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ELECTRONIC VOTING

– A brief study of remote internet voting in Estonia

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The voting system in many countries still relies on the paper ballot system which is cumbersome. The global declining number of voter turnout since the 1990s has been a major concern of all countries. The spoilt ballot is another factor affecting elections. The use of the electronic voting (e-voting) system could minimize or possibly end spoilt ballots. Many countries have started using different e-voting systems. Estonia is the only country to use an internet-based e-voting system nation-wide in all forms of elections.

This thesis aims to study the remote internet voting system used in Estonia, its impact on voter turnout, spoilt ballots and overall election. Various documents, reports and statistics were analyzed to prepare this thesis.

The thesis found out that e-voting has increased the convenience for the voters and has been able to make a little positive impact on the declining voter turnout. The number of spoilt ballots has been reduced to minimum. The election expenses have also reduced. However, the question on its integrity and reliability has been raised by political parties and experts. Pointing the risks involved in e-voting, the independent report by the team of the University of Michigan and Open rights group has recommended to discontinue it.

KEYWORDS:

e-voting, i-voting, election, voter turnout, verification, authentication

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LIST OF ABBREVIATIONS

BEL   Bharat Electronic Limited

DRE   Direct recording electronic

E-voting   Electronic voting / Internet voting

E2E   End to End

EBM   Electronic ballot marker

ECIL   Electronic Corporation of India limited

EVM   Electronic vióting machine

FPTP   First Past the Post

I-voting   Internet voting

ICT   Information and Communication Technology

LE   Local Election

OMR   Optical Mark recognition

OSM   Optical scanning machine

OTP   One time programmable

PE   Parliamentary Election

PIT   Public Instruction test

SEO   State Electoral Office

STV   Single Transferable Vote

TSE   Tribunal Superior Eleitoral

VDC   Voting District Committee

VVPAT   Voter Verified Paper Audit Trail

1 INTRODUCTION

The development of science and technology has facilitated the possibility of performing election in a very convenient way. The most important use of Information and Communication Technology (ICT) in elections is casting and counting votes. The use of the electronic system in elections has made elections easier and faster. In some countries, e-voting has managed to enable voters to vote remotely from home or anywhere which has benefited voters with disabilities and voters living abroad.

The discussion on remote voting started as early as 1862. The author has found the recorded provision in mid 19th century (1864) in United States (US) [1] The military personnel who where abroad or out of their place of voting during election time were given the opportunity using different method such as mail voting or postal voting. Australia introduced postal voting in 1890s. Since then, the concept of electronic voting emerged.

Electronic voting can be defined as the voting process that involves the use of electronic technology or program software either fully or the partially to accompolish the election. The use of electronic voting devices and system has made it easier and faster to conduct election despite the fact that, the paper-based voting system is still used in most of the elections around the world. Although the paper ballot system is old fashioned, time consuming and cumbersome, people still have high trust on it. Some countries like the Netherlands, Germany, France tried electronic voting system and returned to paper ballot system. Germany discontinued after two voters registered a case before the German Constitutional court [2]. On the other hand, there are countries like Brazil, Estonia, India, Namibia, that are shifting their election to paper less form. [3]

Estonia is the first and the only country to fully use internet voting(e-voting) nation-wide in all forms of elections since 2005. While Switzerland, Norway, the UK, France and Canada have also launched pilot e-voting systems with partial success and failure. With the introduction of e-voting, high voter turnout was also expected. The experience is positive but not so exciting. However, the number of e-voter has been rising every year and ballot spoils have been minimum. [4]

Benefits of e-voting

The use of e-voting in the election can attract more people to participate in an election. The ballot can be presented in an attractive and user friendly style. Remote e-voting can even include the voters who can not visit the polling station for various reasons. The possibility to use different assisting devices can help voters with physical disability vote easily. In that way, it is more inclusive. It can eradicate the spoilt ballot. The voting can be smoothend and the results can be delivered fast. Over the time, it also reduces the overall operation cost aswell [5, p. 127].

Weaknesses of e-voting

There is always a risk of unauthorised intervention of unauthorised parties in an e-voting system. It is more difficult to detect the source of error in such complex system. The minor malfunctions of the device and software can also disrupt the whole election process. In case of system failure or data leakage, it is difficult to recover the data. Even if recovered, its reliability can be questioned. In case of remote e-voting, there is high chance friends and family influence it since it is done with out the supervision of any authority.

Some issues with paper-based voting

The paper ballot based voting system seems simple, yet very complex with increasing number of candidates. The size of paper ballot in Afghanistan parliamentary election 2018 was 15 pages newspaper size for just one selection [6]. The size of ballot paper used in Kathmandu Metropolitan city during the local government election 2017 was 51 cm long and 73 cm wide. A voter had to vote for seven different positions in the same ballot paper. While counting it, it took on an average three minutes just to count single vote. It took more than 10 days to publish the final result [7]. The paper ballot system uses single use paper and requires more organization manpower so it is expensive compared to the electronic system [5]. The ink used to mark voter can be washed away with certain detergents or chemicals so there is always the risk of voting multiple times. The spoilt ballot is another major problem with paper-based voting system. Many votes are rejected as a result of minor mistakes such as the unclear marking, multiple marking or blank ballot. Any minor clash or calamities such as riot, booth capturing, rain can easily spoil the collected votes.

1.1 The functional requirements

There are some functional requirements that help in conducting election with electronic voting. The simpler the e-voting system is, the better it is. The simple and user-friendly system is easy to understand and use. The system must be available for the entire election period for the convenience of the voters and to vote from any place or any polling station. It should be able to assist the voters that need additional support.

Accuracy is a must have functional requirement of e-voting. An e-voting system is required to record and count the vote accurately. So, the system must be equipped with high storage capacity. The system should be able to identify the uniqueness of every voter so that no voter votes more than once. In order to prevent vote selling, the system must maintain ballot secrecy and anonymity of vote. The vote must be recorded without any information of the voters. Above all, the system and whole voting process should be transparent and be conducted with fairness. No candidates should be given extra advantage over others. The vote tally must not be revealed during the voting period since it can influence the voters' decision, who are yet to vote.

1.2 Security requirements

The registration of each voter should be completed prior to the election in a computerized registration database. The database must be made available in every polling stations. The system must be able to perform voter authenticity to identify voters and should maintain voter anonymity so that no one would know his/ her vote. The ballot must not record voter information. The system must ensure the voters' privacy. Even election officials are not expected to observe the voters' choice. All the ballots must appear unique while stored in encrypted form. The ballots must be encrypted in order to be stored safely during the election period. The encrypted ballot could be decrypted after the completion of election.

