruning the phone number lists received from operators (as described below).
- **Operators** An operator is interested in obtaining the options associated with a list of telephone numbers. Actually, it provides a list of telephone numbers to the organization operating the Robinson list and receives as output a pruned list where the numbers of the subscribers who opted-out have been removed.

Therefore, four fundamental functions must be supported by system realizing a functional Robinson list, which are listed in the first column of Table 1.

In the current RPO, all these functions are centrally performed by the attestator (i.e., FUB). For opt-in/out and pruning operations, the attestator receives requests from subscribers and marketing operators, respectively, and acts as a trusted intermediary for accessing the Robinson list.

3.1 Towards a Decentralised RPO

In formally listing the requirements, we primarily focused on fully decentralising opting-in/out operations, giving full control to the subscribers without relying on intermediaries. This guarantees the principle of citizen empowerment that is a motivating argument of our approach. Table 1 summarises our choices regarding decentralisation.

In the current proof-of-concept (described in Section 5), the other functions are left centralised leaving the investigation of their possible decentralisation as future work. This choice is also motivated by the following considerations.

We do believe that it is practical and acceptable that the creation of the assets in the Robinson list is centralised, provided that their management (i.e. opt-in/opt-out choice) is fully decentralised. To the best of our knowledge, centralised certification is the only legal method that is currently accepted by Public Bodies to bind subscribers to their phone numbers. We further discuss this problem and possible approaches in Section 7.

About the decentralisation of the pruning function, we consider it as an important part of our future research work (see Section 8).

The following is a formal list of the requirements of our decentralised Robinson list.

1. Each subscriber can own any number of records \(⟨\text{tel}, \text{opt}⟩\) (for distinct values of \text{tel}).
Motivated by Requirements 2, 4 and 5, we realise Robinson List on a blockchain technology. There are a large number of different blockchains, showing different trade-offs between supported features and scalability. In devising our solution, we aimed at requiring a blockchain with a set of features that allow us to fulfill the requirements introduced in Section 3, and supporting high scalability, in view of the future management of a large number of records (about 100Mln considering the italian RPO alone). In addition to standard blockchain characteristics, we require the blockchain technology to support the following features:

- The blockchain should support the creation and transfer of custom tokens to represents IN and OUT options made by subscribers.
- At each instant in time, the choice of a subscriber is either IN or OUT. As will be clear in the following, we need to atomically swap a token IN with a token OUT. For this reason the blockchain should support grouping of transactions so that the whole group is either committed or not.
- The blockchain should support smart contracts to manage citizen choices by an algorithmic governance. In this paper, we are interested in proving that even stateless smart contracts – the less demanding ones – are enough for our purposes.

Custom tokens are supported on many blockchains, either natively [17] or by using proper smart contracts (see for example [18]). In our solution, tokens are used to store the current opt-in or opt-out of a subscriber without relying on smart contracts with persistent state.

In section 5, we present our prototype based on the Algorand technology, which provides all these features.

We now describe our solution. Subscribers are identified by one or more public keys and each telephone number is associated to a public key. How this association can be carried out is discussed in Section 7. Private keys are secretly held by the corresponding subscriber. The attestator is also associated with a key pair. The binding between the public key \( p_k \) and the telephone number \( tel \) is stored on chain. We decided to encrypt those element so that only the key’s owner and the attestator can view the values in clear text. This decision was made to preserve citizen’s privacy, by masking the binding of his/her private key to the phone number.

The binding information, namely the pair \((p_k, tel)\), is hidden into the payload of a transaction that the attestator sends to the user. The masking technique consists in the following steps:

1. The attestator generates \( r_k \), a random 128 bit AES symmetric key and a random 128 bit initialisation vector \( i_v \);
2. The attestator uses \( r_k \) and \( i_v \) to encrypt the pair \((p_k, tel)\) by using AES-CBC (Cipher-Block-Chaining) scheme, obtaining \( e_b \);
3. \( r_k || i_v \) is encrypted with user’s public key and attestator’s public key, producing the values \( r_{ku} \) and \( r_{ka} \) respectively (these encryptions are performed using the PyNaCl library [19, 20] and the X25519 elliptic curve [21]);
4. The triple \((e_b, r_{ku}, r_{ka})\) is written on-chain.

