Electronic Voting Systems – From Theory to Implementation

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Abstract. Electronic voting for local, regional and national elections and referenda is developing rapidly at a global scale as an efficient and low cost alternative to conventional methods of voting, with a positive impact on the quality of democratic representation. Still, despite the growing international experience, the harmonization of electronic voting systems with the legal and statutory frameworks poses a number of major legal, social and implementation challenges, subject to the national environment. This paper presents an overview of legal and social aspects of an electronic voting system focusing on the case of Greece.

Keywords: E-Democracy · Electronic voting

1 Introduction

During the last decade, the issue of electronic voting has gained prominence in academic and public discourse. A broad definition describes electronic voting as a system "where the recording, casting or counting of votes in political elections and referendums involves information and communication technologies" [1]. The basic distinction in electronic voting systems is between *on-site* and *remote* electronic voting. The first describes a system where the physical presence of the voter in the polling booth is required, while in the second case voters can secretly cast her ballot without the restriction to be present at an electoral center. Remote electronic voting has been implemented in a large number of countries (Estonia, France, the Netherlands, Switzerland and the UK are some examples). It has been argued that remote electronic voting has significant potential for increasing the quality of democratic representation of mass publics, by increasing political participation and representation among traditionally underrepresented groups such as the youth and disabled [2, 3, 4] (but see [5]) as well as lowering the costs of becoming politically informed [5]. On top of these, it has been argued that remote electronic voting, compared to conventional voting, can lead to cost-effective and better administered elections [3].

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Despite the merits of adopting remote e-voting technologies, the transition to the new technology comes with a set of challenges from a social, legal and technical standpoint. This paper presents an overview of implementation issues of an electronic voting system for the case of Greece. The article has two aims: The first is to clarify the fundamental principles of election systems as codified in the literature of conventional and electronic voting systems, such as suffrage and the free expression of the will of the voters as well as issues of equality, universality and secrecy of the vote by taking into account the problems of implementation. To this direction, we compare the conventional system using paper ballot as is the case in Greece with a remote electronic voting system. The main argument we develop is that despite broad acceptance of the conventional voting method in the Western world [6], or the "illusion of transparency" as Gueniffey has put it (cited in [7], p. 233), traditional paper ballot voting has significant disadvantages compared to electronic voting systems when it comes to the most common types of election fraud such as vote buying and coercion). Furthermore, it poses barriers to the equality of access to polling stations. On the other hand, while remote electronic voting is promising in addressing these issues, it comes with an important number of challenges. The second aim of the paper is to juxtapose the cryptographic and computational mechanisms that achieve the properties of the ideal voting system of an electronic system, in comparison to the respective mechanisms in conventional systems.

The rest of the article goes as follows: We set and discuss thirteen normative standards regarding the transparency and fairness of a voting system focusing on the potential of conventional and electronic voting systems in meeting them. In the second part of the paper we make a direct comparison of the implementation of these standards between conventional and electronic voting systems as well as a presentation of electronic voting technical characteristics. Finally, we draw some conclusions on the merit and feasibility of remote electronic voting for organizing secret and transparent elections.

2 Normative Standards of Fair and Transparent Elections

In this section we set thirteen normative standards on what constitutes an ideal election in regard to fairness and transparency. These are: equal access to electoral centers, secrecy, vote encoding verifiability, vote tallying verifiability, universal verifiability, voter eligibility, one-voter-one-vote, fault tolerance, fairness, receipt-freeness and coercion resistance. We compare their implementation between conventional and electronic voting systems.

2.1 Equal Access to Electoral Centers

An initial normative standard is that an ideal voting system should ensure unrestricted and equal access of all eligible voters to electoral centers [8]. It must be also noted, that for the case of Greece, the constitutionally fortified principle of universality is perceived as requiring the State's motivation to take all the necessary steps towards the

enlargement of the electorate, including the adoption of appropriate measures that facilitate electors in exercising their right and that prevent their exclusion from voting on the grounds of practical or technical reasons. This in the case of conventional on-site voting systems includes the transportation of voters at the polling station as well the equal access of population groups which have difficulty accessing the stations, such as the elderly, the disabled and voters with health problems. Although this standard is recognized as an international prerequisite of electoral integrity [8] its implementation in conventional voting systems is often compromised as the costs of electoral participation in time and effort for some groups are significantly greater than it is for others. For example, a recent comparative study [9] finds a substantial gap in electoral turnout between those of good and poor health, even after controlling for a large number of socioeconomic status and social integration variables. Apart from the accessibility of those with poor health, it is reasonable to expect that the large number of voters who are registered in a different district than the one they reside creates important obstacles for the implementation of equal accessibility to polling stations, especially during the times of an economic crisis.[1] The merit of remote electronic voting for ensuring the equality of accessibility is apparent, as it bears the potential of bridging the electoral representation gap between social groups and especially in people with poor health, a characteristic that is often used for the adoption of internet voting.