The system must be able to detect any fault in the system so as not to lose any data. All the equipments and software are required to undergo through operational testing by the expert team before using it in election. The administrative authority must not be given to a single entity; instead it must be distributed among multiple administrators.

1.3 Types of e-voting

Different types of voting machines have been employed over the course of time. Voting machines are used in election for various purposes such as collecting, storing and counting votes. These machines are either used just for counting the casted vote or used for the overall session.
Voting machines differ from one another. The standard of security, usability, efficiency and accuracy differ from one machine to another. Some machines are more user friendly than others and some are very difficult for the people with physical disabilities.

1.3.1 Punch card voting machine

The punch card voting machine uses a card and a punching device to record the vote. The voter makes hole next to the name of their favourite candidate and throws it into ballot box or to the electronic vote tabulating device at polling station. Votomatic is the most common punch card system. In votomatic, a standard-size IBM data processing card is used as ballot which is machine readable. There are a maximum of 960 voting positions in 12 columns in it. The votomatic ballot is pre-scored at each voting position so that punching removes the chad from the punched position, leaving the hole on the ballot. Candidate names are not printed on the ballot card and the number of the hole is the only information on the card. A separate booklet or candidate list is placed to indicate the corresponding position for voting. The ballot is placed into the voting machine in proper alignment. The separate booklet has the required information about the candidate and opposite to it is the only exposed column of voting position. When the booklet is turned, a new column of voting position is exposed. The voter uses the punching device to make hole and either drops it to the ballot box or the vote tabulating device, depending on the vote collecting method used in election. The ballot thus collected are feed to a special card reader. The reader reads the information on the ballot and the computer summarizes the vote for each candidate. Votomatic is fast and efficient. [8]

Votomatic was cheaper compared with other voting machines. It weighs only around 3 kilograms compared to other heavy machines which could weigh ten times heavier. The issue of weight also introduced the use of computers in election. It became much popular among other punch card voting machine. However, in 2000 US presidential election in Florida, votomatic faced major problem on its reliability. Many ballot cards had incomplete punching which resulted in smaller holes than expected, or the hanging of chad. Many such ballots were disallowed. The ballot card was also placed in between two list of candidates and because the single column of voting position was exposed voters were confused. Many ended up voting for the wrong candidate which eventually resulted in the abandonment of Votomatic technology from US. [4]

1.3.2 Direct-Recording Electronic (DRE) voting system

The Direct-Recording Electronic (DRE) voting system is the most popular modern electronic voting system currently in use. As the name suggests, it is a system where

each vote is recorded directly using an electronic device. The voter votes directly into an electronic device or machine. The DRE is a paper free setup in election. The ballot paper appears on a digital screen or is listed on a paper opposite to push buttons. The voter pushes the buttons next to their favourite candidate in order to cast a vote. The vote is stored in the inbuilt storage and tabulated in an authorized location after the completion of the election. The evaluation takes less time compared to other traditional paper-based system.

DRE devices are simple effective and easy to use for all. These are equipped with voting assistance for voters with physical disabilities. Braille makes it easy to use for voters with partial or fully eyesight disability. Audio assistance helps voters that need voice assistance. It solves the problems related to invalid votes, since it only accepts valid votes. The vote wastage is due to occur when a voter votes in a wrong way in the traditional paper ballot. Invalid votes are created when a voter marks for more or fewer candidates than required, when casting without marking properly, when marking outside the authorized space or in an ambiguous place.

Despite all these strengths, DRE still has some weakness. Different manufacturers produce the device. Most devices are only used during the time of election and no third party or open testing is performed. Only manufacturer guarantee can not assure the sound function of the device. Being an electronic device, it is impacted by technical problems such as: power related issues, screen and sensor related issues. In such case, it is very difficult or even impossible to recover the casted vote. Even if recovered, questions on reliability can be raised. On the other hand, they are expensive. They require routine maintenance and software updates. These devices are subject to tampering. A single line of programming error or hacking can result in high damage.

1.3.3 Optical Scan voting

The optical scan voting can be further classified into 3 major systems.

Marksense system

Optical scan voting is the combination of paper ballot and electronic device. The voter uses paper ballot and marking device to cast vote. In most cases a graphite pencil is used to mark the ballot paper. The marked ballots are dropped into the ballot box. The ballots are fed into the OSM for electronic tabulation. The Marksense system uses Optical mark recognition (OMR) to read the marks. OMR is the process of reading the marks made by human on the paper or document. OMR are able to read questionnaires, multiple choice marks, lines, shapes from documents. This system is much similar to traditional paper ballot system but it can count and publish result in much shorter time.

Electronic ballot marker (EBM)

The Electronic Ballot Marker (EBM), also called Ballot Marking Device (BMD) is a component of voting system that the voter uses while marking a ballot paper. Some examples are touchscreen, tactile keyboard, head phone, etc. The EBM is only used for marking purpose but not for storing in its memory. Instead, the EBM records vote on paper ballot or prints the paper slip and that ballot is counted manually on optical scan.

Digital Pen

The digital pen is a device capable of marking on the ballot paper and it even scans the marks made on ballot paper. It has a small camera that recognizes where the voter has marked on the digital ballot paper. When the marking is done, the digital pen can transmit the recorded marks into the computer. The digital pen is returned to the polling officer after the voter has voted.

1.3.4 Internet Voting (E-voting)

Internet voting is the e-voting where the voters cast their vote via computer with internet access. It is also called E-voting. It is the rarest of all e-voting that is in practice. E-voting can be further classified into two different forms depending on the nature of voting.

Uncontrolled voting environment

Uncontrolled voting environment is the E-voting that a voter can use freely from any place like home, office, public internet terminal, etc. using own computer connected with internet.

Controlled voting environment

Controlled voting enviroment is the E-voting that is placed in the polling station where voter cast their ballot in controlled or secure environment. The computers and machines are controlled and managed by the election officials. The identification may be carried out by traditional means.

2 ELECTION SYSTEMS

Election is the organized process of selection of political party or position by people's vote. It is one and only way to form democratic government. Every democratic countries exercise the election in regular time interval. There are various types of election system in practice from traditional style to very modern electronic style [9].

