aSSIsT:
Software Security
for the IoT

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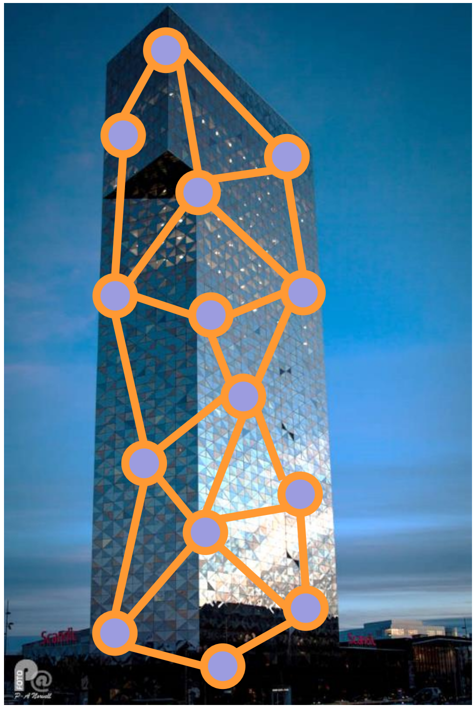
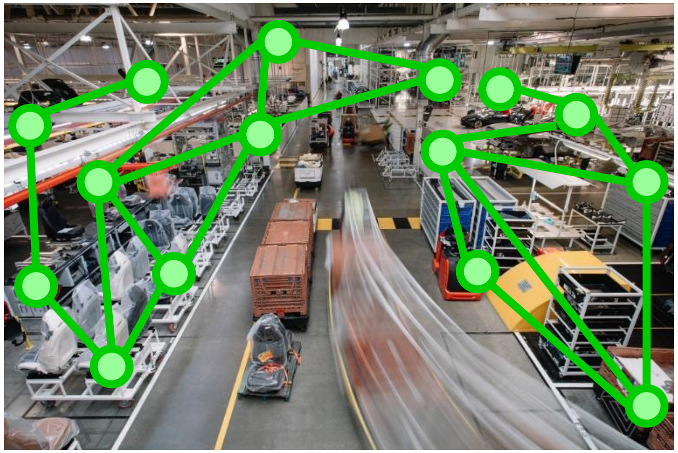
Internet of Things (IoT)



Tens of billions
of connected devices
by 2020?



- Requirements
  - Reliability
  - Long lifetime, low cost
  - Interoperability
  - **Security**

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Security in the IoT

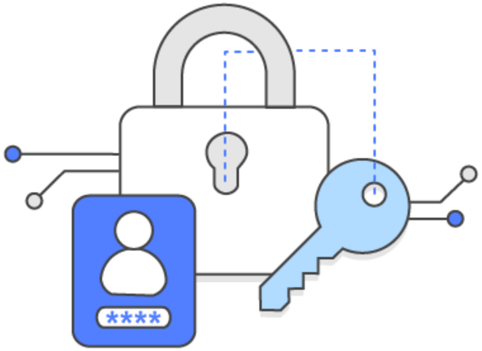
- Recent attacks on IoT networks
  - Takeover of entire IoT networks [Mirai, Linux.Darlloz]
  - Unauthorized control of nodes [Zigbee War-flying]
- Infections spread rapidly and enable coordinated attacks
- Security must be prime concern

Security involves many aspects

- Software

Focus of aSSIsT

- Communication
- Physical Access
- System management
- ....



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aSSIsT: Secure Software for IoT

Project duration: 2018-2023, https://assist-project.github.io
Funding: Swedish Foundation for Strategic Research (SSF)

Challenge

Develop techniques for
making IoT software resilient against security attacks

Participating Groups

IT department, Uppsala University

- Verification group [Bengt Jonsson, Parosh Abdulla, Mohammed Faouzi Atig]
- Programming language technology group [Kostis Sagonas, Tobias Wrigstad]

RISE SICS, Kista

- Networked embedded systems groups [Simon Duquennoy, Luca Mottola, Thiemo Voigt]
- Security lab [Shahid Raza, Ludwig Seitz]