Smart contracts are associated with an identifier that, for many aspects, plays the same role of the public key. Hence, for homogeneity, we call it the public key of the smart contract and, when we generically refer to public keys, we intend also to include smart contracts identifiers.

In our solution, we define two custom class of tokens named IN and OUT. We call IN tokens and OUT tokens the individual units of IN and OUT, respectively. In the system, the global number of IN tokens and of OUT tokens is always the same. To streamline description, we refer to IN as the opposite of OUT and vice versa.

| Function                              | Centralisation | Actor performing the operation |
|---------------------------------------|----------------|-------------------------------|
| Robinson List Creation                 | Centralised    | Attestator                    |
| Binding of subscribers to phone numbers | Centralised    | Attestator                    |
| Choice of opt-in/opt-out by subscribers | Decentralised  | Subscriber                    |
| Pruning lists requested by operators   | Centralised    | Attestator                    |

Table 1: Functions and decentralisation choices.
Each public key is associated with a wallet that holds tokens. Public keys are used to identify source and destination wallets in transactions involving tokens. In our solution, the tokens are kept in smart contract wallets. For simplicity, we also say that the smart contract contains or stores the tokens.

Each telephone number t in the Robinson list is associated with a corresponding smart contract U_t. The system is built to enforce the following **option constraint**: for each telephone numbers t, the wallet U_t contains either only one IN token or only one OUT token. U_t has been designed to avoid the exchange of tokens between subscribers that can lead to the violation of the option constraint. We can express three possible states for each telephone number: opted in, opted out, or no option expressed. The third state is represented by the absence of t and U_t in the system. In our approach there exists another smart contract C that is in charge of realizing the switch of the token stored in U_t with its opposite, while fulfilling the option constraint. It also stores all tokens that are not currently stored by any U_t contract and that may be needed in future switch operations.

Intuitively, a switch operation is performed as follows. Consider a telephone number t with smart contract U_t containing an O token (where O is either IN or OUT). The switch operation consists of the following two transfers: (1) transfer the O token currently in U_t to C and (2) transfer an O token (where O is the opposite of O) from C to U_t. The above transfers are asked by the subscriber of t as a group to be atomically executed. Smart contracts perform the following checks: U_t checks that group is signed by the private key of t (i.e., it come from the owner of t), C checks that the two transfers are consistent with respect to the option constraint. Note that, for security reason, all U_t’s should conform to a template of smart contract in which the only changed part is related to the public key of t that the contract uses to verify the source of the accepted transactions. We call this the **standard template**.

We now formally describe the steps involved in the use cases that initialise or change the content of our Robinson list.

**Robinson list initialisation.** To initialise our decentralised Robinson list the following operations are performed.

1. The attester generates its public/private key pair.
2. The attester creates IN and OUT tokens in a quantity which is supposed to be much larger than the amount of telephone numbers to be managed.
3. The attester deploys a smart contract C.
4. The attester transfers all IN tokens to C.

**Addition of a new telephone number.** To add a new telephone number t to the Robinson list, the following operations are performed.

1. The subscriber of t creates a new public key k_t and the corresponding private key. It also creates, the corresponding U_t according to the standard template.
2. The subscriber asks the attester to associate t with public key k_t (see Section 7) and to add t to the Robinson list.
3. The attester verifies the association of k_t with t (see Section 7) and that U_t conforms to the standard template. If checks are successful, the attester sends one OUT token to U_t. This represents a default opt-out state for a newly listed telephone number.

**Option switching.** To switch the option for a telephone number t whose smart contract U_t contains an O token, the following operations are performed.

1. The subscriber of t prepares two transaction τ and τ’ as follows:
   - τ transfers one unit of O from U_t to C, and
   - τ’ transfers one unit of O’ from C to U_t.
2. The subscriber bundles τ and τ’ into a group to be atomically executed, signs the whole group with the private key associated with t and broadcasts it.
3. Within the execution of the consensus algorithm, both C and U_t are executed:
   - C checks that the two transfers are to and from the same U_t and that transfers are for single opposite tokens (to force the option constraint),
   - U_t checks that the request comes from t.

If checks are successful and regular balance constraints are fulfilled, both transactions are committed.

# 5 PROOF OF CONCEPT

In this section we present the implementation of a proof-of-concept (PoC) [22] of the decentralised Robinson List solution described in Section 4. The main goal of the PoC is to show how the proposed solution can be implemented on a blockchain technology and to provide a first evaluation on the performance of this implementation.