2.2 Secrecy

An ideal voting system should be accompanied by the assurance of the secrecy of the votes in the sense that it should be impossible for a party to extract any information about a voter's ballot beyond what can be inferred from the public tally and the party's insider knowledge taking into account the proximity of the party to the (idealized) system infrastructure. The same principle should apply to coalitions of parties. Depending on the setting, certain collusion conditions under which secrecy is preserved may prescribe. It has been found that conventional paper ballot methods are widely accepted by mass publics as ensuring secrecy [6]. On the other hand, in remote electronic voting systems secrecy relies on various technical preconditions that include mathematical assumptions regarding the way the votes are encoded. For the vast majority of people the understanding and verification of the correctness of these techniques is beyond their ability.

2.3 Coercion Resistance

The voting system should not facilitate for any party to coerce voters to vote in a certain way. Vote-buying or coercion by party officials and candidates and is one of the most common types of election fraud [7]. It is significantly higher in societies with clientelistic traditions [10], such as Greece and it is strengthened in cases where parties

[1] In fact in regions with a high share of voters who are not residents (such as island Greece) turnout was significantly reduced compared to urban centers during the last twin 2012 elections.

can ensure that ballots have been cast in the agreed way [7]. To use some examples, Schaffer and Schedler refer to cases of party officials in the Philippines providing carbon paper to voters so they can record their voting choices, whereas in Italy there have been reported cases where party officials provide mobile phones with cameras to record the vote choice (Schaffer and Schedler 2007, cited in [10]). What is more, turnout buying (the strategy where party officials bribe voters to turn out and vote) or negative turnout buying (where party officials reward voters for not showing up to the electoral station) is common particularly in settings with strong clientelistic ties such as Southern Italy [10]. While there has not been any research on vote-buying in Greece, news reports of rewards for casting preselected ballots are not uncommon.

Electronic Voting on the other hand offers several improvements to coercion. While perfect resistance to coercion cannot be achieved [11] electronic voting systems may provide electors with the ability to correct their vote multiple times or provide them with fake ballots. In this way coercion becomes difficult to achieve, as the coercer cannot ensure that the recorded vote is the elector's final decision. For example, the coercion scenarios we described earlier (where the voter was using a mobile phone or carbon paper to prove to the coercer her vote decision) cannot be applied in an electronic voting system, as the voter can log into the system and change her decision several times (this clause as been successfully implemented in Estonia) or alternatively can use a fake ballot. What is more, coercers cannot conduct positive or negative turn out buying, as is the case with conventional voting, as the voter can vote from the place of her choice in several time points.

2.4 Cast-as-Intended Verifiability

A third parameter of an ideal voting system is vote encoding verifiability, meaning that the voting system should be accompanied by the assurance to the voter that her vote was cast as intended. This requirement suggests that the election procedure has some built-in auditing mechanisms that enable the voter to ensure herself that the way it accepts the ballot is consistent with the intention of the voter. This can be critical in cases where there is a way to encode the voters' intent and the encoding mechanism is electronically assisted. In such cases any adversarial deviation of the encoding mechanism from the prescribed encoding procedure can result in, e.g., switching the voters' choices and violating her intend. In this domain, public trust in traditional paper ballot voting systems is very high: Alvarez and his colleagues report that the vast majority of the American public appeared confident that their vote had been cast as intended, while confidence in elections conducted with the use of punch cards is significantly lower [12].

2.5 Recorded-as-Cast Verifiability

This property requires that the voter can verify that the ballot that was casted was indeed recorded by the system. In paper-based systems this may be achieved by having the voter herself enter the sealed ballot in a ballot-box which is transparent so it is

reasonably ensured that the voter's envelope ends up in the common pile. Electronic (or mechanical) voting systems require more complex auditing mechanisms to ensure recorded-as-cast verifiability.

2.6 Tallied-as-Recorded Verifiability

The fifth parameter of an ideal election is tallied-as-recorded, or the assumption that the voting system should enable the voter to challenge the procedure in the post-election stage and verify that recorded ballots were included in the tally (presumably also her own). This complements the previous types of verifiability and addresses to the setting where the voter wishes to ensure that the vote she submitted was actually included in the tally computation of the election results.