2.1 First Past the Post (FPTP)

It is the election system where the candidate with most votes get elected from the particular constituency or electoral district. It is also called the Plurality system. Countries like the United Kingdom, the United States, Canada, India, and many Caribbean and African states still practice this. The voter votes their favourite candidate or their belonging party's candidate and the one with high vote gets elected. It need not mean that the elected candidate earns more than half of the vote. When there is more than two candidates there is high chance that the majority of the voter actually do not vote for the elected one. It is easy to count as it is clear concept that anyone can understand. But, in the case if two or more candidate receives equal number of votes then, different methods are used in different countries like lucky draw or re-election. Elected candidate represents the constituent area in the Parliament. This is sometimes described as winner takes all. It is one of the popular electoral system in the world.

2.2 Majoritarian System

It is the election system where the candidate with the majority or more than half of the valid vote gets elected. It is just like FPTP with one different rule, only majority wins. Mostly, it is used in the House or Parliament to elect certain jobs like speaker of the house, Prime Ministe. Theae are the places where absolute majority is required. The voters are required to vote single candidate or rank according to their preference as per rule in the particular country or organisation. Then, the candidate with the majority of the vote is announced as elected. If no candidate success to get majority then different rules are applied. In some countries, the second round election is applied with limited candidates most likely top two candidates. Countries like Argentina and Ecuador employs different rule before going for second round of election. If the leading candidate gets 40% or above and the difference with the nearest rival is 10% or above then the leading candidate is declared elected. In some case where voter has preference voting, the vote is transferred from the candidate with least vote to other.

2.3 Majority bonus system

It is the system where the additional seats or representatives in the parliament are given as bonus to the parties with the high votes with the aim of providing stability in the

government. It acts like jackpot for the winning party or alliance. Greece, Armenia are using it. Italy was using it until 2013.

2.4 Single Transferable Vote

It is the election system where the voter cast their vote for one or many candidates on a single ballot. It usually elect two or more candidates from the same constituency. Same political party can run many candidates for all the seats in the constituency. Unlike FPTP, majority has nothing to do with this form of election. Candidates are declared elected after securing certain portion of valid vote i.e quota. The quota for each seat is calculated by dividing the total number of valid vote by number of seats plus one.
$$\frac{Totalseat}{seat+1}$$

The voter has right to make their preference for the available candidates. Instead of marking or stamping the ballot, the voter writes the number next to the candidates. Number 1 representing the first preference, number 2 representing the second preference, number 3 representing the third preference and so on.

The candidates crossing the quota are declared elected. If the seat is unfulfilled then, the exeed vote of the elected candidate is surplus to the second preference with lowering the actual value. If still the seats are not fulfilled then the one with least vote is eliminated and his or her vote is transferred to the other candidate and process goes on until all the seats has been fulfilled. It looks really difficult method to count the vote but the computers can be programmed to count. This system actually represents the voice of the people as those proceed further whom the voters want to.

2.5 Instant-runoff Voting / Alternative Vote

It is the voting system where voter can vote for multiple candidates. The voter votes by arranging the candidates in order of their preference. Voter usually marks with numbers, '1' for their first preference, '2' for second preference and so on. The one with the majority of first preference is announced elected. In case no on receive majority, the one with the lowest vote gets eliminated and his/ her vote is redistributed to the other in the next preference. The process continues until the one achieve the majority. The system is mostly used in internal elections of the political parties, legislature councils, etc. President in India, Ireland are elected through this system.

2.6 Mixed Electroal System

It is the system where two different ballots are used. First ballot is used for FPTP system where the candidate with majority of vote wins and the second ballot is used for the political party where party selects the candidates, thus party has the absolute control over the decision on candidates.

The seats are divided in two proportions such that certain gets elected through FPTP wins and other send by the political party list. The party has the complete authority over the selection of the party list. The main benefits of this system is that it does not let vote go on waste. But as the party list candidates are not directly linked with the voter, thus elected representative might not represent the people. This creates the class between the elected and partylist.

2.7 Two-Round System

It is the system France has been using for its president election, legislature and regional election. About 40 other countries are also using this system [9]. The voter votes for the single candidate on a ballot. The candidate with the majority is declared elected in presidential election. If the candidates fail to get majority, then the second round of election takes place with top two candidates from the first round.

2.8 Borda Count

The borda count is the point based election system where the voters arrange the candidates in the order of their preference like 1 for their first preference, 2 for second preference and so on. Then the vote is counted in the points. The candidate at the last preference gets the least point and the first preference gets the highest point. For example: If the candidate at the first preference gets 10 points then the second preference gets 9, third preference gets 8 and so on. At the last, the candidate with the highest point is declared elected. It is not in use in any national election but it has been used in other places where points matter much.

2.9 Party List Proportional Representation

It is used in more than 80 countries to elect representative [9]. The party provides the list of the candidates that represents in the parliament. The party has the full authority over the list. Usually, the voters are required to vote for political party. The party provides the list of the candidates with respect to the election act of the particular country. In some countries like Finland, Spain each constituency elect certain number of representative while in some entire country represents as one constituency like Israel, Netherland. The total valid votes are counted and party seats are declared with respect to the vote received. Many applies threshold rule of certain percentage to avoid large number of small parties.

2.9.1 Closed list

The voter can only vote for the party and party announces the candidates to represent from the list. The voter has no authority to select the candidate directly.

2.9.2 Open list

The voter can also choose the candidates from the party list in this system. The order of candidate list by party could be reconsidered by the number of vote candidates receive.

3 REMOTE VOTING

The discussion on remote voting started as early as 1862. The author has found the recorded provision in mid 19th century (1864) in US. The military personnel who where abroad or out of their place of voting during election period were given the opportunity using different method like mail voting or postal voting. With postal voting, the ballot is sent via post to the voter and voter marks the ballot and return it to the corresponding or center election office. Most common form of postal voting follow double-envelope principle. The voter first seals the vote in an envelope and puts the envelope in second envelope and post it to the address so that the post reaches before the main election day. It is voters responsibility to ensure they vote in privacy. Countries like USA, UK, Canada, Australia, Switzerland, Spain,etc. are using it. Finland has recently introduced the postal system in 2019 election [10]. It is mainly meant for the voter living abroad during the election period.

Remote Internet Voting

Internet voting is the e-voting where the voter cast their vote via computer with internet access. It is also called i-voting. It is the rarest of all e-voting that is in practice. Countries like Switzerland has been conducting to as test project since early 2000 with limited voters in few Cantons. It used unique passwords through postal system for individual verification.

Norway also had two small pilot projects. The first one in 2011 during the local election and second in 2013 in general elections. Both the pilots were technically successful. However, the government decided to discontinue e-voting due to the possible risk contained in security mechanism. The UK, Canada, France have also launched the pilot project with partial success and failure. Many are returning back to the pen and paper system after the question were raised on its reliability and security.

