

Contents

Foreword	xi
Preface	xiii
Summary	xvii
List of Figures	xxiii
1 Introduction	1
1.1 Digital certificates and PKIs	1
1.1.1 From paper-based to digital certificates	1
1.1.2 Identity certificates	3
1.1.3 Central database paradigm	6
1.1.4 Attribute certificates	9
1.1.5 Certificate revocation and validation	13
1.1.6 Smartcard integration	15
1.2 Privacy issues	20
1.2.1 Privacy dangers	20
1.2.2 Previous privacy-protection efforts and their shortcomings	25
1.2.3 Desirable privacy properties	30
1.3 Outlook	32
1.3.1 Basic building blocks	32
1.3.2 Additional privacy techniques	34
1.3.3 Security techniques	35
1.3.4 Smartcard integration	37
1.3.5 Security and privacy guarantees	39
1.3.6 Applicability	40
2 Cryptographic Preliminaries	41
2.1 Notation, terminology, and conventions	41
2.1.1 Basic notation	41

2.1.2	Algorithms, security parameters, and probability	42
2.1.3	Interactive algorithms and protocols	44
2.1.4	Attack models	45
2.1.5	Security reductions and the random oracle model	48
2.2	One-way functions	49
2.2.1	Definition	49
2.2.2	The DL function	51
2.2.3	The RSA function	56
2.3	Collision-intractable functions	58
2.3.1	Definition	58
2.3.2	The DLREP function	59
2.3.3	The RSAREP function	62
2.3.4	Comparison	65
2.4	Proofs of knowledge	66
2.4.1	Definition	66
2.4.2	Security for the prover	67
2.4.3	Proving knowledge of a DL-representation	71
2.4.4	Proving knowledge of an RSA-representation	75
2.5	Digital signatures	77
2.5.1	Definition	77
2.5.2	From proofs of knowledge to digital signature schemes	79
2.5.3	Digital signatures based on the DLREP function	81
2.5.4	Digital signatures based on the RSAREP function	84
2.6	Digital certificates	86
2.6.1	Definition of public-key certificates	86
2.6.2	Definition of secret-key certificates	87
2.6.3	Comparison	89
2.7	Bibliographic notes	90
3	Showing Protocols with Selective Disclosure	91
3.1	Introduction	91
3.2	How to commit	92
3.3	Formulae with zero or more “AND” connectives	93
3.3.1	Technique based on the DLREP function	93
3.3.2	Technique based on the RSAREP function	105
3.4	Formulae with one “NOT” connective	108
3.4.1	Technique based on the DLREP function	108
3.4.2	Technique based on the RSAREP function	118
3.5	Atomic formulae connected by “OR” connectives	119
3.5.1	Technique based on the DLREP function	119
3.5.2	Technique based on the RSAREP function	123
3.6	Demonstrating arbitrary Boolean formulae	123

3.6.1	Technique based on the DLREP function	123
3.6.2	Technique based on the RSAREP function	126
3.7	Optimizations and extensions	128
3.8	Bibliographic notes	130
4	Restrictive Blind Issuing Protocols	131
4.1	Restrictive blinding	131
4.2	Practical constructions	134
4.2.1	Restrictive blinding based on the DLREP function	135
4.2.2	Restrictive blinding based on the RSAREP function	139
4.2.3	Comparison	140
4.3	Analysis	146
4.3.1	Completeness	146
4.3.2	Privacy for the receiver	147
4.3.3	Security for the Certificate Authority	149
4.3.4	Additional properties	160
4.4	Parallelization of protocol executions	162
4.4.1	Masking the initial witness	163
4.4.2	Swapping exponents in the verification relation	166
4.5	Other certificate schemes	171
4.5.1	DSA-like certificates	171
4.5.2	Certificates based on Chaum-Pedersen signatures	175
4.6	Bibliographic notes	178
5	Combining Issuing and Showing Protocols	181
5.1	Integration	181
5.1.1	Making the match	181
5.1.2	Coping with delegation	185
5.2	Privacy improvements for certificate holders	189
5.2.1	Issuing protocol techniques	189
5.2.2	Showing protocol techniques	191
5.3	Privacy improvements for certificate verifiers	193
5.4	Limited-show certificates	197
5.4.1	Static one-show certificates	197
5.4.2	Dynamic one-show certificates	201
5.4.3	Increasing the threshold	207
5.5	Security improvements	208
5.5.1	Benefits of encoding identifiers	208
5.5.2	How to discourage lending	211
5.5.3	Non-repudiation	212
5.5.4	How to discourage discarding	213
5.5.5	Guarding the secret key of the Certificate Authority	213

5.6	Bibliographic notes	216
6	Smartcard Integration	219
6.1	Shortcomings of the smartcard-only paradigm	219
6.1.1	Privacy dangers	219
6.1.2	Other shortcomings	223
6.2	Combining smartcards and software-only devices	224
6.2.1	Benefits	225
6.2.2	How not to cope with subliminal channels	227
6.3	Secure smartcard integration	230
6.3.1	Technique based on the DLREP function	230
6.3.2	Technique based on the RSAREP function	236
6.4	Privacy protection	238
6.4.1	Inflow prevention	239
6.4.2	Outflow prevention	240
6.4.3	Prevention of other data leakage channels	242
6.4.4	Restricting the level of privacy protection	245
6.5	Other techniques	247
6.5.1	Implementation in low-cost smartcards	248
6.5.2	Returning certificates	250
6.5.3	How to discourage remote lending	251
6.5.4	Bearer certificates	252
6.5.5	Loose ends	253
6.6	Bibliographic notes	254
	Epilogue: The Broader Perspective	257
	References	273
	Curriculum Vitae	307
	Index	307