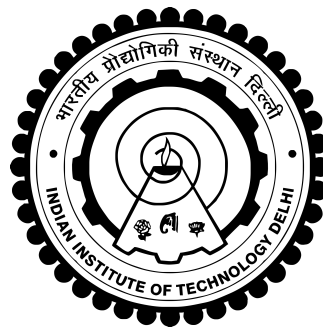


SECURING DEMOCRACIES: BUILDING TRUST IN LARGE PUBLIC ELECTIONS

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
AUGUST 2024

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by

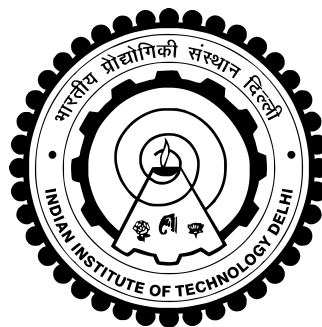
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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



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To the pursuit of knowledge

CERTIFICATE

This is to certify that the thesis titled “**SECURING DEMOCRACIES: BUILDING TRUST IN LARGE PUBLIC ELECTIONS**”, submitted by **Prashant Agrawal**, to the Indian Institute of Technology, Delhi, for the award of the degree of **Doctor of Philosophy**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Prashant Agrawal

ABSTRACT

KEYWORDS: election security, dual voting, recoverability, electoral rolls

This thesis presents innovative advancements to enhance public trust in large public elections, particularly in contexts similar to Indian elections. We develop our proposals based on the concept of dual voting, a hybrid approach combining cryptographic voting techniques with paper audit trails. Dual voting mitigates risks associated with relying solely on either electronic or paper ballots, which is crucial for engendering public trust in large elections.

Our first contribution is a comprehensive analysis of the voter-facing component of various existing voting protocols, identification of their usability and security flaws, and the development of a new dual voting design that addresses these flaws.

Next, we observe that although existing voting protocols are verifiable, they do not provide easy methods of recovery in case verifications fail, at least not without reposing trust on a paper audit trail. We introduce the novel concept of “recoverability” in dual voting systems, proposing mechanisms that allow for effective recovery from audit failures without a complete reliance on either electronic or paper records. Our approach allows selective re-elections in problematic polling stations without necessitating a full re-run of the election. This approach significantly enhances the robustness of the electoral process and maintains public confidence even if there are isolated discrepancies. A technical innovation underlying our recovery protocol is a novel concept we introduce, called “traceable mixnets,” which extends traditional mixnets with the ability to prove special membership relationships between input ciphertexts and output plaintexts of a mixnet in zero-knowledge.

Lastly, we address the so-far overlooked issues of security and privacy of electoral rolls (voter lists) and polling-booth eligibility verification processes. We analyse various threats related to electoral roll manipulation, ballot stuffing, voter denial and voter profiling and propose a protocol that protects against them, ensuring that voters’ identity information is protected from misuse, all eligible voters can fairly participate in the electoral process, and the eligibility verification process is sound, i.e., ballot stuffing is detectable.

Collectively, these contributions not only enhance the technical integrity of voting systems but also address broader concerns about public trust in electoral processes. By bridging the gap between cryptographic security and practical electoral requirements, this work lays a foundation for more secure, transparent, and inclusive democratic elections.

सार

मुख्य शब्द: चुनावी सुरक्षा, द्वैत मतदान, रिकवरेबिलिटी, मतदाता सूची

यह शोध बड़े सार्वजनिक चुनावों में और विशेष रूप से भारतीय चुनावों में जन-साधारण के विश्वास को बढ़ाने के लिए नवीन प्रगतियों को प्रस्तुत करता है। हम अपने प्रस्तावों का विकास द्वैत मतदान की अवधारणा पर आधारित करते हैं, जो कि क्रिप्टोग्राफिक मतदान तकनीकों और कागजी ऑडिट ट्रेल्स को मिलाने वाला एक हाइब्रिड दृष्टिकोण है। द्वैत मतदान केवल इलेक्ट्रॉनिक प्रणालियों या कागजी मतपत्रों पर निर्भर रहने से जुड़े जोखिमों को कम करता है, जो कि बड़े चुनावों में जनता के विश्वास को सुदृढ़ करने के लिए महत्वपूर्ण है।

हम अपने पहले योगदान के तौर पर विभिन्न मौजूदा मतदान प्रोटोकॉलों में मतदाता के अनुभव का व्यापक मूल्यांकन करते हैं, उनकी उपयोगिता और सुरक्षा-दोषों की पहचान करते हैं और इन दोषों को संबोधित करने के लिए एक नए द्वैत मतदान प्रोटोकॉल का विकास करते हैं।

