Functional Encryption & Homomorphic Encryption for RIOT

Experiences with Benchmarking Advanced Cryptography in RIOT

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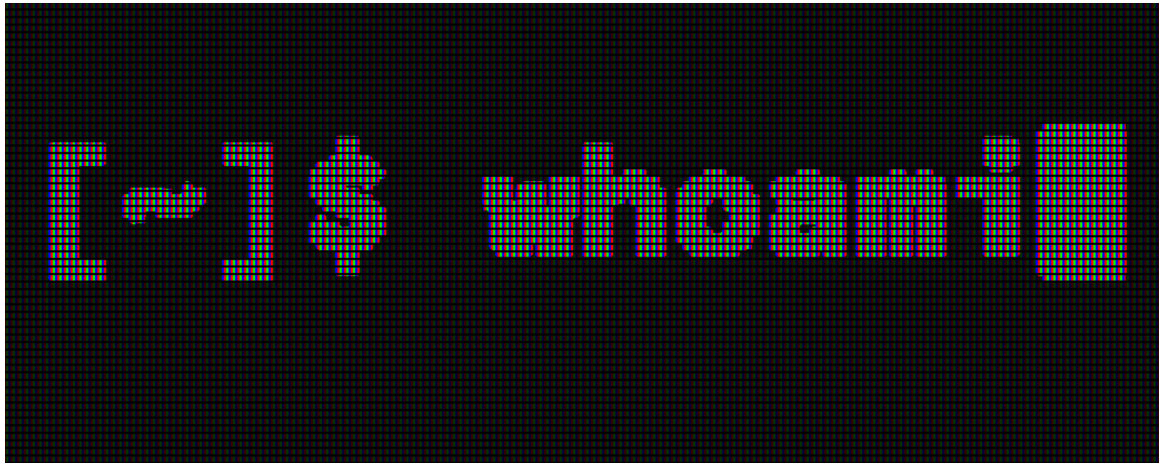
Bio

- Max Pengrin
- B. Sc. Computer Science
- Prospective M. Sc. IT-Security
- Academic Associate at HFT Stuttgart, SensAR

Sensory data and augmented reality, a research project at HFT Stuttgart sponsored by the Carl-Zeiss-Foundation (https://www.hft-stuttgart.com/research/projects/current/sensar)



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[~]$ whoami
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Overview of this Talk

- Objectives of our Work
- Introduction to selected Crypto Schemes and their Applicability to IoT-Scenarios
- Such special Crypto Schemes in RIOT
- Benchmarking Challenges and initial results
- Lessons Learned
- Outlook & Future Work

Advances in the Crypto-Community

- Many specific crypto schemes have been developed beyond traditional symmetric/asymmetric crypto (AES, RSA)
  - E.g. Secure multiparty computation, proxy re-encryption, functional encryption, homomorphic encryption, quantum-proof encryption, …
  - Each of these offer useful properties/features for many IoT scenarios
  - Mostly theoretic work by the formal crypto community, but some prototype implementations exist

→ There is still a lack of **systematic exploration** and a thorough evaluation of the actual scalability and performance of these approaches, in particular on **restricted IoT-nodes**

Objectives

- Our goals …
  - **Closing the gap between the theoretical cryptography community** (i.e. mathematical proofs) **and the network security community** (i.e. applied cryptography in actual real-world systems)
  - Working out ready-to-use applied cryptography solutions that **make special crypto usable in RIOT** and **providing performance estimations** to the IoT community
- Current Work and Focus
  - Functional and Homomorphic encryption
  - Enabling comparable benchmarking for various such schemes under RIOT

Functional Encryption

Identity-based Encryption (IBE)

- Allows anyone to generate a public key for some entity based on an ASCII string
  - No need to retrieve public keys / certificates for encryption
  - Receiving entity receives corresponding private key for decryption from special trusted third party

