

A modular eballot system – V0.6

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December 22, 2006

Abstract

We consider a reasonably simple voting system which can be implemented for web-based ballots. Simplicity, modularity and the requirement of compatibility with current web browsers leads to a system which satisfies a set of security requirements for a ballot system which is not complete but sufficient in many cases. Due to weak-eligibility and vote-selling, this system cannot be used for political or similar ballots.

1 Introduction

Most of current (commercial) web-based voting, balloting or polling system include little if no real security, in particular concerning privacy of the voter. Ballots are collected on a web site and stored in a database. Privacy of the voter is often guaranteed only as far as the vote is recorded in the database independently of the voting credentials. Indeed some commercial services have warnings that the system administrators can learn what every voter has voted for.

Here we present a simple, modular protocol, based on sound and common cryptography and previous results in the literature [1, 2] which can be implemented as a web service compatible with current web browsers and not requiring any user education. Most of the cryptographic operations required in the protocol can be implemented with common tools like PGP or gnupg [3].

Our system does not satisfy all requirements for a complete voting system, for example it is possible to sell a vote, and for this reason it is not suitable for political election and in general in all cases in which are requested some of the properties that our system does not satisfies. For this reason we prefer not to call it a *voting system* but only a *balloting system*. We do not call it either a *polling system* in which results are statistical, since our protocol guarantees that each vote is counted correctly and each eligible voter can cast her ballot.

In section 3 we list which requirements are satisfied by our system and which are not. In section 4 we describe our protocol, in section 5 we discuss how the security requirements are satisfied and in section 6 we discuss some threats and countermeasures.

In Appendix A we describe a variation of the protocol which uses blind signatures [4, 2].

In a companion paper [5], we discuss how to implement our protocol in practice in its simplest version.

2 Preliminaries

We start by indicating the components of our protocol. There are 6 human roles, who have well precise duties. As we will see, some aspects of the security of the protocol are based on the *separation of duties* among the managers of the system. The 6 roles are:

1. *the Voter*: no request is made on the Voter, except to be able to use a common web browser and in some cases to install a piece software on her own machine
2. *the Authentication Managers (AuthMgr)* must organize the ballot selecting the eligible voters and providing them with the voting credentials; at the end of the voting period they must check that only eligible voters have casted a ballot
3. *the Managers of the Authentication Web Server (AuthSysMgr)* must setup and run the Authentication Web Server and provide the AuthMgr with the list of voters that have casted a ballot at the end of the voting period
4. *the Managers of the Anonymizer System (AnonSysMgr)* must guarantee that all connections to the Vote Web Server do not leak information on the IP address of the voter computer
5. *the Vote Managers (VoteMgr)* must count the votes at the end of the voting period and announce the result of the ballot
6. *the Managers of the Vote Web Server (VoteSysMgr)* must setup and run the Vote Web Server and provide, at the end of the voting period, the VoteMgr with the encrypted votes that have been casted.

Moreover, the system is divided in 4 modules

1. *the Voter (or Client)*: this is the voter machine and software, for example a personal computer with a web browser and in case a local specialized proxy
2. *the Authentication Server (AuthSrv)* verifies the credentials of each voter and gives to the voter a Authentication Token (called VoteAuthorization) which allows the voter to cast her ballot
3. *the Anonymizer* renders all accesses to the Vote Server anonymous
4. *the Vote Server (VoteSrv)* allows the voter to cast only once the ballot in an anonymous way.

3 Requirements

Some requirements often used in defining an electronic voting system are:

1. *Unreusability (prevent double voting)*: no voter can vote twice
2. *Privacy*: nobody can get any information about the voter's vote
3. *Completeness*: all valid votes should be counted correctly
4. *Soundness*: any invalid vote should not be counted
5. *Individual verifiability*: each eligible voter can verify that her vote was counted correctly
6. *Weak Eligibility*: only eligible voters can get voting credentials from trusted authorities
7. *Eligibility*: no one who is not allowed to vote can vote
8. *Fairness*: nothing can affect the voting
9. *Robustness*: the voting system should be successful regarding of partial failure of the system
10. *Universal Verifiability*: anyone can verify the fact that the election is fair and the published tally is correctly computed from the ballots that were correctly casted
11. *Incoercibility*: a voter cannot be coerced into casting a particular vote by a coercer
12. *Receipt-freeness*: a voter neither obtains nor is able to construct a receipt proving the content of her vote.