दूसरे, हम पहचानते हैं कि हालांकि मौजूदा मतदान प्रोटोकॉल सत्यापनीय हैं, वे सत्यापन विफल होने की स्थिति में आसान रिकवरी के तरीके प्रदान नहीं करते, कम-से-कम कागजी ऑडिट ट्रेल पर भरोसा किए बिना नहीं। हम द्वैत मतदान में "रिकवरेबिलिटी" की नवीन अवधारणा प्रस्तुत करते हैं और ऐसे तंत्र प्रस्तुत करते हैं जो ऑडिट विफल होने पर प्रभावी रूप से उबरने में सहायक हैं और न तो पूर्ण रूप से इलेक्ट्रॉनिक न ही कागजी रिकॉर्ड्स पर संपूर्णतः निर्भर करते हैं। हमारा दृष्टिकोण ऑडिट विफल होने पर पूरे निर्वाचन क्षेत्र में पुनः चुनाव कराये बिना केवल समस्याग्रस्त मतदान केंद्रों में पुनः मतदान कराने में सहायक है। यह दृष्टिकोण चुनावी प्रक्रिया की दृढ़ता को काफी बढ़ाता है और अलग-थलग विसंगतियों की घटना में भी जनता का विश्वास बनाए रखता है। हमारे रिकवरी प्रोटोकॉल का तकनीकी आधार है "ट्रेसबल मिक्सनेट्स"। यह एक नयी क्रिप्टोग्राफिक तकनीक है जो पारंपरिक मिक्सनेट्स पर आधारित है और मिक्सनेट के इनपुट साइफरटेक्स्ट और आउटपुट प्लेनटेक्स्ट के बीच विशेष सदस्यता संबंधों को साबित कर सकती है, बिना इससे अधिक कोई भी जानकारी दिये।

अंत में, यह शोध चुनावी सुरक्षा में एक और अनसुलझे मुद्दे को संबोधित करता है: मतदाता सूचियों की सुरक्षा और गोपनीयता। हम इस मुद्दे से जुड़ी विभिन्न समस्याओं का विश्लेषण करते हैं, जैसे मतदाता सूचियों में हेरफेर, मतदाताओं का मताधिकार वंचन और मतदाता प्रोफाइलिंग। हम मतदाता सूची बनाने और मतदान के दौरान उनका उपयोग करने में सहायक एक नया प्रोटोकॉल प्रस्तुत करते हैं जो एक तरफ पंजीकरण व मतदाता परीक्षण प्रक्रियाओं को सुरक्षित करता है वहीं दूसरी तरफ मतदाता प्रोफाइलिंग से जुड़ी समस्याओं के प्रति संरक्षण प्रदान करता है। हमारा प्रोटोकॉल सुनिश्चित करता है कि सभी योग्य मतदाता चुनावी प्रक्रिया में निष्पक्ष रूप से भाग ले सकें।

कुल मिला कर, ये सभी योगदान ना सिर्फ चुनावी प्रक्रिया की तकनीकी अखंडता को सुदृढ़ करते हैं बल्कि उनमें जनता के विश्वास को स्थापित करने के मुद्दे को भी उचित रूप से संबोधित करते हैं। इस तरह से यह कार्य क्रिप्टोग्राफिक सुरक्षा और व्यावहारिक चुनावी जरूरतों के बीच के अंतर को पाटते हुए अधिक सुरक्षित, पारदर्शी और समावेशी लोकतांत्रिक चुनावों के लिए एक आधार तैयार करता है।

Contents

CERTIFICATE	i
ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
सार	iv
LIST OF FIGURES	ix
ABBREVIATIONS	x
1 INTRODUCTION	1
1.1 Democracy principles for voting	2
1.2 A brief world history of voting processes	3
1.3 Electoral rolls and eligibility verification	15
1.4 Indian elections	20
1.5 Problem statement	22
1.6 Thesis contributions	23
2 SECURITY FRAMEWORK AND PRIMITIVES	28
2.1 Notation	28
2.2 High-level security framework	29
2.3 Basic number theory	35
2.4 Basic abstract algebra	37
2.5 Hard cryptographic problems	41
2.6 Concrete security	42
2.7 Security primitives	44
3 EXISTING VOTING PROTOCOLS	61
3.1 E2E-V voting backends	61
3.2 E2E-V frontends for pollsite voting	66
3.3 E2E-V frontends for internet voting	83
3.4 Risk-limiting audits	85
3.5 Eligibility verification mechanisms	86
3.6 Real-world deployments of E2E-V systems	86
4 SECURING THE VOTING FRONTEND	88
4.1 High-level structure	88
4.2 Threat model	89
4.3 Design requirements	91
4.4 Analysis of existing frontends	94
4.5 Our proposal	103