Internet voting is convenient. Voter can use their voting right any time during the advanced voting period which helps in lessen crowd. Internet voting can increase and improve voter access. The people with physical disabilities, health conditions, mobility issues, crowd shyness, away from home otherwise would not vote can vote. Internet voting has significantly reduce ballot error and spoil and little voter turnout has been experienced.

Internet voting (E-voting) in Estonia

The experience has been positive in Estonia. It is the only country to implement internet voting successfully in all the elections nation-wide. The small nation in the Baltic reason with around 1.3 million population, has successfully used internet voting in all election till the date. The first internet based voting was held in October 2005 for local government. Internet voting is called as 'I-voting' in Estonia but the term 'E-voting' has been used in

this thesis. E-voting in Estonia takes place in uncontrolled environment, that means the voter can vote from any place they like without having to visit polling center. The voting is not monitored of supervised by any election officials. In recent election 2019, 44% Estonians used e-voting to cast their vote. In Estonia roughly 10% would not have voted without the provision of e-voting, says the report by Alvarez, Hall and Trechsel [11].

E-voting allow voters to cast vote via the internet. The vote thus casted is transmitted to the central server of the election authority. The voters need a computer with an internet connection and ID-card or mobile ID to cast vote. If using ID-card, voter also needs a smart ID card reader to identify himself/ herself. The facility is open during advanced voting period which is tenth to fourth day before election day.

3.1 Software components

The remote internet voting is composed many software applications. The voter application allow voter to perform E-voting from the computer. It is capable of performing all the necessary duties like voter authentication, vote registration, server communication, vote encryption and verification QR code. Verification application can be installed in the smart devices and check whether the vote has been recorded accurately or not. It scans the QR code generated after the vote has been casted. The key application is used to generate a public key and a private key for each voting. The public key is used to encrypt the vote and the private key is used to decrypt the encrypted vote. The processing application is the main component for the processing phase.The authorised officials provide the input and then, it checks the individual integrity of the votes, annuls the duplicate votes, creates list of the people who voted, creates list of anonymised votes. Mixing application mixes the anonymised encrypted votes. Audit application for auditing purposes. It checks the correctness of the published results. [12, p. 10]

3.2 E-voting server infrastructure

There are four different servers used in the election and they are vote forwarding server, vote storage server, log server and cote counting server. Vote forwarding server is the server that voter has access during voting period where voter cast vote. It collects and forward the vote to the vote storage server. Vote storage server stores the encrypted votes. The log server keeps the record of the events from vote forwarding server and vote storing server. Vote counting server is only used while tabulating the votes.

3.3 Envelope Scheme

Like in the postal voting, where the voter puts the ballot in an anonymous envelope which is again placed in outer envelope with voters' name and signature. The voter application

encrypts the vote and random number with election specific public key. This encrypted vote can be considered as inner envelope. The encrypted vote with digital signature can be considered outer envelope. This system is called envelope scheme. Envelope scheme records the vote as anonymous. The anonymous encrypted vote can not be decrypted without private key. [12]
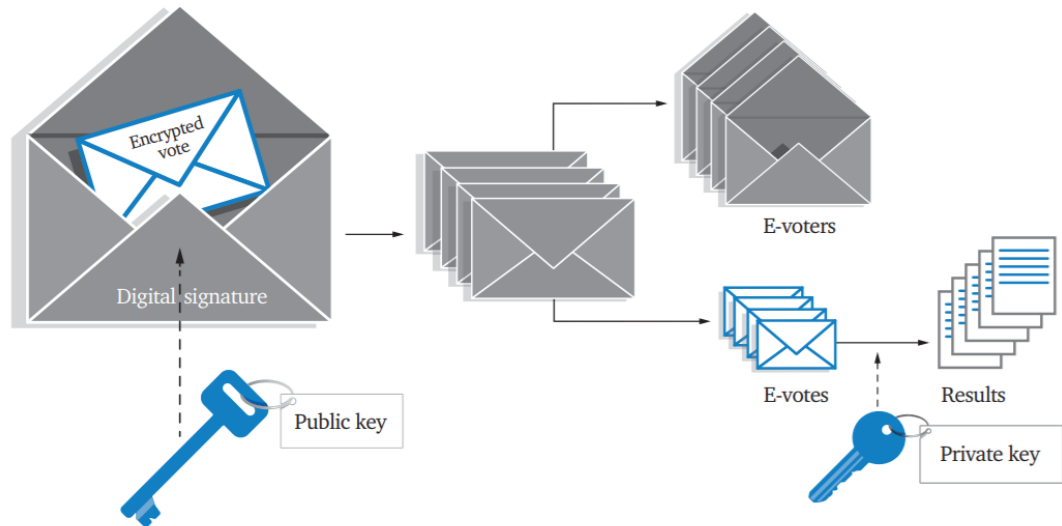

Figure 1. Envelope scheme

(source: https://skytte.ut.ee/sites/default/files)

3.4 Authentication method

Estonia has been using the following authentication methods:

3.4.1 Identity card

In Estonia, identification card (ID-card) is credit card sized personal identification document. The functionality of ID-card is based on an electronic chip and two pin codes that comes with the card. The chip carries embedded files. The 384-bit ECC public key encryption can be used as definitive proof of ID in an electronic environment [13]. It is issued by the police and Border Guard Board. It is mandatory for all citizen and can be used regularly for various purposes such as legal travel document within the Europe, national health insurance card, login identification and authentication in internet banking, digital signatures, to cast vote using internet e-voting, to handle online taxation, to use e-prescriptions, etc.

ID-card can be used for personal identification and digital signatory. It is used to identify while voting online. For voting through internet, one has to install voting application that is available in the official website https://valimised.ee in their computer. Upon opening

the application, user has to identify using the ID-card and PIN code. The application system then checks if the user is eligible to vote or not. After confirmation, if the user is eligible to vote then the application leads to voting interface and displays the list of candidates on the screen. When the voter selects the candidate he/ she wishes to vote and ready to cast vote, the second PIN-code is asked for confirmation as digital signature. After the confirmation, vote is sent to the server and be counted on the official counting time.

The authentication is somehow similar to the internet banking. A customer needs user-code and pin-code to login the internet banking where he/she can check his/her account information, balance, invoice, assets, etc. However, to pay any invoice a customer is asked to authenticate with digital signature.