Our system satisfies only the first 6 requirements. In particular it does not satisfies Eligibility (only Weak Eligibility) nor Receipt-freeness, both of which mean that a voter is able to prove to someone else how she has voted, and so to sell her vote.

4 The modular protocol

We describe now at high level the protocol and its components following the procedure of a ballot.

4.1 Step 1 – Distribution of credentials

This step is done off-line. The Authentication Managers provide the voters with the voting credentials:

1. *a username+password and/or SSL/TLS client certificate* which can be reused or shared among various voters and which allows the voters to be authenticated at the AuthSrv

2. a *VoteToken*¹ (a PseudoRandom-string) unique for each voter and for each ballot, which can be used only once
3. the *SSL/TLS fingerprints* of the web SSL/TLS certificates of the AuthSrv and VoteSrv.

For higher security the username+password (and/or client certificate) and VoteToken should be distributed using different communication channels.

4.2 Step 2 – the Voter

In principle the Voter can access the balloting system with *one* of the following systems listed in increasing security. In the practical implementation of the protocol only one of the following must be used by all voters in the same ballot, that is before the ballot it must be decided which one of them the voters must use. The possible voter's systems are:

- a *standard SSL/TLS web browser*
- a *standard web browser and a client proxy*: the client proxy is an application which runs on the voter's machine, receives http requests from the voter web browser, anonymizes the requests and connects securely to the AuthSrv and VoteSrv
- a *purpose built https client*: in practice a reduced version of a SSL/TLS web browser dedicated only to this purpose which includes the features both of the web browser and of the client proxy
- a *purpose built hardware device*: (for example something similar to a smart-phone or handheld device) in this case the hardware, the operating system and the browser are custom made.

4.3 Step 3 – Authentication Server

The AuthSrv is a secure web server running an application able to implement the protocol which will be presented below. The AuthSrv, managed by the AuthSysMgr, needs to have:

1. the *public key of the AuthMgr*
2. its *own private/public key certificate* used to establish the SSL/TLS session with the voter's browser
3. its *private/public key* to digitally sign the VoteAuthorizations (see below)
4. the *public key of the VoteSrv* to encrypt the VoteAuthorizations
5. the *list of username+password and/or client certificates*
6. the *list of valid VoteTokens*.

The authentication procedure is the following:

¹This is also called a *Secret Token* to stress the role of this credential.

1. the voter connects to the AuthSrv with her web browser, checks the fingerprints of the server digital certificate and is authenticated using username+password and/or client digital certificate; finally the voter submits her VoteToken to the AuthSrv
2. the AuthSrv checks that the VoteToken has not been used and creates a unique PRN (Pseudo-Random-Number) called the *VoteAuthorization* and optionally a short PIN (see below)
3. the AuthSrv digitally signs and encrypts with the VoteSrv public key the VoteAuthorization (if the PIN is used, this is added to the VoteAuthorization before encryption)
4. the AuthSrv records that the VoteToken has been used (for example by signing and encrypting it together with the current time and username with the AuthMgr public key and writing it to a file with the same name)
5. the AuthSrv sends to the voter's web browser the signed and encrypted VoteAuthorization. If the PIN is used, it is also sent to the voter not encrypted; the PIN must not be stored by the client-proxy nor forwarded automatically in clear to the VoteSrv, but only shown by the browser to the voter who should record it off-line; notice that the PIN is also included in the encrypted VoteAuthorization.

The PIN could be useful if the vote phase (step 5 below) is done at a later time than the authorization phase (this step 3). In this case the voter must store the VoteAuthorization somewhere: the voter can write the VoteAuthorization on a piece of paper or, more likely, store it as a file on the computer either directly or in the client-proxy. In this second case there is the risk that someone else can access the voter computer, find the VoteAuthorization and use it. If a PIN is used and the voter has saved off-line the short PIN when has received the VoteAuthorization, then a third person will not be able to use the stolen VoteAuthorization.

