

Contents

Foreword	xi
David POINTCHEVAL	
Chapter 1. Public-Key Encryption and Security Notions	1
Nuttapong ATTRAPADUNG and Takahiro MATSUDA	
1.1. Basic definitions for PKE	2
1.1.1. Basic notation	2
1.1.2. Public-key encryption	2
1.1.3. IND-CPA and IND-CCA security	2
1.1.4. Other basic security notions and relations	4
1.2. Basic PKE schemes	5
1.2.1. Game-based proofs	5
1.2.2. ElGamal encryption	6
1.2.3. Simplified CS encryption	8
1.2.4. Cramer–Shoup encryption	11
1.2.5. Other specific PKE schemes	14
1.3. Generic constructions for IND-CCA secure PKE	16
1.3.1. Hybrid encryption	17
1.3.2. Naor–Yung construction and extensions	19
1.3.3. Fujisaki–Okamoto and other transforms in the RO model	21
1.3.4. Other generic constructions for IND-CCA secure PKE	23
1.4. Advanced topics	25
1.4.1. Intermediate notions related to CCA	25
1.4.2. IND-CCA security in multi-user setting and tight security	26
1.4.3. Key-dependent message security	28
1.4.4. More topics on PKE	30
1.5. References	31

Chapter 2. Signatures and Security Notions	47
Marc FISCHLIN	
2.1. Signature schemes	47
2.1.1. Definition	47
2.1.2. Examples of practical schemes	49
2.2. Unforgeability	51
2.2.1. Discussion	51
2.2.2. Existential unforgeability under chosen-message attacks	53
2.2.3. Unforgeability of practical schemes	54
2.3. Strong unforgeability	56
2.3.1. Discussion	56
2.3.2. Strong existential unforgeability under chosen-message attacks	57
2.3.3. Strong unforgeability of practical schemes	58
2.3.4. Building strongly unforgeable schemes	59
2.4. Summary	60
2.5. References	60
Chapter 3. Zero-Knowledge Proofs	63
Ivan VISCONTI	
3.1. Introduction	63
3.2. Notation	64
3.3. Classical zero-knowledge proofs	64
3.3.1. Zero knowledge	65
3.4. How to build a zero-knowledge proof system	68
3.4.1. ZK proofs for all \mathcal{NP}	70
3.4.2. Round complexity	71
3.5. Relaxed security in proof systems	72
3.5.1. Honest-verifier ZK	72
3.5.2. Witness hiding/indistinguishability	73
3.5.3. Σ -Protocols	74
3.6. Non-black-box zero knowledge	75
3.7. Advanced notions	75
3.7.1. Publicly verifiable zero knowledge	76
3.7.2. Concurrent ZK and more	77
3.7.3. ZK with stateless players	78
3.7.4. Delayed-input proof systems	79
3.8. Conclusion	80
3.9. References	80

Chapter 4. Secure Multiparty Computation	85
Yehuda LINDELL	
4.1. Introduction	85
4.1.1. A note on terminology	87
4.2. Security of MPC	87
4.2.1. The definitional paradigm	87
4.2.2. Additional definitional parameters	89
4.2.3. Adversarial power	89
4.2.4. Modular sequential and concurrent composition	91
4.2.5. Important definitional implications	92
4.2.6. The ideal model and using MPC in practice	92
4.2.7. Any inputs are allowed	92
4.2.8. MPC secures the process, but not the output	92
4.3. Feasibility of MPC	93
4.4. Techniques	94
4.4.1. Shamir secret sharing	94
4.4.2. Honest-majority MPC with secret sharing	95
4.4.3. Private set intersection	97
4.4.4. Threshold cryptography	99
4.4.5. Dishonest-majority MPC	100
4.4.6. Efficient and practical MPC	100
4.5. MPC use cases	101
4.5.1. Boston wage gap (Lapets et al. 2018)	101
4.5.2. Advertising conversion (Ion et al. 2017)	101
4.5.3. MPC for cryptographic key protection (Unbound Security; Sepior; Curv)	101
4.5.4. Government collaboration (Sharemind)	102
4.5.5. Privacy-preserving analytics (Duality)	102
4.6. Discussion	102
4.7. References	103
Chapter 5. Pairing-Based Cryptography	107
Olivier BLAZY	
5.1. Introduction	108
5.1.1. Notations	108
5.1.2. Generalities	108
5.2. One small step for man, one giant leap for cryptography	109
5.2.1. Opening Pandora’s box, demystifying the magic	110
5.2.2. A new world of assumptions	112
5.3. A new world of cryptographic protocols at your fingertips	116
5.3.1. Identity-based encryption made easy	117