Reference group of SMEs with IoT software development

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The IoT OS Landscape

RIOT

Apache mynewt

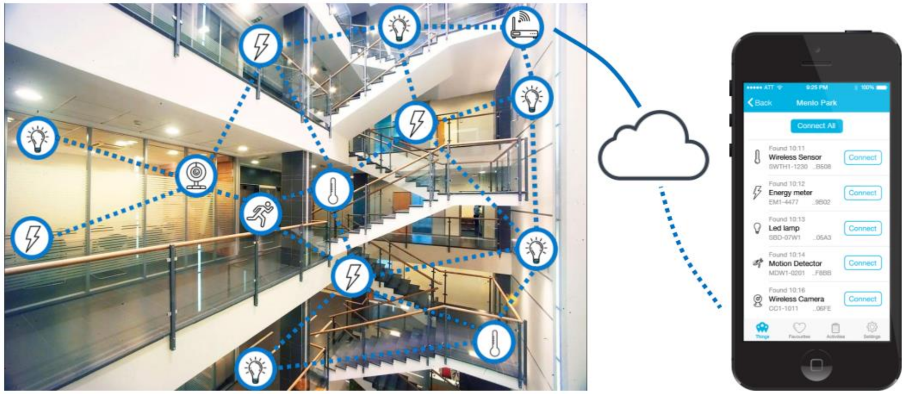
arm MBED

Contiki NG

Zephyr

Introducing Contiki-NG

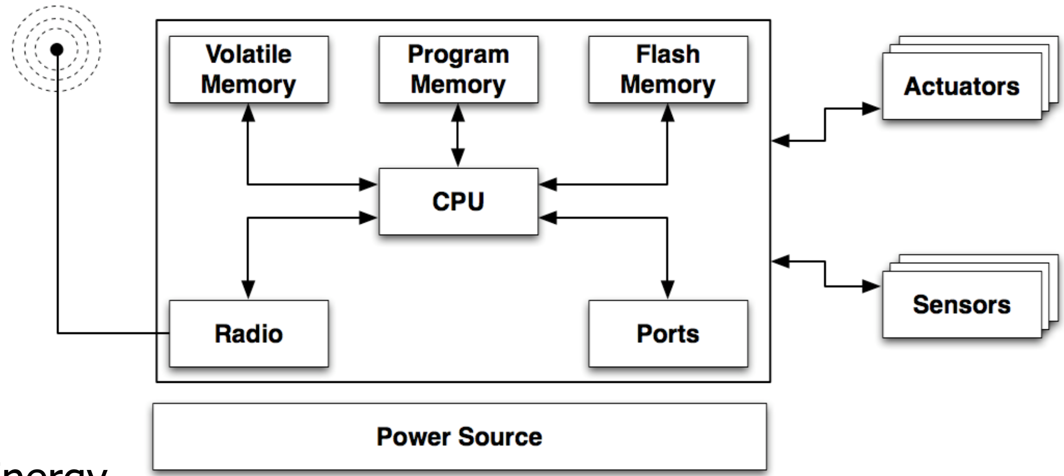
- An Open-source OS for the IoT
- Several Swedish companies build products on top
- Focus on standard-based, interoperable systems
  - 6LoWPAN, 6TiSCH, RPL, CoAP, DTLS, LWM2M etc.
- Focus on **dependable** communication
  - Security: link-layer (IEEE 802.15.4) and application-layer (DTLS)
  - Reliability: brand-new RPL. 99.999% in RPL/TSCH mesh!
- Focus on modern IoT platforms
  - 16 and 32 bits, with low-power radio capabilities
  - Homogenized interfaces for H/W features



IoT Hardware

- CPU
  - ROM for program
  - RAM for variables
  - Flash for long-term storage
  - Ports for I/O
- Radio
  - Low-power, low datarate
  - IEEE 802.15.4, Bluetooth Low Energy, LoRa, etc.
- Power source
  - Battery, or capacitor and harvester
- Sensors / Actuators
  - Application-specific

Picture credit: *Luca Mottola*



Challenges for IoT Software Security

Large attack surface

- Internet
- Wireless
- Physical tampering

Resource-constrained

- Lack much useful support
  - Memory protection and isolation (MCU)
    - Intruders get access to entire system
  - Intrusion detection and mitigation
  - Component replacement
- Highly optimized programming style
  - untyped pointers, limited defensive programming, …

Platform-specific constructs

- For accessing peripherals

aSSIsT: Secure Software for IoT

Goals: Develop techniques and tools for

1. Detecting software vulnerabilities
   - Software analysis, fuzzing
2. Testing and verification of (security) protocol implementations
   - Conformance testing, security testing
3. Run-time protection mechanisms
   - Memory protection, intrusion monitoring

Demonstrators:

- Contiki OS
- IoT protocols, including:
  - DTLS (Datagram TLS)
  - TSCH (Time-Slotted Channel Hopping) MAC-layer protocol for IoT

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Software Analysis

Dynamic techniques
- Testing, symbolic execution
- Exercise paths in the code

Static techniques
- Static analysis, formal verification
- Analyze code for (possible) errors

\+ Easy to set up
\+ Scales well
\+ No (few) false positives
\- Do not provide guarantees

\- Can be difficult to set up
\- Tradeoff scalability/false negatives
\+ Do provide guarantees

Software Analysis

Dynamic techniques

- Testing, symbolic execution
- Exercise paths in the code

←→

+ Easy to set up
+ Scale well
+ No (few) false positives
- Do not provide guarantees

HowTo:

1. Instrumentation:
   - Convert properties to be checked into assertions
2. Exploration
   - Exercise as many program paths as possible to search for crash/violation