4.4 Step 4 – Anonymizer

The VoteSrv must not know nor be able to discover who is voting. Notice that if the voter uses a normal web browser some information, like the contents of the UserAgent field, are sent to the VoteSrv.

Since the connection between the voter and the VoteSrv is encrypted using SSL/TLS, the contents can be anonymized only by the client itself for example by the client-proxy.

But also the IP packets reaching the VoteSrv must be anonymized so not to disclose the IP address of the voter machine. This can be done in various ways of which we list some here in increasing security:

1. a NAT or double-NAT device: in this way all packets will reach the VoteSrv with the same source address
2. a Crowd scheme [6]

3. a Chaum mixer [7]
4. Tor [8] or similar scheme [9].

The Manager of the Anonymizer must choose a anonymizer system in relation to the requirements of the ballot. Notice that some anonymizing schemes can introduce very large delays in the traveling of the IP packets, making it almost impossible to vote in real time, but giving higher guarantees of truly anonymize the traffic.

4.5 Step 5 – Vote Server

The VoteSrv is a secure web server with an application able to implement the protocol which will be presented below. The VoteSrv, managed by the VoteSysMgr, needs to have

1. *the public key of the AuthMgr*
2. *the public key of the VoteMgr*
3. *its own private/public key certificate* used to establish the SSL/TLS session with the voter's web browser
4. *its private/public key* to sign the Votes (see below).

The procedure to vote is the following:

1. the voter connects with her browser to the VoteSrv through the anonymizer and checks the fingerprints of the digital certificate of the VoteSrv used for the SSL/TLS session
2. the VoteSrv sends the Web Form to cast the ballot to the voter (if the PIN is required, this is requested in the Form)
3. the voter casts her ballot and sends to the VoteSrv the Form filled-in and the VoteAuthorization (this is usually done automatically by the browser or the client-proxy which has stored the VoteAuthorization for the voter)
4. the VoteSrv decrypts the VoteAuthorization and checks the signature of the AuthSrv, checks that the VoteAuthorization has not been already used and that the optional PIN given by the voter in the submitted Form matches the one inside the VoteAuthorization
5. the VoteSrv records that the VoteAuthorization has been used (for example by signing and encrypting it with the AuthMgr public key and writing it to a file with the same name)
6. the VoteSrv generates a digest of the vote including a precise timestamp and a random string as the *VerificationCode*, signs and encrypts with the VoteMgr public key the vote together with the VerificationCode and writes it in a file with the same name (that is the name of the file is the VerificationCode)
7. the VoteSrv sends to the voter's web browser the VerificationCode, the digital signature of the VerificationCode, the precise timestamp and the random string. In this way the voter can recompute the VerificationCode and verify

that it corresponds to her vote. The voter has to keep off-line the Verification-Code to check that her vote is correctly counted in the results of the ballot.

4.6 Step 6 – Vote counting

This step is done off-line and is composed by:

1. the AuthMgr receives from the AuthSysMgr the signed and encrypted VoteTokens, decrypts them, checks the signatures and records each used VoteToken together with the time of use and the username which has used it
2. the AuthMgr receives from the AuthSysMgr the signed and encrypted VoteAuthorizations created, decrypts them, checks the signatures and makes the list of *created* VoteAuthorizations
3. the AuthMgr receives from the VoteSysMgr the signed and encrypted VoteAuthorizations used, decrypts them, checks the signatures and makes the list of *used* VoteAuthorizations
4. the AuthMgr checks that the two lists of VoteAuthorizations are consistent (notice that according to the protocol there is no recorded information that links the VoteTokens to the VoteAuthorizations so that, unless the AuthSysMgr cheats by recording extra information and passing it to the AuthMgr, the list of used VoteTokens and used VoteAuthorizations are not linked)
5. the VoteMgr receives from the VoteSysMgr the signed and encrypted Votes, for the moment the VoteMgr does not decrypt them but makes the list of VerificationCodes (which are the file names)
6. the VoteMgr checks with the AuthMgr that the number of votes is consistent with the number of valid and used VoteAuthorizations (notice that according to the protocol there is no recorded information that links the Votes to the VoteAuthorizations so that, unless the VoteSysMgr cheats by recording extra information and passing it to the VoteMgr, the list of Votes and used VoteAuthorizations are not linked)
7. the AuthMgr publishes the list of used VoteTokens and the timestamp of their use so that voters can check that the time at which they obtained the VoteAuthorization is correct (this is the time at which the voters have authenticated, not the time of vote); the AuthMgr publishes also the list of VoteTokens which have not been used, that is of eligible voters who did not vote
8. the VoteMgr publishes the list of VerificationCodes so that voters can check if their VerificationCode is present in the list; if a voter does not find her VerificationCode in the list, she must inform the VoteMgr of this before the votes are decrypted, in this way if there has been a problem in the procedure, the ballot can be canceled before counting the votes (this step also prevents a voter to false claim that her VerificationCode is not present if the ballot had a result she did not like); to report a missing VerificationCode, a voter should present to the VoteMgr her VerificationCode with its digital signature

9. after the VerificationCodes have been checked by the voters, the VoteMgr decrypts the signed and encrypted Votes, checks the signatures, makes the list of Votes and counts them
10. the VoteMgr publishes the list of VerificationCodes and individual Votes so that voters can check that their votes have been counted correctly, and publishes the result of the ballot.

5 Security requirements analysis

We now consider the security properties of the protocol just described.

In the following discussion when we say that a system manager cheats by modifying the software so that it does not follow the protocol described, it is equivalent to the fact that the server has fallen under control of an attacker who can then do what a system manager can do.

Unreusability: both the VoteToken and the VoteAuthorization can be used only once, at the AuthSrv and the VoteSrv respectively; the AuthSysMgr could issue more VoteAuthorization for the same VoteToken, analogously the VoteSysMgr could allow multiple votes for the same VoteAuthorization, but this is discovered by the cross checking of the number of VoteTokens, VoteAuthorizations and votes done by the AuthMgr and VoteMgr.

Privacy: the information received by the VoteSrv does not allow the VoteSysMgr to learn who is casting a vote; privacy can be theoretically violated only if at least two system managers are cheating:

- if the AuthSysMgr records the connection between the the VoteToken and the VoteAuthorization and the VoteSysMgr records the connection between the VoteAuthorization and the Vote, then by combining this information is possible to know who has voted what
- if the AnonSysMgr records the IP addresses (and tcp ports) of the voter machine when connecting to the VoteSrv and the time of connection, and the VoteSysMgr records the connection between the VoteAuthorization and the Vote and the time of the vote, then by combining this information is possible to know which client IP has casted a vote and at what time.

Completeness: it is not possible to modify a vote and all votes are counted, so that it is not possible to force to count the votes in a wrong way.

Soundness: every vote is signed by the AuthSrv and encrypted with the VoteSysMgr public key so that it is not possible to count invalid votes.

Individual verifiability: a verification code is given to each voter to allow to verify that her vote has been counted correctly.

Weak Eligibility: the AuthSrv verifies that only eligible voters can obtain a VoteAuthorization; the VoteSrv checks that the VoteAuthorization has been issued by the AuthSrv but not directly the voter credentials, thus obtaining the weak

eligibility requirement; the AuthMgr could issue VoteAuthorizations to non eligible voters or the VoteMgr could accept non valid VoteAuthorizations, but the vote counting procedure by the AuthMgr and VoteMgr and the checking of the public results by the voters will discover it.

6 Threats analysis

Although the protocol guarantees its self-correctness, in practice two factors can reduce its security:

1. implementation errors (like software bugs)
2. human intervention.

We analyze threats from two points of view: the purpose of the attack and the system attacked.