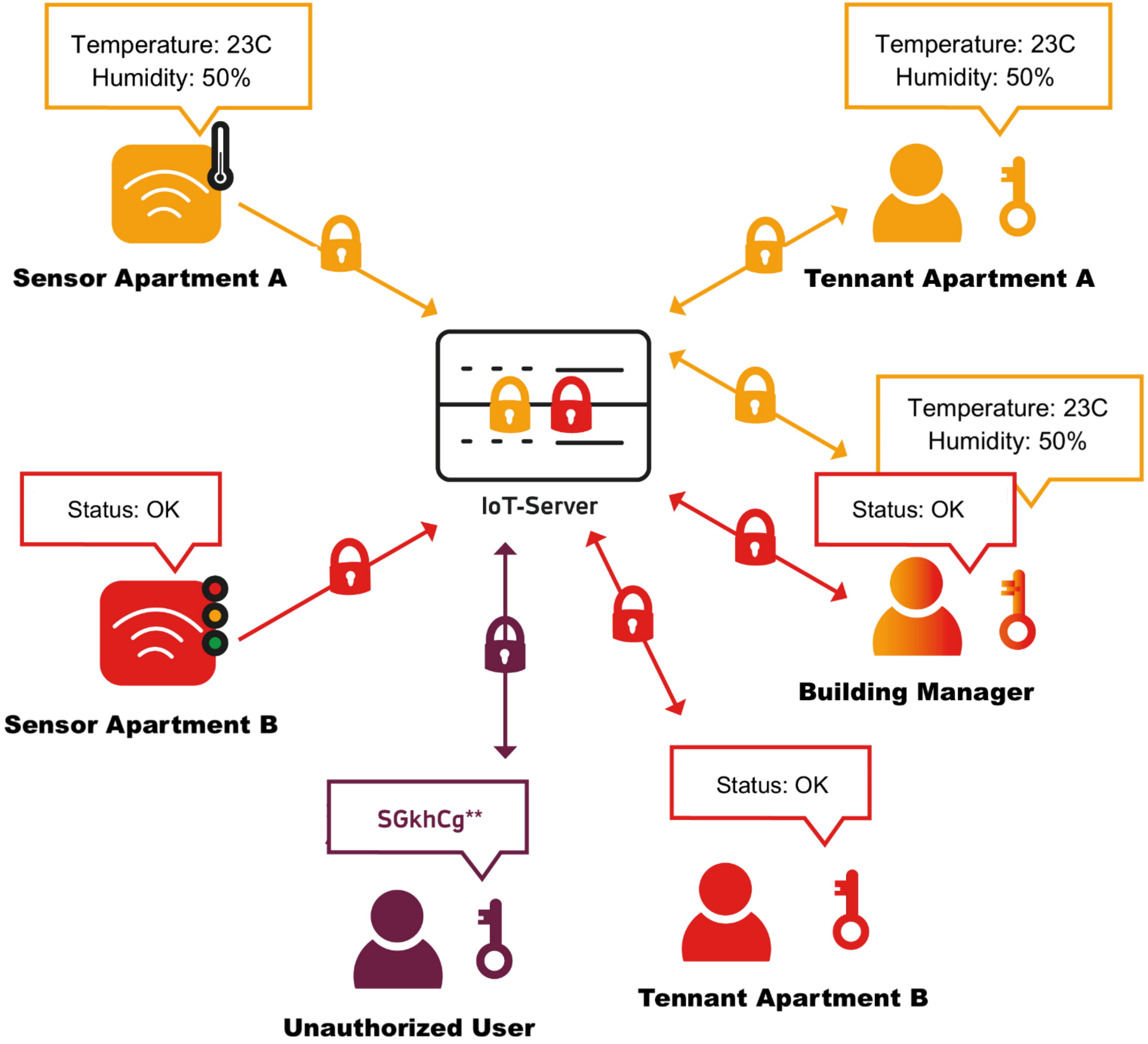
➢ **IoT nodes can encrypt different data for various receivers without the need to retrieve / store multiple public keys**

Attribute-based Encryption (ABE)

- Allows to encrypt data with a policy attached
  - Example policy: (level = manager OR department = C)
- Only entities whose private key matches the policy can decrypt the data