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RISE

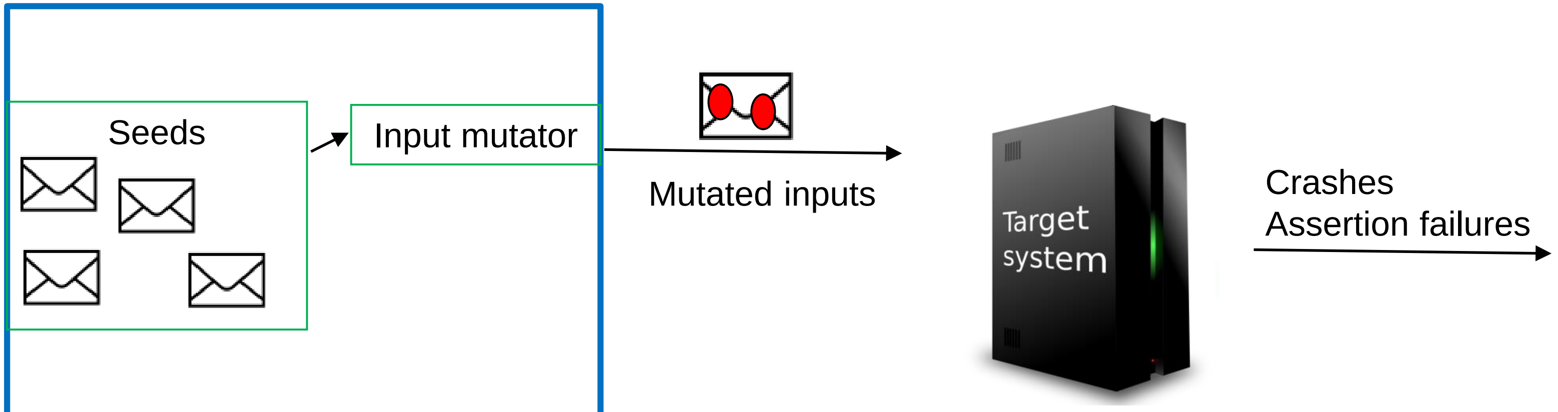
Random Testing

Random inputs →

Crashes
Assertion failures →

- \+ easy to set up
- \+ large number of tests per second
- \- hard to achieve reasonable coverage

Blackbox Fuzzing



Tools include Radamsa

+ easy to set up
+ large number of tests per second
- hard to achieve reasonable coverage

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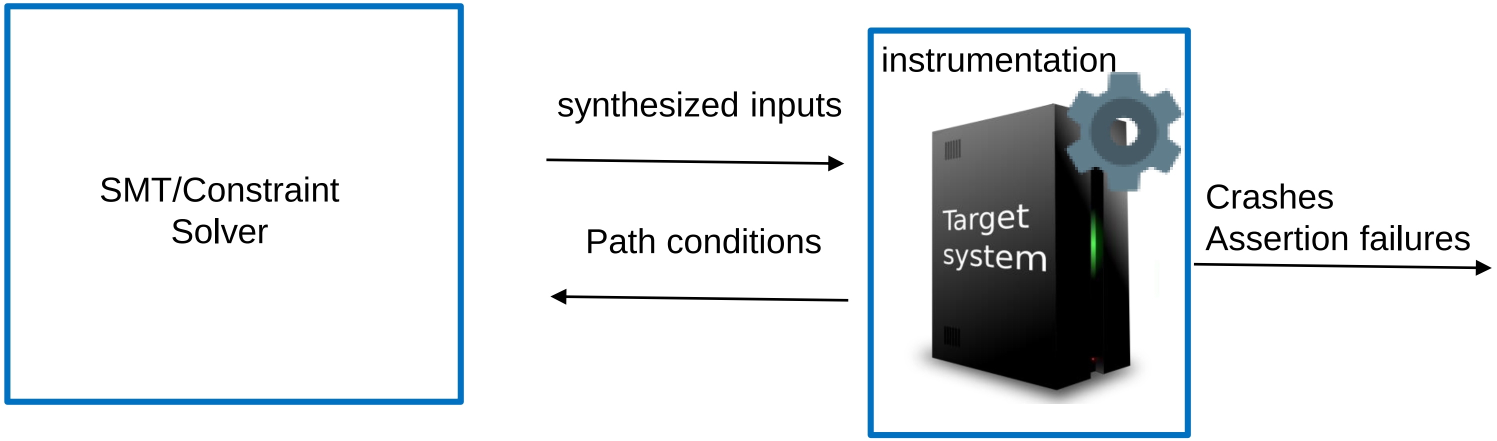
Whitebox Fuzzing