## 5.1 Technical components

The PoC has been developed on Algorand [23] because it supports all the necessary features to implement our solution as discussed in Section 4 and it is one of the solutions claiming to address the blockchain trilemma [24, 25], thus providing state-of-the-art performance in terms of latency and scalability.

Its inter-block time is very short: about 5 seconds.

To support the reader in a better understanding of our PoC, we briefly describe how Algorand implements smart contracts, tokens management and atomically committed transactions.

**Algorand Standard Assets (ASA)** are standard mechanisms for creating, managing, transferring and destroying digital tokens (or assets). In Algorand, an account should explicitly allow their use to be able to receive them.

**Algorand Smart Contracts (ASC)** are small programs that serve various functions on the blockchain and operate at layer-1. Smart contracts are separated into two main categories, **stateless** and **stateful**. The language for coding ASC is named **Transaction Execution Approval Language (TEAL)**. Stateless ASC can validates and signs transactions and it can be used as a **Contract Account**. A Contract Account looks like any end-user account except that it validates spending transactions according to its code logic.

Recently, Algorand released stateful ASC that provide local variables. These variables could be used to store the citizens choices thus providing an alternative way of implementing our solution. One contribution of our PoC is to prove that even simple stateless ASC are enough for our goal.
Atomic Transfers are indivisible and irreducible batch operations where a group of transactions are submitted as a unit and all transactions in the batch either pass or fail. In our PoC, Atomic Transfers handled by a suitable ASC are employed to swap an IN asset for an OUT one without the involvement of any intermediary and vice versa.

5.2 Architecture

Now we formally describe the architecture of our PoC.

There is one attestator and several subscribers, each one with only one telephone number associated with its public key. This association is kept encrypted in the blockchain (see Section 4) and cached in a database by the attestator. In the current implementation, the $U_t$ contract has not been implemented and the IN/OUT token is kept directly in the subscriber account. We recall that the main goal of the PoC is to evaluate feasibility and performance, and the $U_t$ contract, whose main purpose is to achieve a higher level of security, has a very minor impact on that and it will be consequently implemented in future releases.

Figure 1 shows a simplified architecture of the system. The whole interaction with the Algorand blockchain back-end is performed by a web application developed with the Django framework.

The attestator set-ups the system generating all the IN and OUT assets. Then, it deploys the Contract Account $C$ and explicitly allow $C$ to receive both IN and OUT tokens. The set-up ends with an asset transfer transaction of all IN tokens from the attestator to $C$.

During the initialisation of the subscriber, the attestator binds the public key of the subscriber to its mobile phone (see Sections 4 and 7). The subscriber explicitly enables reception of IN and OUT tokens in its wallet, then, if the binding is successful, the attestator transfers one OUT token to the subscriber wallet. For the sake of simplicity, current PoC assumes that binding is always successful. The initialisation is then completed transferring one OUT token from $C$ to the subscriber wallet. This is done at the first access of the user into the web interface.

The subscriber can swap the OUT token with an IN one by executing an Atomic Transfer with $C$. The TEAL code of $C$ is designed to approve the atomic transfer only if it consists of two transactions: (a) OUT token from the subscriber’s wallet to $C$ and (b) IN token from $C$ to the subscriber’s wallet. A symmetric atomic transaction lets the user swap the IN token with the OUT one.

6 EVALUATION

The proposed solution is functionally effective, as it proves that a users can express their choice of being contacted on their personal phone numbers on a distributed and decentralised ledger.

Nevertheless, in order to be actually employed, the solution should be comparable to the current centralised one in terms of costs and performance. In fact, while a blockchain solution provides an evident improvement in terms of resilience to network failures or data integrity and traceability, it might suffer of significant issues in terms of scalability, bandwidth, latency and operational costs, in particular in view of a possible public/permissionless deployment.

The purpose of this section is to quantitatively measure to what extent our approach can actually successfully compete with the current Italian centralised solution for the Italian RPO service (see Section 1). Our testing activity was carried on running our PoC on a VM on a Linux OS with 40GB of disk and 4GB of RAM.

The environment has been implemented on docker and runs in three containers.

- **Web**. The presentation layer.
- **DB**. The identity database (owned by the attestator) that caches the binding between the public keys (i.e., the blockchain addresses) and the telephone number of the subscriber.
- **Algorand-Node**. The Algorand node realising a private network.