4.6	Security analysis	108
4.7	Potential extensions and usability improvements	110
4.8	Chapter summary	111
5	<i>OPENVOTING: RECOVERABILITY FROM FAILURES IN DUAL VOTING</i>	112
5.1	Introduction	112
5.2	Design requirements	113
5.3	Formalisation	116
5.4	The <i>OpenVoting</i> protocol	118
5.5	Security analysis	127
5.6	Chapter summary	128
6	TRACEABLE MIXNETS	130
6.1	Introduction	130
6.2	Formal definitions	137
6.3	Preliminaries	141
6.4	Our construction	145
6.5	Security analysis	153
6.6	Implementation and benchmarks	162
6.7	Chapter summary	165
7	PUBLICLY AUDITABLE YET PRIVATE ELECTORAL ROLLS AND ELIGIBILITY VERIFICATION	166
7.1	Introduction	166
7.2	Design requirements	168
7.3	Formalisation	171
7.4	Preliminaries	179
7.5	Our protocol	180
7.6	The dynamic model	190
7.7	Security analysis	192
7.8	Practicalities	198
7.9	Chapter summary	199
8	CONCLUSION	200
8.1	Summary of contributions	200
8.2	Limitations, challenges and future directions	201
A	APPENDICES TO CHAPTER 6	205
A.1	From honest-but-curious to malicious model	205
A.2	Hybrid experiments for Theorem 5	206
A.3	Secrecy in the malicious model	226

List of Figures

1.1	A DRE+VVPR voting system with risk limiting audits	8
1.2	An E2E-V voting system	10
1.3	The Prêt à voter ballot	10
1.4	An Indian EVM	21
1.5	Traditional vs. traceable mixnets	25
2.1	The EUF-CMA experiment for digital signatures and the IND-CPA experiment for public-key encryption	31
2.2	The ideal/real security paradigm	33
2.3	The reduction proof technique	34
2.4	The El Gamal and Paillier encryption schemes	46
2.5	Σ -protocol for proving knowledge of discrete logarithm	53
3.1	A decryption mixnet	63
3.2	A re-encryption mixnet	63
3.3	Randomised partial checking	64
3.4	The Punchscan ballot	67
3.5	Backend processing and verification in Punchscan	68
3.6	The Scantegrity I ballot	69
3.7	The Scantegrity II ballot	70
3.8	The Scantegrity III ballot	71
3.9	The Prêt à voter ballot	72
3.10	The Scratch & Vote ballot	73
3.11	ThreeBallot	75
3.12	The STAR vote system	76
3.13	The Wombat voting system	77
3.14	The Markpledge system	78
3.15	Bingo voting	79
3.16	Benaloh's VopScan	80
3.17	Prêt à voter with human-readable paper audit trail	81
3.18	Sigma ballots	83
4.1	Our target dual voting protocol structure.	89
4.2	Comparison of frontend designs of existing polling-booth E2E-V voting protocols	95
4.3	Our basic ballot design	104
4.4	Modified voter workflow to prevent randomisation attacks	106
5.1	A recoverable dual voting protocol design	114
5.2	Potential disputes and failures in a dual voting protocol	115
5.3	Overview of the <i>OpenVoting</i> protocol	121
5.4	The distributed ballot generation process	124
5.5	The BallotGen protocol for generating a ballot	125
5.6	The Tally protocol	125