aka. symbolic/concolic execution



Tools include Klee, CREST

\+ Can search for new paths efficiently

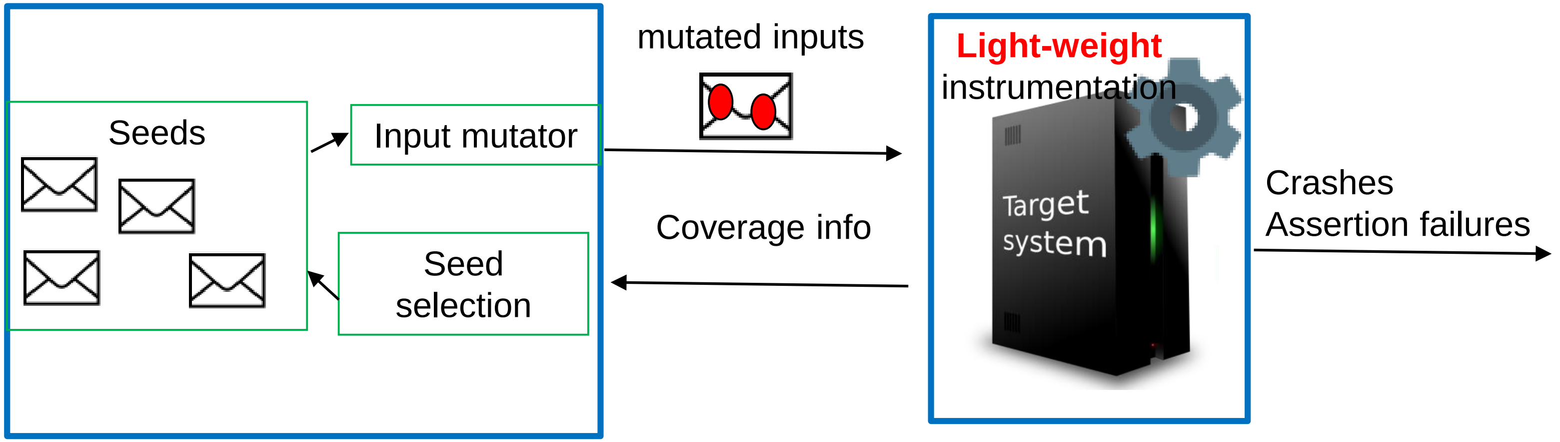
\+ Can find deep bugs / achieve high coverage

\- Non-trival to set up

\- High overhead per test case

\- Some path conditions difficult to analyze

Greybox Fuzzing



Tools include AFL, libFuzzer

\+ easy to set up

\+ (rather) large numbers of tests per second

\+ Can efficiently search for new paths

\- Hard to find "magic numbers"

Challenges for aSSIsT

Goal: Powerful fuzzing techniques for IoT Software

- Device platform characteristics
  - Device-specific ways to access peripherals
  - Proper usage of driver APIs
- Handling interrupts and threading
  - Provoking arbitrary interaction patterns
  - Optimizations to combat state-space explosion
    - Leveraging our previous work for multithreaded software
      e.g., using Nidhugg [Kokologiannakis Sagonas, SPIN 17]
- Approaching complete coverage (as, e.g., [Christakis Godefroid VMCAI 15])
  - Modularization into modest-size components
  - Specification of component interfaces

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Contiki-NG Github Issues

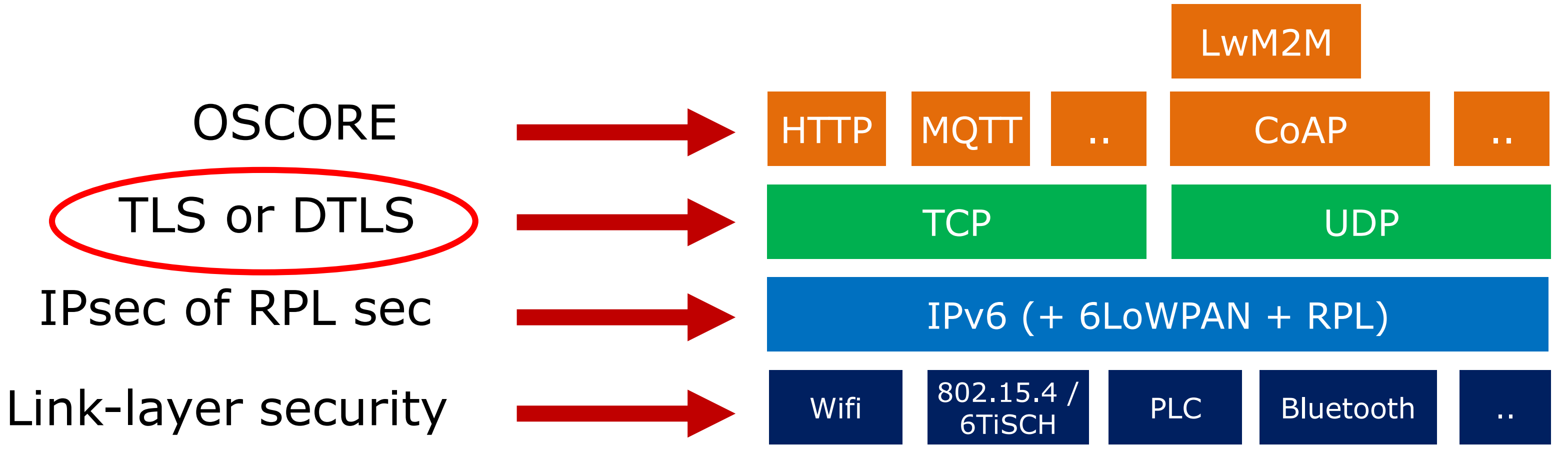
- Vulnerability reports (includes CVEs)