We evaluated the performance of our prototype in terms of time consumption, investigating the different phases whose subscription process is made of. In the decentralised scenario, the subscription event is composed of 5 different phases:

- **Create Wallet** - subscriber’s wallet, that should contain the OUT or IN token, is created;
- **Init Wallet** - the attestator transfers a minimal amount of coins to the wallet, to enable the subscriber to perform transactions on the blockchain;
- **Binding** - the attestator binds the public key of the subscriber to its mobile phone writing it on the blockchain in an encrypted form (as described in Section 4) and in clear text in the local identity database;
- **Opt-In ASA** - the subscriber explicitly enables reception of IN and OUT tokens in its wallet;
- **Transfer ASA** - the attestator transfers the OUT token to the subscriber’s wallet.

RPO currently manages over 1.5 million of users’ fixed phone numbers and, starting from 2021, should be able to support over 100 million of users’ phone numbers, as also mobile numbers will be included.

Thanks to the data provided by FUB, responsible for managing RPO’s infrastructure, we were able to analyse the history of users’
interaction since 2011 (when RPO was initially deployed), in order
to obtain aggregated data about subscription rate. A first concern
comes from the fact that a public service, like the one offered by RPO,
can suffer from peaks of legitimate service requests known as flash
crowding attack. This particular event can occur as a consequence of
mass announcements (e.g. through TV or journal advertisements),
that are usually followed by users concentrating their requests in a
very short time interval straight after the announcement, resulting
in something very similar to a DDoS attack.

We observed this situation in RPO’s history, finding few dates
when more than 20000 subscriptions occurred in a day, which is an
extremely high number with respect to the ordinary subscription
daily rate.

In order to provide a complete analysis of our proposed archi-
tecture, we used this particular events as a scalability benchmark.

The histogram of the subscriptions, namely the insert opera-
tion of a new phone user on a centralised database, during a flash
crowding day (in 2011) is represented in figure 2.

We observed a total of 25566 subscriptions in a day, grouped
into two intervals in the day. The gathering of subscriptions in two
intervals of the day (one at night time and the other around noon)
confirmed us that the insert on database operations were executed
in batch scripts.

Analysing our log in peak periods we calculate that the average
time for the insert operation is about 200ms.

We decided to use standalone accounts rather than wallets to
overtake the operational cost of creating a wallet. A standalone
account is an Algorand address and private key pair that is not
stored on disk. A user can invoke, on his/her premises, the algo-sdk
to generate a pair of public and private keys. The time cost for
generating an account is significantly reduced. With reference
to the benchmark, we evaluated the time consumption for registering
20’000 users: In this way we reached 3.6 subscriptions per second,
which is a comparable rate with the one observed during flash
crowding events.

### Table 2: Time consumption for registering 20’000 users

| Iteration | Blockchain only | Cache DB |
|-----------|-----------------|----------|
| 1         | 1’59”           | 14”      |
| 2         | 1’54”           | 16”      |
| 3         | 1’58”           | 16”      |

| Iteration | Blockchain only | Cache DB |
|-----------|-----------------|----------|
| 1         | 1’59”           | 14”      |
| 2         | 1’54”           | 16”      |
| 3         | 1’58”           | 16”      |

Table 3: Pruning Blockchain only and Cache DB

6.1 Pruning Test

Currently, the main service offered by the current centralised RPO
consists in filtering a list of telephone numbers provided by a mar-
tking operator, in order to return them the same list but without
the opted-out subscribers. This operation is also known as pruning.
We performed a pruning test operation on a list of 10’000 mobile
phone numbers. Indeed, 10’000 numbers is the mean amount of
phone numbers for which the telemarketing operators request the
pruning activity to RPO.

Our decentralised RPO can operate the filtering process in two
different modes:
- by looking on chain for the opt status associated with a
  specific public key bound to a phone number;
- by enquiring a private database that acts as a cache for the
  binding information on chain, similarly to what happens in
  the current centralised implementation.

The former solution is preferable because it would prevent RPO
to maintain a private database with sensitive information, lowering
the risks in case of malicious attacks. Nevertheless, as the binding
between the public key and the phone number has been encrypted
on the chain, and considering that the phone number is the only
input to the filtering process, the first solution would also require to
exhaustively look into the whole blockchain, decrypting the binding
transactions, till finding the desired phone number and associated
public key, which is evidently more expensive than performing a
search over a private indexed database.