3.4.2 Mobile id

Mobile ID is a secure digital ID provided by the mobile phone operator. The identification is based on mobile SIM card. It can be activated by signing mobile-id service agreement with mobile operator or can be activated on Police and Border Guard Board website. It is nationally recognised and secured by PIN codes. The exchange of data between mobile phone and e-service is performed over an encrypted connection. Mobile id works on smartphone, regular phone, tablet and computer without need of ID card reader. It allows people to access secure e-services and digitally sign documents like ID-card. About 20% Estonian voters used the mobile ID authentication during the recent parliamentary election. To use mobile-id in e-voting, the voter is required to have same setup as mentioned earlier in ID-card system. At the time of identification voter has to choose mobile-id instead of ID-card and provide PIN1 code. Then after the selection, confirmation is done using PIN2 code.

3.5 The E-voting procedure

The State Electoral Office (SEO) manages the necessary setup for the e-voting with the cooperation of the Information System Authority. The SEO puts voter application on voting website "https://www.valimised.ee". Every voter needs a computer with an internet connection, ID-card with ID card reader or mobile-id to vote using e-voting. E-voting is not available in smartphone. The voter must download and install the voter application in the computer in order to use the e-voting. The website also contains a free online security scan called "HouseCall" to prevent e-voting from any complications.

Voter application requests for voter identification method and voter is required to choose either ID-card or Mobile-id as verification method and feed in with PIN1 code. The voter application automatically checks the voter's eligibility and displays appropriate candidates list. After choosing from the candidates list, the voter confirms the vote using digital signature, in this case PIN2 code. The confirmed vote is then sent to the collecting server by the voter application. The independent registration service records the time stamp on each vote so that it can verify that the vote later.

The casted votes are encrypted using a latest crypto-algorithm [14]. A vote is encrypted with the help of two encryption keys. In order to maintain the secrecy of voting the personal identity of the voter is not recorded with the casted vote, however e-vote has election identificator and a candidate registration number. An e-vote is subjected as anonymous votes. Only the members of the National Electoral Committee have access to vote opening key. Keys are distributed among the members, so a single member can not use it alone.

The voter has the right to change his/her vote even after submitting until e-voting is open. This provision is to ensure voter's actual expression and counters coerced. Since e-voting takes place in an uncontrolled environment, there are chances of influence, threat, pressure, common mistake. A voter can vote again after becoming free from coercer. The voter simply follows the same procedure of identification in the application then confirm with the digital signature and change vote. The change can be done as many times as voter wish. Only the last cast e-vote is recorded in the server and all previous votes are annulled. E-vote can be changed by using paper ballot as well. If the voter visits the voting station and uses paper ballot then all his/ her electronically casted votes are annulled. This provision is only available during advance voting. E-vote can not be changed on the election day.

3.6 Vote verification

The Organisation for Security and Co-operation in Europe/ Office for Democratic Institutions and Human Rights (OSCE/ODIHR) recommended to use end-to-end verification to add the security level and ensure the high integrity [15]. OSCE/ODIHR has been observing the electins upon invitation from the country. The individual vote verification was used in 2013 local election. The voter can check and verify whether their e-vote has been recorded as intended or not. Any smart devices operating with Android, iOS or Windows operating system and equipped with camera and internet connection can be used for checking purpose, using verification application called 'EH kontrollrakendus' which is available in google play, appstore and microsoft store, developed and published by Cybernetica AS.

The computer creates cryptogram using the voter's choice and a generated random number. The cryptogram is sent to the server and it generates the session code for each e-voting and sent it back to voter application. Random number and session code produces QR code which is displayed on the screen. The verification application scans the QR code and send the session code to the server and then the server returns the encrypted data and with the use of private key it is decrypted afterward. The application has time limit of 30 seconds. The application does not show any personal information of the voter.
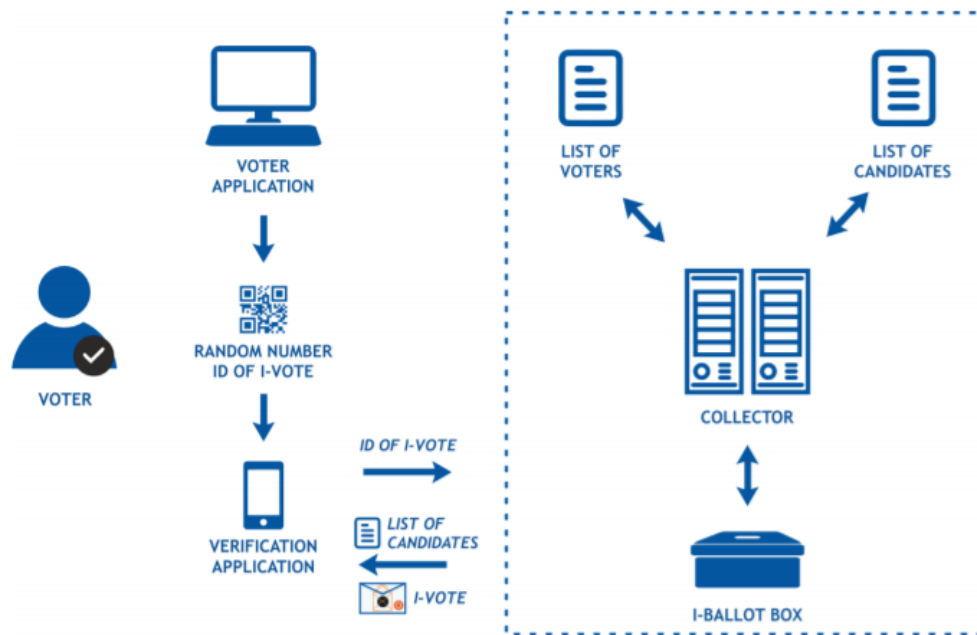
Figure 2. Vote verification process

(source: https://www.valimised.ee/sites/default/)

3.7 Voter application

It is the application that has made e-voting possible. The voter application can be downloaded from 'valimised.ee'. It is available for windows, macOS, and linux operating systems. The application does not work on smart device.

Vote counting

The counting of the vote is performed after the end of election day. The e-votes are retrieved from the collector. The key application with the private key is used to open and count the vote. The application is maintained in an off-line environment. The list of candidates, electoral districts and anonymised votes are loaded into the key application. The vote opening keys, which are disturbed among the members of National Electoral Committee are paired to activate the private key [12, p. 18]. The votes are then decrypted using private key.

4 STATISTICS IN ESTONIA

Estonia has been organizing elections regularly since 1992. In early 2000s, they introduced pilot of internet voting with some hope to tackle the declining voter turnout and add the convenience to the citizens to take part in election. The statistics of the different elections are gathered from Estonian National electrol committee's website and tabled in this chapter [16].