2 Open ✓ 7 Closed — Author ▾ Labels ▾ Projects ▾ Milestones ▾ Assignee ▾ Sort ▾

- Stack based buffer overflow while parsing JSON file `bug` `bug/vulnerability`
  #601 opened on Jul 11 by cve-reporting
- Stack based buffer overflow while parsing MQTT messages (parsing PUBLISH message with variable length header) `bug` `bug/vulnerability`
  #600 opened on Jul 11 by cve-reporting
- Stack based buffer overflow while parsing AQL (storage of relations) `bug` `bug/vulnerability`
  #599 by cve-reporting was closed on Aug 28
- Global buffer overflow while parsing AQL (lvm_shift_for_operator) `bug` `bug/vulnerability`
  #598 by cve-reporting was closed on Aug 28
- Global buffer overflow while parsing AQL (lvm_register_variable, lvm_set_variable_value, create_intersection, create_union) `bug` `bug/vulnerability`
  #597 by cve-reporting was closed on Aug 28
- Global buffer overflow while parsing AQL (lvm_set_op, lvm_set_relation, lvm_set_operand) `bug` `bug/vulnerability`
  #596 by cve-reporting was closed on Aug 28
- Stack based buffer overflow while parsing AQL (parsing next string) `bug` `bug/vulnerability`
  #595 by cve-reporting was closed on Aug 28
- Stack based buffer overflow while parsing AQL (parsing next token) `bug` `bug/vulnerability`
  #594 by cve-reporting was closed on Aug 28
- [Potential] Security Vulnerabilities within Erbium `bug` `bug/vulnerability` 💬 7
  #425 by bsmelo was closed on May 4