5.7	The Audit protocol	126
6.1	Traditional vs. traceable mixnets	131
6.2	Additional information leak in TraceIn/TraceOut queries via proofs of shuffle and verifiable decryption techniques	133
6.3	Completeness experiment for traceable mixnets	139
6.4	Soundness experiment for traceable mixnets	139
6.5	Secrecy experiment for traceable mixnets	141
6.6	Single prover ZKP of reverse set membership	147
6.7	A summary of our traceable mixnet construction	148
6.8	Our traceable mixnet construction	149
6.9	Protocol DB-SM	150
6.10	Protocol DB-RSM	151
6.11	Extractor $\mathcal{E}$ for the soundness of DB-RSM	156
6.12	Rules for privacy risk analysis of a given set Q of TraceIn/TraceOut queries	161
6.13	Performance of DB-SM and DB-RSM	164
7.1	Relationship between our electoral roll protocol and traditional E2E-V voting protocols	174
7.2	Soundness experiment	177
7.3	Outputs published in our protocol (the static model)	180
7.4	The Setup protocol	182
7.5	The Register protocol, IndRAudit protocol and ERR audit steps of the UnivAudit protocol	183
7.6	The PrepER protocol and PrepER audit steps of the UnivAudit protocol	186
7.7	The Cast protocol, IndCAudit protocol and ER audit steps of the UnivAudit protocol	188
7.8	The dynamic model	191
8.1	A graphical summary of the contributions of this thesis	201
A.1	Secrecy of our traceable mixnet construction: Hybrid experiment E_1	206
A.2	Secrecy of our traceable mixnet construction: Hybrid experiment E_2	207
A.3	Secrecy of our traceable mixnet construction: Hybrid experiment E_3	208
A.4	Secrecy of our traceable mixnet construction: Hybrid experiment E_4	209
A.5	Secrecy of our traceable mixnet construction: Hybrid experiment E_5	210
A.6	Secrecy of our traceable mixnet construction: Hybrid experiment E_6	211
A.7	Secrecy of our traceable mixnet construction: Hybrid experiment E_7	212
A.8	Secrecy of our traceable mixnet construction: Hybrid experiment E_8	213
A.9	Secrecy of our traceable mixnet construction: Hybrid experiment E_9	214
A.10	Secrecy of our traceable mixnet construction: Hybrid experiment E_{10}	215
A.11	Secrecy of our traceable mixnet construction: Hybrid experiment E_{11}	216
A.12	Secrecy of our traceable mixnet construction: Hybrid experiment E_{12}	217
A.13	Secrecy of our traceable mixnet construction: Hybrid experiment E_{13}	218
A.14	Secrecy of our traceable mixnet construction: Hybrid experiment E_{13} with some details abstracted out	219
A.15	Secrecy of our traceable mixnet construction: Hybrid experiment E_{14}	220
A.16	Secrecy of our traceable mixnet construction: Hybrid experiment E_{15}	221
A.17	Secrecy of our traceable mixnet construction: Hybrid experiment E_{16}	222

A.18	Secrecy of our traceable mixnet construction: Hybrid experiment E_{17}	. . .	223
A.19	Secrecy of our traceable mixnet construction: Hybrid experiment E_{18}	. . .	224
A.20	Secrecy of our traceable mixnet construction: Hybrid experiment E_{19}	. . .	225

ABBREVIATIONS

BMD	Ballot Marking Device
CDH	Computational Diffie-Hellman
DB-RSM	Distributed Batched Reverse Set Membership
DB-SM	Distributed Batched Set Membership
DCR	Decisional Composite Residuosity
DDH	Decisional Diffie-Hellman
DL	Discrete Logarithm
DPK	Distributed Proof of Knowledge
DRE	Direct Recording Electronic
E2E-V	End-to-End Verifiable
EA	Election Authority
ECI	Election Commission of India
EO	Eligibility Officer
ER	Electoral Roll
ERR	Encrypted Registration Request(s)
EUFCMA	Existential Unforgeability under Chosen Message Attacks
EV	Encrypted Vote(s)
EVM	Electronic Voting Machine
GCD	Greatest Common Divisor
HRPAT	Human-Readable Paper Audit Trail
IND-CPA	Indistinguishability under Chosen Plaintext Attacks
ITM	Interactive Turing Machine
NIZK	Non-interactive Zero Knowledge
NIZKPK	Non-interactive Zero-Knowledge Proof(s) of Knowledge
OSV	Optical Scan Voting
PK/PoK	Proof(s) of Knowledge
PO	Polling Officer
PPT	Probabilistic Polynomial Time
RLA	Risk-Limiting Audit(s)
RO	Registration Officer
RPC	Randomised Partial Checking
RSA	Rivest-Shamir-Adleman (the cryptosystem)
SDH	Strong Diffie-Hellman
TM	Turing Machine
TTP	Trusted Third Party
VVPAT	Voter Verified Paper Audit Trail
VVPR	Voter Verified Paper Record
ZKP	Zero-Knowledge Proof(s)
ZKPoK	Zero-Knowledge Proof(s) of Knowledge
zkSNARK	Zero-Knowledge Succinct Non-interactive Argument(s) of Knowledge