Table 1. Voter turnout in Parliamentary Election

Parliamentary Election (PE)	Eligible voters	Participating voters	Invalid ballots (%)	Voter turnout (%)
PE 2019	887420	565045	0.7	63.7
PE 2015	899793	577910	0.7	64.2
PE 2011	913346	580264	0.9	63.5
PE2007	897243	555463	0.7	61.9
PE 2003	859714	500686	1.2	58.2
PE 1999	857270	492356	1.7	57.4
PE 1995	791957	545801	0.92	68.9
PE 1992	689319	467628	2.0	67.8

(source: https://www.valimised.ee/en/archive/statistics)

Table 2. Voter turnout in Local Election

Local Election (LE)	Eligible voters	Participating voters	Invalid ballots (%)	Voter turnout (%)
LE 2017	1100647	586519	0.7	53.3
LE 2013	1086935	630050	0.7	58
LE 2009	1094317	662813	0.7	60.6
LE 2005	1059292	502504	1.2	47.4

(source: https://www.valimised.ee/en/archive/statistics-about-internet-voting-estonia)

The table 1 shows the voter turnout in the last Parliamentary Election (PE) was 63.7% which shows slight decline of 0.5%, compared to the PE 2015. In 2019, the average voter turnout in legislative election in Europe was 64.9%, 66.1% across EU member states and 71.9% across Western Europe [17]. The turnout in last four PE are over 60% but the statistics are still below the average voter turnout in Europe. The voter turnout in the first election after independence, in 1992 was 67.8%. In 1995, the small improvement was achieved to make it 68.9%, while it dropped to 57.4% in 1999 and 58.2% in 2003.

After the successful implementation of e-voting in Local Election (LE) 2005, it was also introduced in PE in 2007 which showed the voter increment of 3.7% to reach 61.9%. The voter turnout reached 63.5% and 64.2% in next two PE held in 2011 and 2015 respectively. The voter turnout in LE has been declining for two consecutive elections, thus accounting average voter turnout for just 54.8%. The average voter turnout in PE after the introduction of e-voting is 63.3% while the overall voter turnout is 63.2%.

The significant progress e-voting has achieved is in minimizing the spoiled or invalid ballot. E-voting has no possibility of spoiled ballot. The invalid ballots are reduced to 0.7% in past two PE, which were 2.0%, 0.9%. 1.7% and 1.2% in PE 1992, 1995, 1999 and 2003 respectively. The bar heights in parliamentary election have remained steady with the e-voting which experienced downward trend till 2003.
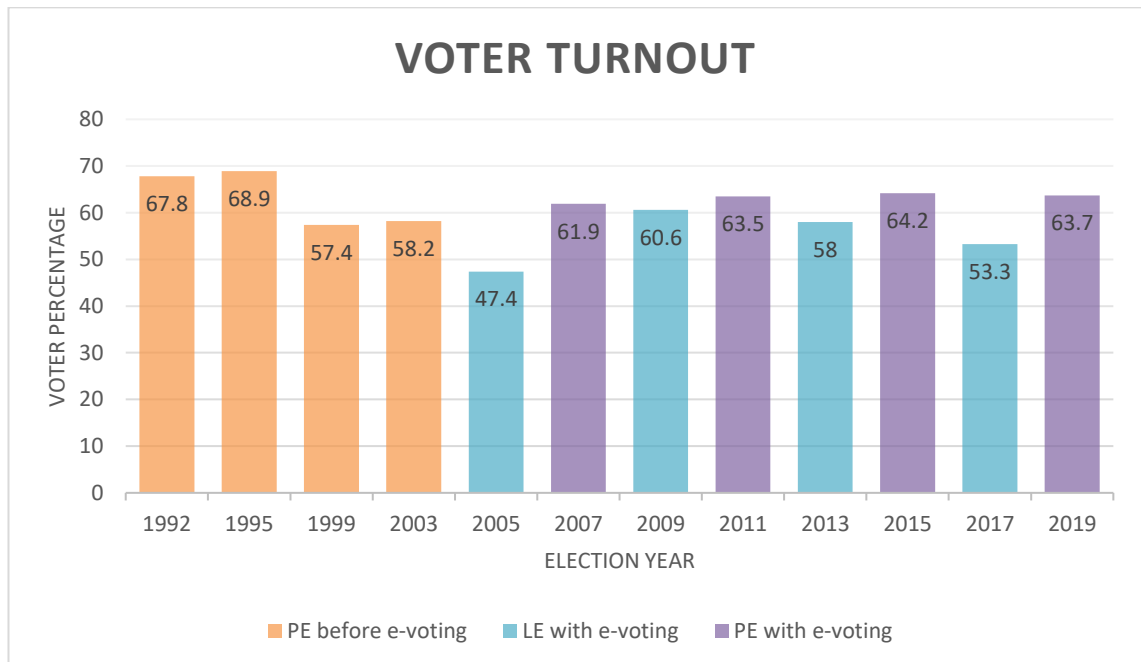

Figure 3. Bar graph showing the voter turnout.

Table 3. Internet voting in Parliamentary Election [16].

Parliamentary Election	E-voters among eligible voters (%)	E-voters among participating voters (%)	E-votes cast abroad among E-votes (%)	Cancelled e-votes (replaced with paper ballot)	Multiple e-votes (replaced with e-vote) %
PE 2019	27.9	43.8	6.3	191	2.6
PE 2015	19.6	30.5	5.7	162	2.6
PE 2011	15.4	24.3	3.9	82	3.1
PE2007	3.4	5.5	2	32	2.6

(source: https://www.valimised.ee/en/archive/statistics-about-internet-voting-estonia)

Table 4. Internet voting in Local election

Local Election	E-voters among eligible voters (%)	E-voters among participating voters (%)	E-votes cast abroad among E-votes (%)	Cancelled e-votes (replaced with paper ballot)	Multiple e-votes (replaced with e-vote) %
LE 2017	16.9	31.7	4.1	163	2.4
LE 2013	12.3	21.2	4.2	146	2.3
LE 2009	9.5	15.8	2.8	100	2.3
LE 2005	0.9	1.91	*n/a	30	3.9

(source: https://www.valimised.ee/en/archive/statistics-about-internet-voting-estonia)

The e-voting was introduced in 2005 local election(LE). Relatively small number of voters used the internet voting or e-voting at that time. The total 9287 votes were counted which was less than 2% of total voters. However, the number has been increaseing in every election. When it was introduced in 2005 LE, only 1.91% voter used it. It reached 5.5%

in PE 2007. Recently 43.8% voter used the e-voting PE 2019. In 2007 e-voting was enabled for the people living abroad. That year, about 2% of all e-votes were from abroad which countinuously grew to reach 6.3% in 2019.