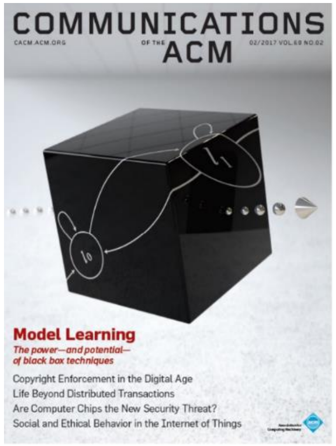
aSSIsT: Communication Security

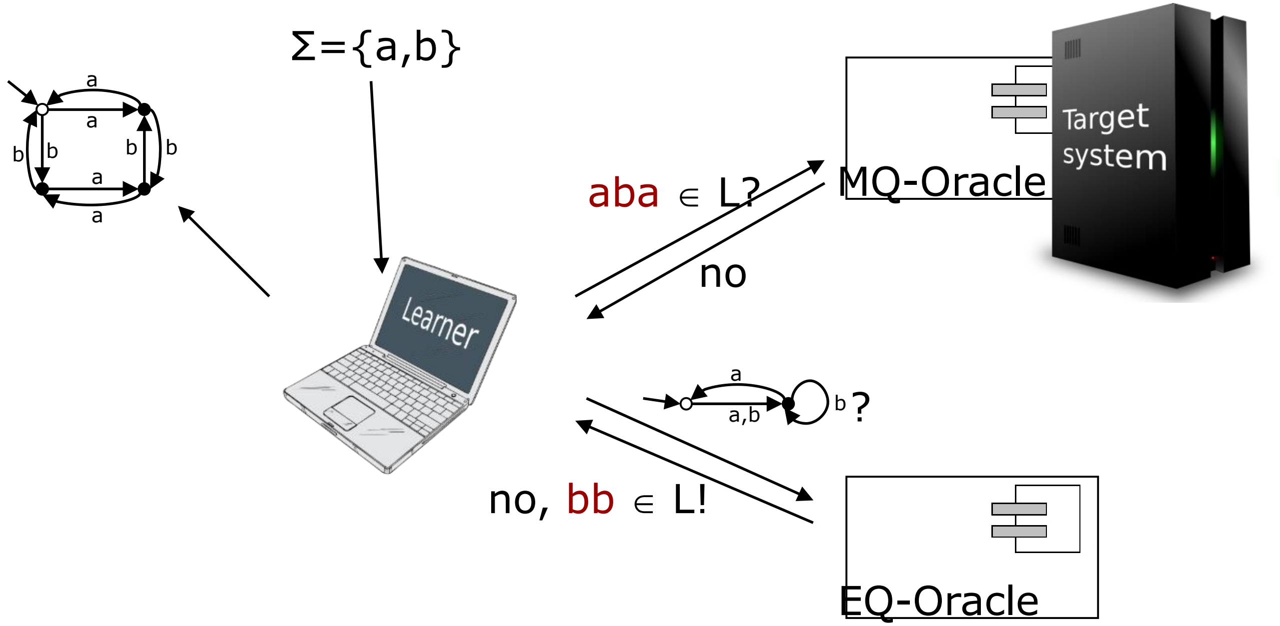
Security in low-power IPv6



- Implementation correctness important
  - Conformance to protocol standard
  - Absence of vulnerabilities
- Weaknesses in TLS implementations discovered in recent years, e.g.,
  - Cryptographic function implementations exposing side channels
    - E.g., Bleichenbacher attack, ..
  - Unexpected input messages may bypass authentication

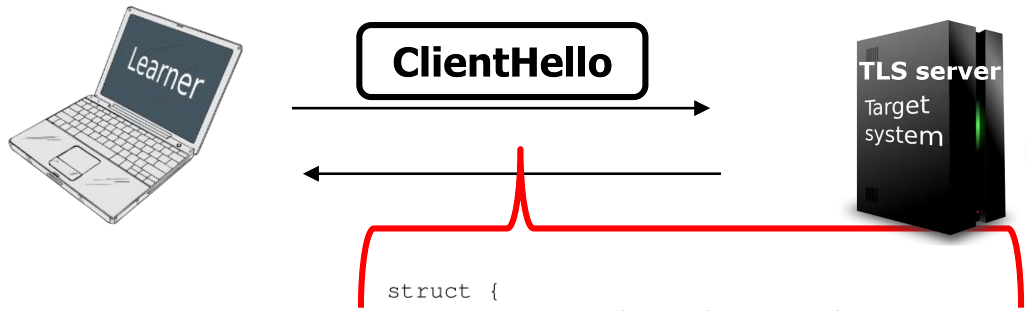
Model Learning





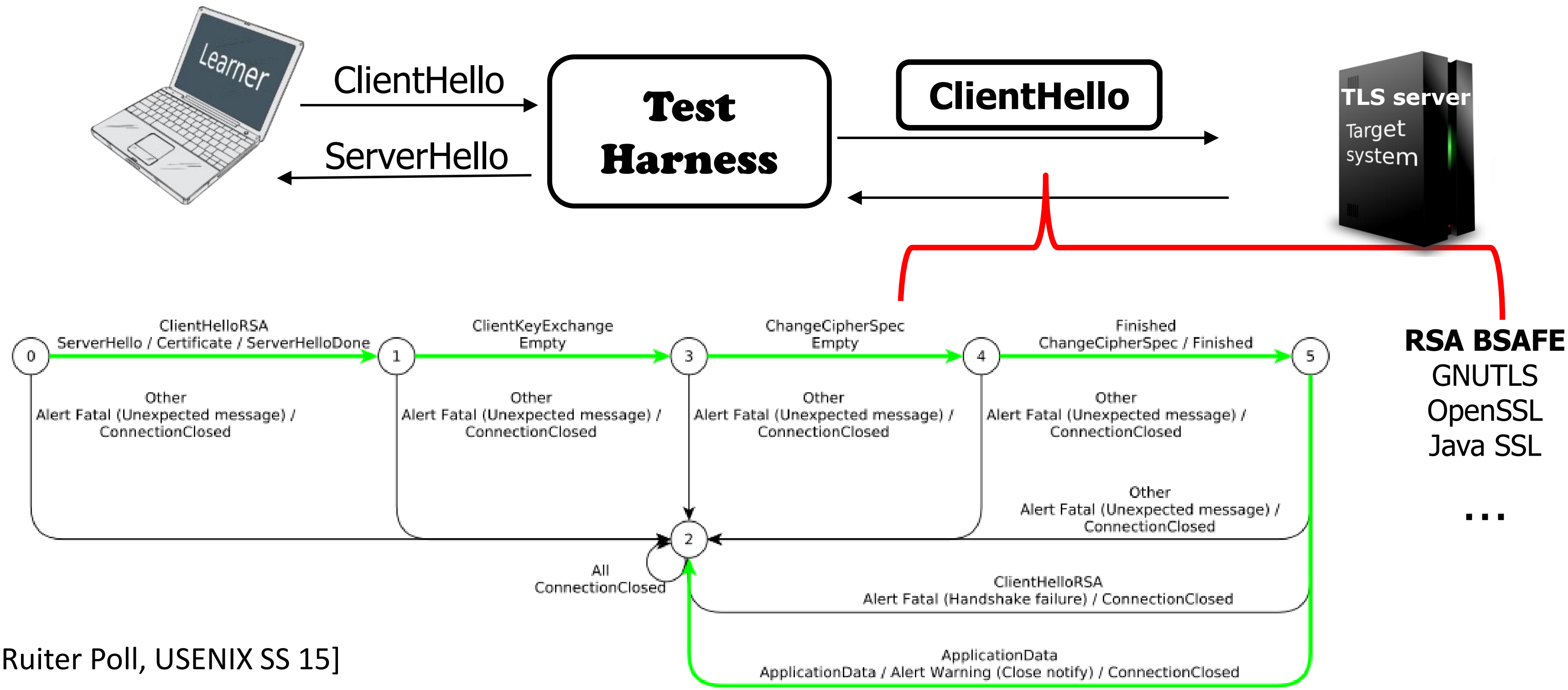
- Learning finite state machines from adaptive test suites
- Starting from only the interface signature, generates
  - Model (finite automaton or Mealy machine), and
  - Conformance test suite
- Techniques well understood for the finite-state case