6.1 Threat model

An attacker can be interested to

1. influence the final result (system integrity threat)
2. capture information on votes (privacy threat)

6.1.1 System Integrity

System Integrity attacks can be performed by:

1. multiple use of credentials
2. vote modification
 - by the VoteSrv
 - by network man-in-the-middle attacks
 - on the voter's machine
3. stealing of vote credentials from the AuthSrv.

All of these threats, except for that on the voter's machine, are mitigated by countermeasures in the protocol so that any such attempt will be discovered.

The protocol does not have countermeasures against *Vote Selling*, indeed it lacks the *receipt-freeness* property since it bases some of its security properties on the receipt given to the voter by the VoteSrv. Indeed a voter can prove to a third party, if she wishes, how she has voted by showing the VerificationCode, or a voter can pass her voting credentials or VoteAuthorization to someone else and have the attacker cast directly the vote.

6.1.2 Privacy

Privacy attacks can be performed

1. by sniffing on the connections between the voter and the servers: this threat is countered by encrypting all traffic
2. by installing sniffers on the AuthSrv and VoteSrv to record all information: this threat must be countered by the system managers
3. if at least two system managers collude in violating the system
4. by installing a sniffer on the voter machine: the protocol does not provide any countermeasure to this threat.

6.2 System vulnerabilities

Attacks by intruders in a system can lead to complete compromise of the machine so that the attackers takes complete control of it, in other words they are able to act as the system manager. Notice that we need to trust the system managers and the correct status of the systems for the protocol to work as stated.

Compromise of the voter machine can lead to the loss of privacy and the possibility for the attacker to modify the vote (loss of integrity). Voter are able to recompute their VerificationCodes, and they can discover if their votes have been modified. (Notice that today this kind of attack is the most likely and easy to implement.)

Compromise of the AuthSrv can lead to the stealing of vote credentials and loss of privacy if there is also a compromise of the VoteSrv. These risks are reduced due to countermeasures in the protocol.

Compromise of the Anonymizer can lead to a loss of privacy if there is also a compromise of the VoteSrv.

Compromise of the VoteSrv can lead to modification of votes, countermeasures for this risks are present in the protocol. Compromise of the VoteSrv together with the compromise of the Anonymizer or AuthSrv can also lead to a loss of privacy.

6.3 Off-line threats

The AuthMgr and VoteMgr must be trusted. If they cheat they can modify the results of the ballot. In particular:

- the AuthMgr can distribute vote credentials to not eligible voters (no countermeasures)
- the AuthMgr can give more than one vote credential to the same voter (no countermeasures)
- the VoteMgr could fabricate votes and add them to the final tally, but this is discovered by the AuthMgr checking the number of votes w.r.t. the number of voters and the voters verifying that their votes have been counted correctly
- the VoteMgr can change the votes of the voters, but this is discovered by the individual checks of the voters.

6.4 Other threats

6.4.1 Attacks to the VerificationCode

Format of the VerificationCode is crucial to prevent the VoteSysMgr to modify votes. Assume for example that the VerificationCode is a PRN. In this case the VoteSysMgr could modify the protocol as follows. Suppose there is a Yes/No ballot and the VoteSysMgr wants to fix the result for No. The first voter that votes Yes is processed correctly, all other voters who vote Yes (or enough of them to make No win) will have their vote changed to No but will receive the same VerificationCode of the first voter. In this way all Yes voters will have the same VerificationCode corresponding to a published and correctly counted Yes vote. Only by checking the VerificationCode among Yes voters it would be possible to discover that they are all equal, which must not be since they should be PRN. But voters must keep confidential their VerificationCodes since otherwise the privacy of their votes will be lost.

For this reason the VerificationCode is a digest of the vote and of the time of the vote, in such a way that the voter can recompute the digest using as ingredients her vote and the timestamp.

But a public computable VerificationCode which includes *only* the vote and a timestamp is liable to a brute force attack. Indeed the vote and the procedure to compute the VerificationCode are public and the only missing information is the timestamp. By computing all VerificationCodes with that vote and all reasonable timestamps, the attacker can find the correct timestamp. By matching the computed timestamp to the time of the authentication recorded by the AuthSrv and published by the AuthMgr, the attacker could, in some circumstances, discover the name of the voter.