The voters have used the opportunity to change their e-vote both using e-voting and paper ballot. However, very few e-votes were changed using paper ballot.
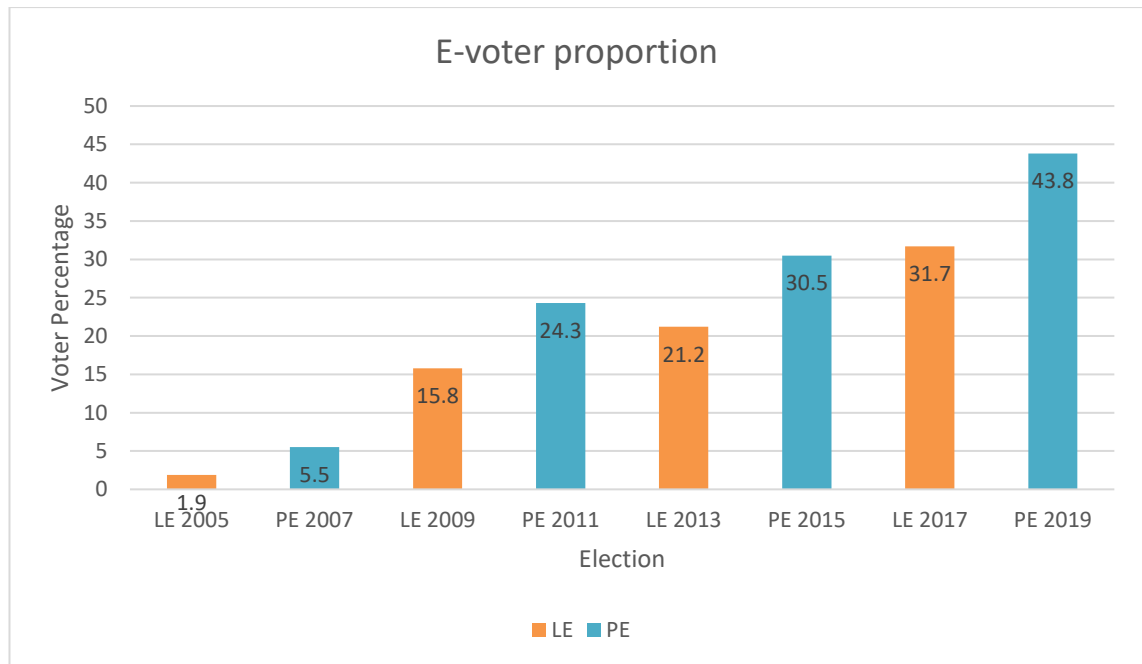

Figure 4. Bar diagram showing e-voter proportion.

The height of the bar has increased every election of same kind. The voter participation in parlriamentary election is greater than that of local election.

Table 5. Turnout in advance voting period

Election	Participating during advance voting	Participating during advance voting (%)	E-voters among advance voting (%)
PE 2019	346409	61.3	71.4
PE 2015	296014	51.2	59.6
PE 2011	250043	43.1	56.3
PE 2007	171518	30.8	17
PE 2003	125389	25.0	n/a
PE 1999	71455	14.5	n/a
PE 1995	125101	22.9	n/a

(source: https://www.valimised.ee/en/archive/statistics)

Advance voting takes place on 10th to 4th day prior to the election day. The voter participation during advanced voting has increased significantly over the years which has helped in reducing the crowed on election day. More than 60% votes were casted during advanced voting during last PE election which is nearly 3 times than in 1995. Three fourth of votes from advanced voting were e-votes which was just 17% when e-voting was first introduced.

The statistics has shown that the introduction of e-voting has managed to overcome the declining voter turnout to some extent, although it has not achieved the likes of 1992 and 1995 yet. E-voting has become convenient option rather than attracting new voters.

5 E-VOTING EXPERIENCES AROUND THE WORLD

5.1 Brazil

Superior Electoral Court (Tribunal Superior Eleitoral, TSE) has been implementing e-voting since 1996. The electronic voting machine is capable of performing voter identification, vote casting and tallying result. Electronic Voting Machine (EVM) is a tough small dimensions, lightweight box with energy independence and security features. Biometric system is used in voter identification and verification since 2012. The voter turnout in 2018 was 79.5% [18].

TSE also funds in research aimed at improving the security. In 2009 it organised the hacking competition to check if there is any loophole. The machine records the vote and the internal shuffling and security mechanisms prevents the voter's privacy. It is no way possible to know which candidate the voter voted. Political parties have the access to the voting machine for auditing.

EVM was designed to meet the following requirements:
Universal solution: Record of the vote by the number of voters, candidates and parties.
User-friendly process: Easy to use by the voter with on-screen visualization of the candidate's data before confirmation of the vote.
Reduced cost: Being the country with large population and high number of polling station EVM was expected to economically viable.
Durability: The possibility of using several elections ultimately reducing the election cost.
Security : Elimination of the possibility of fraud in the registration of the vote and in the tallying the result.

5.2 Finland

In 2008 municipal election, electronic voting was used as pilot project in three municipalities: Karkkila, Kauniainen and Vihti [19]. The voters were allowed to use direct recording voting machine as well as traditional paper ballot at the polling stations under the supervision of election authority. It was found that the dre failed to register 232 votes. The major two issues were noticed. First issue of voter's carelessness, where voter did not press ok button before withdrawal of the voter card. Secondly, system lagging were noticed where touch screen sensitivity was irregular, which took long time to press ok button or to recognize finger.

In 2010, the government decided not to continue e-voting. In 2017, a report was published on the feasibility of the online voting, which suggested that e-voting is technically feasible but the technology is yet not sufficient to the highest level [20].The report suggested not to rush for internet voting, instead wait and observe the progress in other countries. There is the high risk of losing the voters' confidence in the system due to such failure case. Just the simple rumours and false information are enough to change the voters' mind. Such things can be easily spread through internet.

The parliamentary monitoring group concluded that the risk involved are greater than the benefits, thus the use of online voting should not be introduced in general elections. The latest voter turnout in 2019 was 68.73% [18].

5.3 India

India is the largest democracy with around 900 million eligible voters. More than 1 million polling station and 10 million election officials were used in 2019 election. The voter turnout in 2019 was 67.4% [18]. For the accomplishment of the such a large election India has been using EVM since 2000 in all elections. Its first trail was done in 1982 in few selected polling stations in Kerala. The EVM machines are developed and manufactured by Electronic Corporation of India (ECIL) and Bharat Electronic Limited (BEL). Both the companies produce the identical machines.