➢ **Very useful for IoT as a means for enabling Data-Centric Security** (Content Object Security)

- **Access policy is included in the data itself**
- Access policy can be specified at data production time in an abstract way without knowing the exact identities of consumers



IoT Example: Attribute-based Encryption (ABE)

Homomorphic Encryption

- Applying some mathematical function on encrypted data
- Crypto community is working hard on enabling fully-homomorphic encryption (FHE)
  - I.e. using any mathematical function
  - Not realistic for IoT devices anytime soon from a performance perspective …
- But: **partially homomorphic** encryption may be feasible on IoT nodes
  - E.g., homomorphic addition $e(x) + e(y) = e(x + y)$
  - E.g., homomorphic multiplication $e(x) \times e(y) = e(x \times y)$

  $\Big\}$ $with$ $encryption\,function\; e(x)$
- Example IoT Use Case
  - Sensor node A can forward encrypted data to next sensor node B, which can add its encrypted data without reading sensor A's value; sink node can decrypt the sum (and calculate the average)
  - Zero-Knowledge Computation - out-sourcing of computational task, etc. more use cases imaginable

Integrating Functional and Homomorphic Encryption in RIOT?

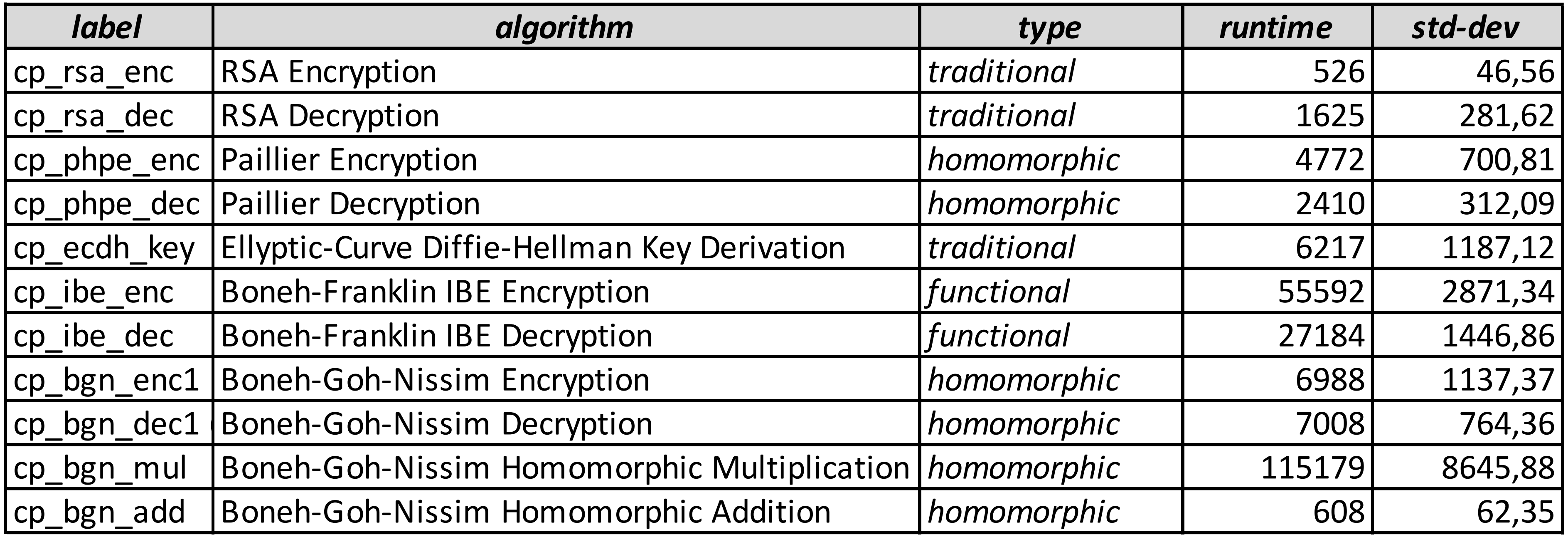
- Several open source libraries exist, but:
    - Some outdated / not maintained
        - E.g. last commit over 2 years old
    - Some not suitable for RIOT
        - E.g. using non-supported programming language
        - E.g. using dynamic memory allocation
- What had been done?
    - Relic toolkit
    - Palisade (FHE, ABE, C++)
    - Paring-based Library Stanford (just one example w\ IBE)
    - SEAL Microsoft (>2GB RAM)
    - TFHE: Fast Fully Homomorphic Encryption (requires x86_64)
    - Many more in development (ibm, google, helib)
- What to do?