To prevent this brute force attack, a sufficiently long random string must be added to the computation of the VerificationCode. Since the VerificationCode is nothing else than a cryptographic hash of the vote, the precise timestamp and the random string, and the voter is asked to verify that the timestamp is correct, it is not possible for the VoteSysMgr to mount the attack discussed at the beginning of this section. Indeed if it was possible, it would mean that by adjusting the random string the VoteSysMgr would be able to construct two different messages (they are different due to the different timestamps) with the same cryptographic hash. But this is not possible by definition of a cryptographic hash function.

6.4.2 Human verifiability

In this protocol a large part of the security relies on the behavior of the people involved, both the managers and officials of the ballot and the voters themselves. In particular the voters must check that their votes are counted correctly, using their VerificationCode, to prevent various possible attacks. It is reasonable to think that most voters who have voted will check their vote. It is less likely that voters will recompute their VerificationCode since, even if it is a very simple procedure, this requires a minimum knowledge about cryptography. Thus the re-computation

of the VerificationCode is something that will be done by experts only. Anyway, the fact that some voters will do it, will be able, at least statistically, to prevent some attacks.

One possible attack venue is to consider voters who do not vote. In each ballot there are always voters that do not cast their vote for many different reasons. It will be very difficult to convince these voters to check that they correctly appear as not having voted in the final lists published by the AuthMgr. Assuming that all eligible voters who do not vote do not check this list, the following attack is possible. The AuthSysMgr logs in to the AuthSrv a few minutes before the end of the ballot and gets the list of not used VoteTokens.² The AuthSysMgr must also have obtained, for example from the AuthMgr, the list of all username+passwords. With these data, the AuthSysMgr can vote instead of all the voters who have not voted and in this way violate the integrity of the ballot. It is still possible to discover this attack by checking the integrity of the AuthSrv since the AuthSrv must be sealed during the time of the ballot and all logins to it must be recorded in the logs. In a correct procedure, the AuthMgr (not the AuthSysMgr) should seal the machine before the beginning of the ballot and remove the seal at the end of the ballot but only after having checked that nobody has logged in the machine during the ballot and no breach of security have happened. (If the AuthSysMgr has installed a program which notifies him of the not used VoteTokens, then the machine is not secure to start with.) Thus it is possible to discover this attack even if all eligible voters who do not vote do not check the list of voters, but it requires a very careful implementation of the procedures, both human and automatic.

Always considering the voters who do not vote, since the authentication is automatically done by the AuthSrv, if a voter complains that she has not voted but her VoteToken appears in the list of the used ones, the AuthMgr has to understand what really has happened. There are a few possibilities and among them the following

- someone has stolen the voting credentials of the voter and, knowing that the voter would have not used them, has voted in her place
- the voter has sold (or has been forced to sell) her voting credentials but now is trying to get the ballot cancelled
- a violation of the AuthSrv has happened, as described before, and unused voting credentials have been used by attackers
- there has been an error in the procedures, for example in the listing and counting of votes and VoteTokens
- the voter has in reality casted her ballot, but has decided to try to cancel the ballot without even knowing the result (in this case is the voter who is cheating).

It is up to the ballot officials to understand what has really happened and decide if the results of the ballot are correct or there has been some violations.

²Actually on the AuthSrv there are only the Hash of the VoteTokens, so the AuthSysMgr must also have obtained, for example from the AuthMgr, the original list of VoteTokens.

7 Conclusions

The effectiveness and security of the protocol are based on

- trust in the people involved in the protocol: they must not collude against the protocol
- absence of bugs in software which could render insecure the implementation of the protocol: from operating system to libraries and applications
- systems correctly managed and in integral state: absence of worms, viruses, trojans, rootkits etc. on all systems involved, included the voter's machine.

Under these conditions we believe that our protocol can be practically implemented and can deliver a web based balloting system with much higher security than those currently commercially available.

Appendix A

In ref. [2] was proposed a protocol similar to ours but based on blind signatures [4]. Our protocol can be easily modified to support blind signatures.