EVM is a stand alone machine with one time programmable (OTP) chip. Every machine has two parts: control unit and balloting unit connected using the cable. Balloting unit consist of ballot paper screen and button next to each candidates' name candidates' symbol. Control unit is the brain of the machine which is operated by the polling officer. After voter identification of the voter, polling officer activates the ballot unit and the voter can proceed to the cast their vote by pressing the appropriate button and then confirming it. In case of wrong button pressed, voter can press the cancel button and correct it. Once the vote is confirmed the balloting unit is turned off.

5.4 Norway

Norway had the first remote e-voting pilot in 2011 local government election in ten municipalities. The second pilot in 2013 parliamentary election included two more municipalities. The pilots had positive response. About 35 percent of the ballots were casted using e-voting. The political disagreement about the pilots and the lack of political desire to introduce e-voting resulted in discontinuing further pilot projects. [21]

5.5 Switzerland

Switzerland has been testing the remote Internet voting since 2003. Many trails have been successfully conducted in some some cantons. Only limited people living in certain places or abroad have been given an opportunity to use e-voting. E-voting is yet to use nationwide. The voter turnout in 2019 was just 45.12% [18], which is relatively low .
The politicians and computer experts has objected ea-voting subjecting the security reasons. Swiss government organizes the Public Instruction Test (PIT) in order to improve the system. Anyone registered for PIT can legally attack its e-voting system,

and publish their findings. The government has price rewards for different penetration and suggestion like if someone discovers undetectable vote manipulation, server-side privacy, destroyed electronic ballot or pointing out any code that goes against security practices.

5.6 USA

The United States has been using e-voting like DRE voting machine and optical scan system while punch card voting system being abandoned following the 2000 presidential election controversy in Florida. In that election, many ballot cards had incomplete punching which resulted in smaller holes than expected, or the hanging of chad resulting spoilt ballot. Different vendors manufacture the voting machine in USA for different states. Some states have provision of online voting for overseas voters and disabled voters. [4]

6 SECURITY DISCUSSION

In Estonia a private company called Cybernetica has been developing the e-voting system. National Election Committee (NEC) tests the system but do not certify the system. The Estonian People's Union and Estonian Centre Party opposed the remote internet voting because of it's unsupervised nature. Center Party even petitions European human Rights Court [22]. Other political parties expected it to make election easier, convenient and increase voter turnout.

There has not been any documented case of cyber attack or hacking till the date [23]. However, many have raised questions on its integrity. The independent group of e-voting experts published a report on security analysis of e-voting used in Estonia where the team coined major security issues in the system and recommended to withdraw the whole e-voting [24]. According to their report published in 2014, 'I-voting system has serious architectural limitations and procedural gaps that potentially jeopardize the integrity of elections.' [24]. The system was not up to date. State-level cyberattacks could be serious threat to Estonian e-voting. E-voting system was not using end-to-end (E2E) verifiability back then. Rather it involved complicated set of procedure. It heavily relies on voters' computer, server and election staffs. The individual vote verification was introduced in 2013 local election. The voters could check and verify that their vote has been registered as intended. Vote verification implements core element of e2e, that is checking and veryifing by individual voter.

6.1 Server-side attacks

E-voting servers are hosted at government data center. There is always possibility of server-side attack since vote counts are invisible. The international e-voting experts' team demonstrated that vote-stealing malware can be injected by a dishonest election official. The team inserted the infectious code that could change the result.

6.2 Client-side attacks

Estonian system heavily trust the voters' computer as well. The client's computer could be attacked by infecting malware because most of the people do not use proper protection. The attacker's software could steal the voting ID informations and PINs without voter noticing it. Then, those informations could be used to change the e-vote.

Although many countries are successfully implementing various form of e-voting, there are still several challenges. No matter how secure they claim their electronic voting system is, they are only secure until they encounter vulnerability. Some of the common challenges are mentioned as follow.

Cost: The voting machines cost a lot at the begining. Regular maintenance and security and software updates makes it expensive. On the other hand in long term, it saves a lot of paper, human resources and time. Brazil has been earning li pttle from its voting

machines by lending it to the other countries like Paraguay and Ecuador. In Estonia, per Internet vote cost €2.32, while paper ballot vote on election day cost €4.37 and advance voting in Voting District Committees (VDC) cost €20.41 [5] [25].

Vote Buying: Even the use of electronic voting system can not ensure financial discipline. The candidate can bribe or coerce the voter to vote them. The voters' identity must not be included or recorded with the vote, instead vote should be anonymous.

Cheating terminal: A cheating terminal records vote other than a voter's choice.

Cheating Supervisor: A cheating supervisor receives and counts the vote dishonestly.

Cheating Proxy: A cheating proxy could be programmed to change the vote.

Malfunction: The electronics are subjected to different malfunctioning.

User unfriendly: The system interface is difficult to use for the voters with less or zero knowledge.

Overloading attacks, Denial of Service attack (DoS): The network resources are made unavailable by disturbing services of a host connected to the internet.

Physical attacks: This includes physical harm on computer, machine or system.

Legal challenges: Many countries do not have legal provision in their constitutional act. In Germany, the constitutional court declared e-voting unconstitutional after the question on transparency was raised. [2]

7 CONCLUSION

This thesis aimed to study the e-voting system used in Estonia, the impacts it made on voter turnout, spoilt ballots, and overall election. Estonia is the only country to use internet voting in the elections nation-wide. The introduction of e-voting in Estonia has brought about little progress in voter turnout when compared to the last paper-only election in 2003. The increment of 3.7% was achieved in 2007 Parliamentary Election from 58.2% in 2003. The recent election in 2019 had 63.7% turnout. However, the turnout is still lower than their all time highest 68.9% in 1995 Parliamentary Election and still below European average 64.9%. E-voting has not succeed in maintaining constant turnout growth but has had positive impact and has made elections convenient. The number of e-voting users has risen over the time from 5.5% in 2007 to 43.8% in 2019. E-voting has also been able to minimize the invalid ballots and cut off election expenses. From these statistics, it can be concluded that Estonia is experiencing little but positive impact.

However, many countries still have doubts about the integrity and reliability of the e-voting system. Although there has not been noticed any cases of hacking, tampering and cyber-attack, the system is always at such risk. Many countries are observing the progress made by Estonia. Some countries have concluded that the technology has not yet reached its highest point to use. The international e-voting experts' team [24] coined security issues and recommended not to use e-voting. Such reports have raised questions whether to use technology or not. The world is yet not ready to adopt e-voting in its current form. Further development could see the world using it in future though.

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