The difference in cost between the two methods has been evalu-
ated by comparing 3 different pruning tests, producing the following
results: As expected, the pruning operation performed without a

cache DB, which means using only on chain data, requires a higher
time effort. Considering B as the total number of blocks and m
the number of mobile phones to be pruned, in the worst case the
cost of search is \( O(B \times m) \), assuming \( B \gg m \). This result suggests
for further investigations in order to foster the usage of on chain
data in real world processes and not only for notarization purposes,
while preserving security and privacy aspects.

6.2 Dimensioning archival nodes

We investigated the storage requirements for archival nodes in
a private Algorand blockchain, as the volume of traffic and the
dimension of the transactions can vary significantly with respect to
the main public network. In our test, we measured the amount of
disk space occupied on 5 different archival nodes when increasing
the number of subscribers to the decentralised robinson list. Results
are shown in figure 3. All nodes occupy the same amount of space
when increasing the number of subscribers to the service, except
for the Primary Node (circle dots) which acts as a relay node and
needs to store log activities.
ASA. Since, in our scenario, each subscriber trades two ASAs, the additional balance is paid 450 000 Algos for the minimum balance of the subscribers, 1500 overall minimum balance is 0.3 Algos.

The minimum balance required to activate an account (i.e. use an account in transactions involving the ASA). The minimum balance required to activate an account is 0.1 Algos [26] and the one to trade a token is 0.1 Algos [17] per ASA. Since, in our scenario, each subscriber trades two ASAs, the overall minimum balance is 0.3 Algos.

Considering the current 1.5M RPO subscribers, the attestator pays 450 000 Algos for the minimum balance of the subscribers, 1500 Algos to transfer it and 1 500 Algos to distribute the OUT tokens. Hence, the attestator pays 453 000 Algos.

Each subscriber pays 0.002 Algos to publish the transaction opting-in the IN and OUT tokens. Swapping the ASA costs 0.002 Algos in total. Hence, the subscriber pays 0.003 Algos. The cost of the initialisation phase is relevant with respect to all other costs. Supposing to use the public Algorand main network, at the current quotation of the Algo cryptocurrency, the cost of initialising the system for 1.5M subscribers is about 500k€. While this may seems very high, it is substantially less than the current annual costs paid by market operators to use RPO. In fact, on average, RPO filters about 400 million of numbers each year. As by May 2021, operators pay, for each filtered number, from 0.004€ to 0.025€, depending on the subscribed bundle. Hence, market operators collectively pays annually more than 1.6M€, which are supposed to cover just operational costs, since RPO is a not-for-profit service. One aspect to consider in this discussion is that our approach does not fully substitute the current centralised realization, hence, some of the costs of the current solution are supposed to exists also in our approach, like identity verification costs. However, we think that this simple analysis is enough to say that in case of realization on the public blockchain costs are still comparable with the current centralised approach.

### 6.3 Economic costs

In this section, we analyze the economic costs of our approach, focusing on our PoC realization.

The following are the main costs a subject has to sustain in the proposed decentralised solution:

- Each subscriber needs to possess a minimum amount of Algos to participate to the network. In our PoC, the attestator supports this cost transferring to each subscriber these Algos.
- A subscriber opts-in to trade both IN and OUT tokens, issuing two transactions.
- The attestator transfers 1 OUT token to each subscriber.
- Every time a subscriber wants to change state, it publishes an atomic transfer composed by two transactions to swap the two different tokens. The first transaction is in charge of the subscriber, the second one is paid by C. The balance of C is monitored by the attestator that refills it with Algos, when necessary.

In Algorand, each transaction costs 0.001 Algos. Moreover, each account must maintain a minimum balance to be considered active (i.e. use an account in transactions) and an additional balance is needed to trade ASAs (i.e. use an account in transactions involving the ASA). The minimum balance required to activate an account is 0.1 Algos [26] and the one to trade a token is 0.1 Algos [17] per ASA. Since, in our scenario, each subscriber trades two ASAs, the overall minimum balance is 0.3 Algos.

Considering the current 1.5M RPO subscribers, the attestator pays 450 000 Algos for the minimum balance of the subscribers, 1500 Algos to transfer it and 1 500 Algos to distribute the OUT tokens. Hence, the attestator pays 453 000 Algos.