The main implementational difference between our protocol and a version using blind signatures is that the VoteAuthorization is not created by the AuthSrv but by the voter's client proxy (blind signatures are not possible with current web browsers).

The procedure in Step 3 is then modified as follows:

1. the voter connects to the AuthSrv with her web browser through the client proxy, checks the fingerprints of the server digital certificate and is authenticated using username+password and/or client digital certificate
2. the voter creates a PRN (not unique, so there is a very small chance that two voters will create the same PRN in which case only one of them will be able to vote; the probability of this depends on the space of the PRN w.r.t. the number of voters), prepares a blind signature of it and sends to the AuthSrv the blind signature and the VoteToken
3. the AuthSrv checks the VoteToken and does the blind signature, that is digitally signs the encrypted PRN without knowing the value of the PRN
4. the AuthSrv records that the VoteToken has been used (for example by signing and encrypting it together with the current time and username with the AuthMgr public key and writing it to a file with the same name)
5. the AuthSrv sends the blind signature to the voter who extracts the signed PRN which is her VoteAuthorization.

In this case the AuthSrv does not know and cannot compute the VoteAuthorization, so even if the AuthSysMgr would collude with the VoteSysMgr, they will not be able to obtain information on which voter has which VoteAuthorization. On the other hand, if blind signatures are used there is the (possibly small) risk that two

voters will create the same VoteAuthorization and one of them will be prevented from voting.

Afterwards in the protocol, in step 5, the client-proxy encrypts the VoteAuthorization with the public key of the VoteSrv before sending it. Thus the AuthMgr should provide the voter together with the voting credentials also with the public key of the VoteSrv.

To introduce blind signatures in our protocol, it is then sufficient for the voter to use a client proxy and to modify accordingly the AuthSrv. The rest of the protocol does not change.

The protocol with blind signatures has the advantage of eliminating the possibility of collusion between the AuthSysMgr and the VoteSysMgr to violate the privacy of the voters. On the other side, if blind signatures are used, it is not possible to guarantee that all eligible voters can vote. For this reason, the protocol proposed in ref. [2] was called a *polling* protocol in which statistical, but not exact, results are obtained.

Notice also that blind signatures can not be implemented with current web browsers. Thus implementing practically the protocol with blind signatures today is technically more complicated because it requires designing, realizing and maintaining a program which should run on every voter's machine.

Acknowledgments

We thank D. Bruschi and A. Lanzi for discussions, and H. Bechmann-Pasquinucci for inspiring remarks.

References

- [1] For a recent review of electronic voting systems, mixnet etc., see B. Adida, *Advances in cryptographic voting systems*, PhD thesis 2006, MIT; see also D. Gritzalis editor, *Secure electronic voting*, Kluwer Academic Publisher 2002, and B. Schneier, *Applied Cryptography*, Wiley 1996
- [2] D. Bruschi, I. Nai Fovino, A. Lanzi, *A Protocol for Anonymous and Accurate E-Polling*, Proceedings of *E-Government: Towards Electronic Democracy*, International Conference TCGOV 2005, Bolzano Italy 2005, Lecture Notes in Computer Science 3416 Springer 2005
- [3] see e.g. rfc1991, rfc2440, rfc3156, <http://www.pgp.com/>, <http://www.gnupg.org/>
- [4] D. Chaum, *Security without identification; transaction systems to make big brother obsolete*, Comm. ACM 28(19) 1985, 1030
- [5] A. Pasquinucci, *Implementing the modular eballot system V1.0*, 2006, <http://eballot.ucci.it/>
- [6] M.K. Reiter, A.D. Rubin, *Anonymous web transactions with Crowds*, Comm. ACM 42(2) 1999, 32

- [7] D. Chaum, *Untraceable electronic mail, return address and digital pseudonyms*, Comm. ACM 24(2) 1981, 84
- [8] *The Onion Router*, <http://tor.eff.org/>
- [9] R. Dingledine, N. Mathewson, P. Syverson, *Tor: the second-generation onion router*, <http://tor.eff.org/>