2.7 Universal Verifiability

The voting system should enable any party, including an outsider, to be convinced that a well defined set of votes has been collected and they have been included in the final tally according to the election system. This differs from the voter and tally verifiability property as it refers to external observers and is not concerned with the fate of any individual vote in particular. Universal verifiability has the benefit of delegating the task of verifying certain aspects of the election procedure to interested third parties. In fact, when combined with the previous two properties it may be feasible for a group of voters to delegate the complete audit of the election to an external entity. We note that the universal verifiability property refers to a setting where no privately owned information by the voter is needed for verifying the correct tallying. In conventional voting systems a weak form of universal verifiability is ensured by the presence of party delegates in the vote count.

2.8 End-to-End Verifiability

In many settings the combination of the verifiability properties has been termed as *end-to-end* verifiability. In some systems it is possible for voters to pass or outsource auditing information to a third party thus enabling a single external entity to ensure all levels of verifiability (including capturing the voter intent). It is worth noting that universal verifiability by itself is insufficient for end-to-end verifiability as there is no guarantee that the complete election transcript is not "cooked up" (in this way the election result will be well-defined and properly computed however it will be incongruent with true voter intent).

2.9 Voter Eligibility

The voting system should only permit eligible voters as listed on the electoral roll to cast a ballot. The importance of eligibility cannot be understated. For each district or

precinct, it is critical that the eligible voters can be identified. This cuts both ways: ineligible voters should not be capable of submitting a ballot while eligible voters should not be disenfranchised. These issues become particularly complex when an election spans multiple districts and the electoral rolls in separate districts have to deal with duplicate registrations (due to instances of relocation for example). At the same time, the need for identification poses threat to eligible voters that for various reasons may be incapable of acquiring the proper credentials or may be discouraged from participating in elections by lengthy verification procedures [13]. In the case of Greece, voters' addition in electoral poll does not require any action on the part of the citizens. In cases where by mistake an eligible voter has not been included in the electoral records, she can participate in elections with an attestation from local authorities, which is issued on the same day of the election.

2.10 One-Voter-One-Vote

The voting system should not permit voters to vote twice. While voter eligibility deals with the identification of voters, it is also very critical to ensure that eligible voters are participating in the process as specified: in most election procedure instances this coincides with restricting voters to a single vote. We already noted that for various reasons (some of them in fact security related) a system may allow voters to submit their vote multiple times and only a single instance of such ballot submission will be assumed as the valid submission for the election. This enables voters to change their mind throughout the time the election still takes place and has been proposed as a mechanism in some systems to deal with issues of coercion (see below).

Conventional paper ballot in Greece is subject to fraud resulting from voters voting twice because they are eligible to vote in more than one electoral district. In fact this became a serious political issue ahead of the 2002 local and municipal elections, when the opposition directly accused the government of attempting electoral fraud by using 50.000 voters who had registered in more than one electoral district. Although the Ministry of Interior Affairs cleaned up electoral catalogues with the cooperation of local municipal authorities the problem has not yet been fully resolved.

2.11 Fault Tolerance

The voting system should be resilient to the faulty behavior of possibly up to a number of components or parts. We note that some reliance to the correct operation of electronic equipment can be expected for the proper operation of an e-voting system. Nevertheless, a certain degree of equipment faults should be easy to recover from and should be incapable of disrupting the election process. Alternatively widespread equipment faults should be at least detectable (if not recoverable from). We note that fault resilience should be interpreted in the form of the ability of the voting system to report the correct election results.

2.12 Fairness

The voting system should ensure that no partial results become known prior to the end of the election procedure. We note that in some cases this property may be violated by the way an election is managed. As before we state that we are concerned with failures of the electronic equipment and not with procedural failures of a large scale electoral process. For example when running an election process in a large geographic region it might be possible to have districts finalizing their tallies and publishing them prior to the termination of the election in other districts. This is common in the United States for example and it is even considered legitimate to capitalize its advantages in election procedures that seek to elect the presidential nominees of political parties. Fairness is an important concern as it may induce what is known as the *bandwagon effect* where a certain candidate gains momentum by winning on a handful of districts and subsequently capitalizes on this momentum by either having more voters previously undecided turning to her side or having voters supportive of other candidates opting out from participating in the election process [14].

2.13 Receipt-Freeness

The voting system should not facilitate any way for voters to prove the way they voted. The ability of a voter to obtain a receipt of the way she voted opens the possibility for a voter to sell or auction her vote (see previous section). Receipt-freeness specifically refers to the apparent lack of any receipt produced by the voting system, or at least of a receipt that cannot be easily falsified by a voter.