5.3.2. Efficient deterministic compact signature	118
5.4. References	119
Chapter 6. Broadcast Encryption and Traitor Tracing	121
Duong HIEU PHAN	
6.1. Introduction	121
6.2. Security notions for broadcast encryption and TT	123
6.3. Overview of broadcast encryption and TT	125
6.4. Tree-based methods	129
6.5. Code-based TT	132
6.6. Algebraic schemes	135
6.7. Lattice-based approach with post-quantum security	142
6.8. References	143
Chapter 7. Attribute-Based Encryption	151
Romain GAY	
7.1. Introduction	151
7.2. Pairing groups	152
7.2.1. Cyclic groups	152
7.2.2. Pairing groups	152
7.3. Predicate encodings	153
7.3.1. Definition	153
7.3.2. Constructions	154
7.4. Attribute-based encryption	156
7.4.1. Definition	156
7.4.2. A modular construction	158
7.5. References	165
Chapter 8. Advanced Signatures	167
Olivier SANDERS	
8.1. Introduction	167
8.2. Some constructions	169
8.2.1. The case of scalar messages	169
8.2.2. The case of non-scalar messages	171
8.3. Applications	173
8.3.1. Anonymous credentials	173
8.3.2. Group signatures	176
8.3.3. Direct anonymous attestations	180
8.4. References	184

Chapter 9. Key Exchange	187
Colin BOYD	
9.1. Key exchange fundamentals	187
9.1.1. Key exchange parties	188
9.1.2. Key exchange messages	189
9.1.3. Key derivation functions	189
9.2. Unauthenticated key exchange	191
9.2.1. Formal definitions and security models	191
9.2.2. Constructions and examples	192
9.3. Authenticated key exchange	194
9.3.1. Non-interactive key exchange	195
9.3.2. AKE security models	196
9.3.3. Constructions and examples	200
9.4. Conclusion	206
9.5. References	207
Chapter 10. Password Authenticated Key Exchange: Protocols and Security Models	213
Stanislaw JARECKI	
10.1. Introduction	213
10.2. First PAKE: EKE	215
10.3. Game-based model of PAKE security	218
10.3.1. The BPR security model	218
10.3.2. Implicit versus explicit authentication	221
10.3.3. Limitations of the BPR model	221
10.3.4. EKE instantiated with Diffie–Hellman KE	223
10.3.5. Implementing ideal cipher on arbitrary groups	224
10.4. Simulation-based model of PAKE security	225
10.4.1. The BMP security model	225
10.4.2. Advantages of BMP definition: arbitrary passwords, tight security	229
10.4.3. EKE using RO-derived one-time pad encryption	230
10.4.4. BMP model for PAKE with explicit authentication (PAKE-EA)	231
10.5. Universally composable model of PAKE security	232
10.6. PAKE protocols in the standard model	236
10.7. PAKE efficiency optimizations	239
10.8. Asymmetric PAKE: PAKE for the client-server setting	242
10.9. Threshold PAKE	244
10.10. References	246

Chapter 11. Verifiable Computation and Succinct Arguments for NP	257
Dario FIORE	
11.1. Introduction	257
11.1.1. Background	258
11.2. Preliminaries	259
11.3. Verifiable computation	260
11.4. Constructing VC	261
11.4.1. VC for circuits in three steps	261
11.4.2. Succinct non-interactive arguments for non-deterministic computation	263
11.4.3. Verifiable computation from SNARG	264
11.5. A modular construction of SNARGs	264
11.5.1. Algebraic non-interactive linear proofs	265
11.5.2. Bilinear groups	267
11.5.3. SNARGs from algebraic NILPs with degree-2 verifiers using bilinear groups	269
11.6. Constructing algebraic NILPs for arithmetic circuits	271
11.6.1. Arithmetic circuits	271
11.6.2. Quadratic arithmetic programs	271
11.6.3. Algebraic NILP for QAPs	274
11.7. Conclusion	279
11.8. References	279
List of Authors	283
Index	285