Applying Model Learning to TLS



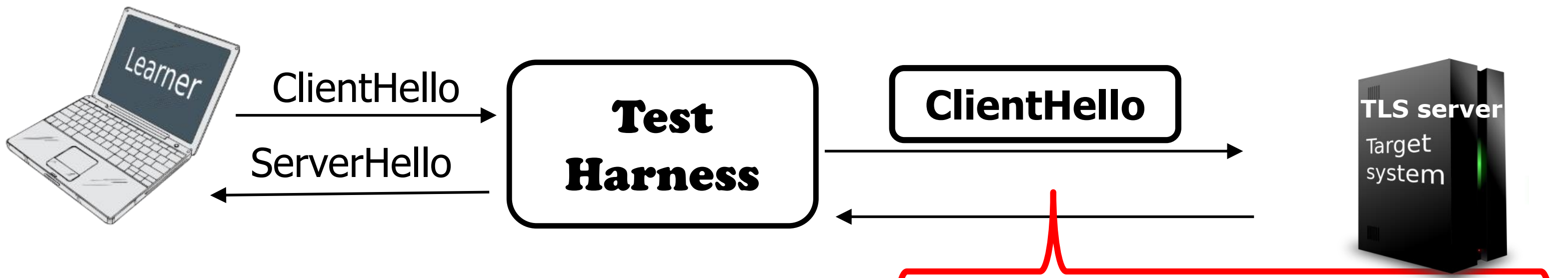

```
struct {
    ProtocolVersion client_version;
    Random random;
    SessionID session_id;
    CipherSuite cipher_suites<2..2^16-2>;
    CompressionMethod compression_methods<1..2^8-1>;
    select (extensions_present) {
        case false:
            struct {};
        case true:
            Extension extensions<0..2^16-1>;
    };
} ClientHello;
```

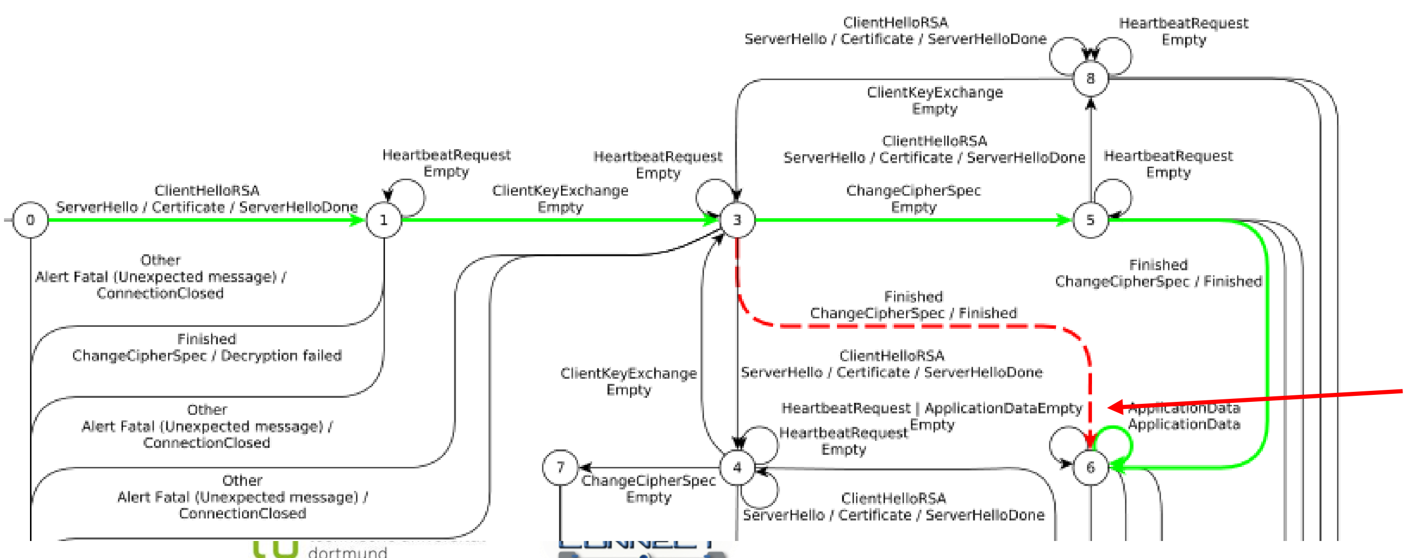
Model Learning: Scenario



[deRuiter Poll, USENIX SS 15]

Model Learning: Scenario





RSA BSAFE
GNUTLS
OpenSSL
Java SSL

...

unencrypted!