~~Integrating~~ Functional and Homomorphic Encryption in RIOT

- What's *done* **in RIOT**?
  - Relic toolkit
    - Developed with embedded in mind
    - Supports many interesting special crypto schemes that have not been investigated in depth in RIOT
      - "Cryptographic protocols (RSA, Rabin, ECDSA, ECMQV, ECSS (Schnorr), ECIES, Sakai-Ohgishi-Kasahara ID-based authenticated key agreement, Boneh-Lynn-Schacham and Boneh-Boyen short signatures, Paillier and Benaloh homomorphic encryption systems)"
    - RELIC already used/integrated in RIOT - Available as a plugin

Repository and Image: https://github.com/relic-toolkit/relic

Some Initial Results



label	*algorithm*	*type*	*runtime*	*std-dev*
cp_rsa_enc	RSA Encryption	*traditional*	526	46,56
cp_rsa_dec	RSA Decryption	*traditional*	1625	281,62
cp_phpe_enc	Paillier Encryption	*homomorphic*	4772	700,81
cp_phpe_dec	Paillier Decryption	*homomorphic*	2410	312,09
cp_ecdh_key	Ellyptic-Curve Diffie-Hellman Key Derivation	*traditional*	6217	1187,12
cp_ibe_enc	Boneh-Franklin IBE Encryption	*functional*	55592	2871,34
cp_ibe_dec	Boneh-Franklin IBE Decryption	*functional*	27184	1446,86
cp_bgn_enc1	Boneh-Goh-Nissim Encryption	*homomorphic*	6988	1137,37
cp_bgn_dec1	Boneh-Goh-Nissim Decryption	*homomorphic*	7008	764,36
cp_bgn_mul	Boneh-Goh-Nissim Homomorphic Multiplication	*homomorphic*	115179	8645,88
cp_bgn_add	Boneh-Goh-Nissim Homomorphic Addition	*homomorphic*	608	62,35

Runtime of various crypto schemes under RIOT
(RIOT-native on i7 CPU, results in µs)

Benchmarking Challenges

- Relic build-in benchmarks not supported in RIOT
  - partly hardcoded parameters
  - Me = Noob - no development background
- Ongoing work on harmonizing keylengths etc. to enable comparable benchmarking of different algorithms
  - two types of keys at the same time elliptic curve- & prime-based
  - Key length != Key length; Securitybits?
- Repository: https://github.com/maksim-ka/RIOT_Projects

Lessons Learned

- Memory is crucial, also Power usage (but not necessarily in our usecases), Architecture, Library jungle, Buildsystems are hard ...etc. pp.
- RIOT-OS is nice, because...
  - Process managing
  - Drivers
  - Plugins
- More mainstream like/newbie-friendly access would be appreciated
  - Vscode extension (out of the box debugging)
  - Arduino-Code/Libs, PlatformIO support
- Thanks to the friendly 😉 RIOT community for help in getting started
  - Special thanks to Peter Kietzmann for lots of initial assistance!

Outlook and Future Work

Ongoing Work

- Harmonizing benchmarking among various crypto schemes
- Running large-scale experiments on FIT-IoT-Lab

Future Work

- Have students run experiments on IoT hardware
  - at HFT Stuttgart security lab
- Integrate more advanced crypto into RIOT
  - Find suitable crypto-libs / open-source implementations
  - With interesting crypto-schemes (e.g. quantumproof-crypto)