The cost of the initialisation phase is relevant with respect to all other costs. Supposing to use the public Algorand main network, at the current quotation of the Algo cryptocurrency, the cost of initialising the system for 1.5M subscribers is about 500k€. While this may seems very high, it is substantially less than the current annual costs paid by market operators to use RPO. In fact, on average, RPO filters about 400 million of numbers each year. As by May 2021, operators pay, for each filtered number, from 0.004€ to 0.025€, depending on the subscribed bundle. Hence, market operators collectively pays annually more than 1.6M€, which are supposed to cover just operational costs, since RPO is a not-for-profit service. One aspect to consider in this discussion is that our approach does not fully substitute the current centralised realization, hence, some of the costs of the current solution are supposed to exists also in our approach, like identity verification costs. However, we think that this simple analysis is enough to say that in case of realization on the public blockchain costs are still comparable with the current centralised approach.

### 7 PRIVACY AND IDENTITY MANAGEMENT

As already observed, the main contribution of this paper is the decentralisation of the opt-in/opt-out choice. Subscribers choices are personal data that have to comply with privacy regulation, like for example the GDPR [27]. Decoupling the data from the personal identity (pseudonymization) is a widely used approach for this kind of compliance. In the previous sections, we deliberately avoided to introduce any in-chain information that can help to associate choices to related telephone numbers or subscribers. From this point of view, the solution we have described so far is not affected by privacy concerns. However, in practice, operators do need to know both telephone numbers and choices. In this case, regulations require that operators can have knowledge of that binding, but no other subject should be able to get it.

Creating and storing bindings between telephone numbers and public keys are essentially identity management problems [12]. The simplest approach to them is to delegate both verification of this binding and the management of the corresponding database to a trusted third party. For example, the identity database could be managed by the same attestator A introduced in Section 4 (and this is the choice in our PoC). When a subscriber S asks A to add to the Robinson list a telephone number t, with public key k₁, A should check the binding and store it in its identity database. For example, A can ask the subscriber to sign a random challenge c using the private key paired with k₁, where c is communicated to S by making use of t (e.g., by SMS or by voice call). In pruning operations, operators should ask A to obtain either k₁ or directly the current choices for t.

Our solution, with this identity management approach, might be deemed acceptable and regarded as a substantial improvement with respect to current practices. The obvious next step is to ditch any involvement of A from regular operation of the Robinson list.
In the just described scenario, $A$ performs three tasks that we would like to decentralise.

1. It checks bindings of telephone numbers to public keys.
2. It stores them into a private identity management database.
3. It replies to operators queries.

Task 2 is easy to decentralise, since the identity pairs $(t, k_1)$ can easily be stored in clear text into the blockchain. However, this would be a clear privacy violation, since blockchain is supposed to be accessible to a multitude of subjects. If we accept to keep Task 3 centralised, then the identity pairs can be encrypted so that only $A$ and the owner of $t$ can decrypt them, as described in Section 4. A scheme that allows operators to access identity pairs autonomously, while respecting privacy regulation, is more challenging to devise. This is especially true if we admit operators to be granted or denied access, dynamically. By the way, this also introduces the problem of who is authorized to grant or deny access to operators or if this should be performed in a decentralised manner, as well. We intend to develop these aspects in the future.

Regarding Task 1, the work in [28] describes two blockchain-based approaches to perform this kind of checks in a decentralised fashion. It relies on a randomly selected committee of participants to the blockchain that is different for each check and it is hard to predict in advance. Each member performs the check autonomously and then write in the blockchain its “proof” about the binding. A summary of the proofs can then be computed at the consensus level and written on-chain as a regular identity pair. Again, while this approach looks promising, privacy aspects are yet to be developed.

8 CONCLUSIONS AND FUTURE WORK

In this paper, we show the technical feasibility of a decentralised Robinson list and the adequacy of the performances of our approach. Our solution enables citizens to express their choice in complete independence while costs, even in case of adoption of a public blockchain, are comparable with costs of current centralised RPO. The validity of our approach was also recognized in public competitions¹. Concerning future works, we plan to investigate a completely decentralised solution (including both pruning and binding) where we see two main challenges: conformity to privacy regulation and automatic management of fees, where citizens may possibly be rewarded for accepting marketing calls.

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¹See Future of Blockchain 2 competition https://medium.com/future-of-blockchain-competition/future-of-blockchain-2-summary-and-prizes-e87Dec6392f