3 Comparison of Generic Traditional and E-Voting Systems

Table 1 extends the comparison between generic conventional and electronic voting systems presented in Sect. 2 by discussing practical implementation differences between the two systems and presenting an overview of the basic mechanisms used in

Table 1. Comparison of Generic Traditional and E-Voting Systems

Property	Generic Traditional Voting	Generic E-voting System
Equal access to electoral centers	In a small scale, traditional voting operates ideally in terms of accessibility. However, large scale deployments have high potential to cause significant problems in terms of accessibility given that voters may be assigned to remote districts and the update of the electoral roll per district can be cumbersome	Remote e-voting provides a very high level of accessibility among voters familiar with the use of digital equipment in general. On the other hand, onsite e-voting exhibits a similar accessibility pattern with traditional voting however it can be possible to perform substantially better through the automation of the voter registration system

(Continued)

Table 1. *(Continued)*

Property	Generic Traditional Voting	Generic E-voting System
Secrecy	Secrecy relies on physical assumptions about the configuration of the voting environment (e.g., private voting booths). These mechanisms are intuitive and their proper operation can – in principle – be easily verified by the voter	Secrecy relies on various technical preconditions that include mathematical assumptions regarding the way the votes are encoded. For the vast majority of people the understanding and verification of the correctness of these techniques is beyond their ability
Vote encoding verifiability	In the paper-ballot setting the voter can follow simple rules to ensure her choices are properly encoded (e.g., only a specific number of "crosses" are allowed – the cross signs have to be non-ambiguous etc.) The ability of the voter to cast a "spoiled" ballot can be in some cases significant as a form of political expression	The voter choice is either encrypted or cast via the submission of a specially prepared code. The verification of the proper encoding is impossible without trusting the underlying equipment or requiring from the voter to perform additional verification steps beyond ballot-casting (however it may possible that such actions can be delegated). Typically there is no way for the voter to cast a "spoiled" ballot
One-voter one-vote	It is ensured by the election officials committee. For instance, the name of the voter is crossed out from the list and no second vote is allowed to be submitted	It is ensured via the proper interoperation of the voter registration system and the ballot casting system
Fault-tolerance	The election relies on the election officials' ability to execute the election protocol properly. Deviations, intentional or not, pose a significant threat to the election process	Tolerating faults is achieved via the distribution of the state of the various sub-systems that comprise the election. Distributed systems provide resistance to faults however they are much harder to analyze and maintain than "monolithic" single server systems. The latter is unfortunately the norm for the vast majority of e-voting implementations
Fairness	The tallying of the results is revealed after the end of the election. This relies on the election officials' adherence on the proper timing of the tallying process. For instance in a multi-precinct election, no ballot box should be "opened" prior to the termination of the ballot-casting process	The tallying system is supposed to provide output only after the termination of ballot-casting. This property can be violated if the system is subverted by an attacker. The ability to distribute the vote collection system state is essential for preventing the violation of fairness (cf. fault-tolerance)

(Continued)

Table 1. *(Continued)*

Property	Generic Traditional Voting	Generic E-voting System
Receipt-freeness	Some forms of receipt are feasible, e.g., via the photographing or videotaping of the ballot casting procedure (e.g., a video shot by the voter, as she seals an envelope with a visible vote choice). Such techniques may not necessarily offer conclusive proof however they may be used as a form of a weak receipt. The collection of uncast paper ballots may also form a weak receipt	Systems that publicly reveal the casted ballot in an encoding form can be prone to receipt generation via digital means. Encryption schemes require randomness that, if accessible to a malicious voter, can be used to prove a certain voter choice depending on the system configuration
Coercion resistance	Private voting booths are congruent with coercion resistance, however the extraction of a receipt as described above may leave the voter vulnerable to coercion	In the case of onsite voting the coercion aspects of e-voting are similar to the conventional case with the additional potential of digital attacks (e.g., against the ballot casting system or the ballot encoding scheme). Remove e-voting on the other hand provides a number of clauses that improve voters' resistance to coercion efforts

electronic voting systems. Overall, despite the significant potential of remote electronic systems, some fundamental challenges remain especially in regard to voters' level of internet literacy and trust.

4 Conclusion

Electoral integrity is a strong prerequisite of effective democratic representation. Contemporary democratic theory posits that elections should be characterized by transparency, fairness and equality of access and these imperatives constitute an integral element of the constitutions of liberal democracies around the world. This paper compared the potential of the Greek conventional paper ballot system with a remote electronic system in the implementation of fundamental aspects of free and fair democratic elections. The main conclusion is that despite broad public trust in electoral systems, conventional paper ballot systems come with significant drawbacks in security especially on ensuring resistance from coercion, double-voting and the equality of accessibility across the electorate. Electronic voting systems are potentially efficient in resolving core deficiencies of traditional paper ballot systems in these domains, yet face a number of significant legal and technical challenges especially on issues of secrecy and vote verifiability.

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