[deRuiter Poll, USENIX SS 15]

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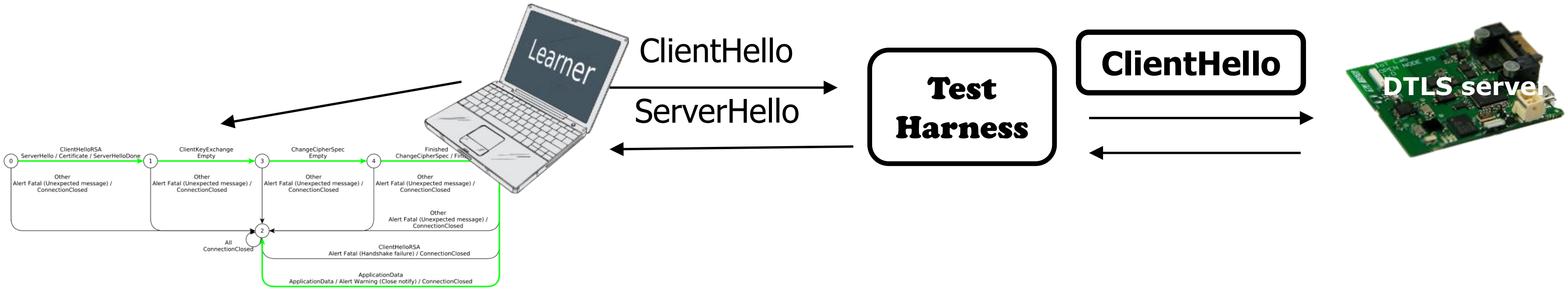
aSSIsT: Plans for Testing DTLS



- Build test harness for DTLS,
  - Start from *TLS attacker,* powerful test harness for TLS
    - Developed at Univ. Bochum [Somorovsky, CCS16]
    - Supports many known cryptographic attacks
- Generate state machine model of DTLS implementation
- Use model:
  - Model checking conformance to standard
  - Checking vulnerability to cryptographic attacks
  - As seed for fuzzing

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Hardware-based Isolation

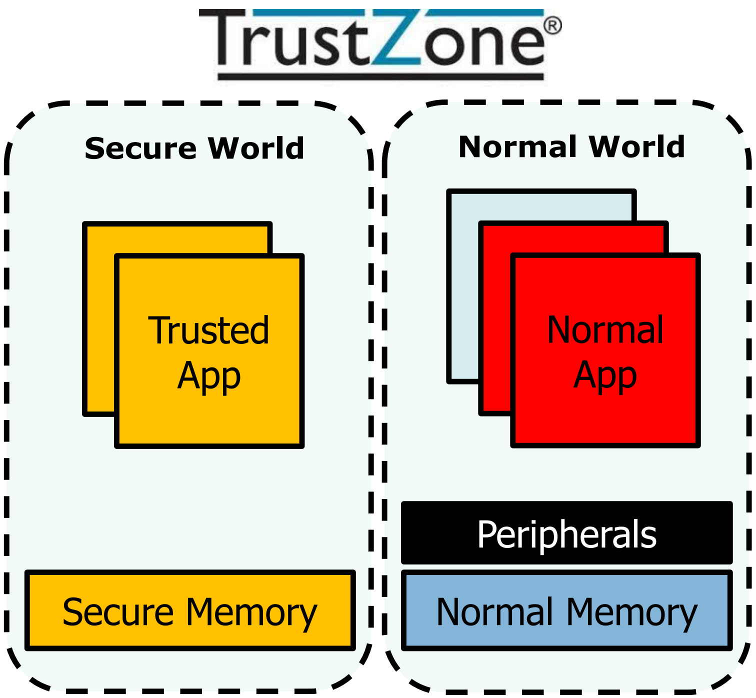
By default, Cortex M0 does not support memory protection/isolation

ARM TrustZone: Hardware-protected area, unaccessible from outside

- Provides memory isolation
- Storage for encryption keys
- …

Challenges

- Best use for Contiki-NG
- Secure communication between trusted and un-trusted zones
- Safe storing of persistent data between transient executions



Enabling (Remote) Updates

SUIT (Software Updates for IoT)

- New protocol for software updates for IoT
- PKI-based

Challenges:

- Implement and evaluate SUIT protocol-set for Contiki
- Formal verification of PKI for IoT (possibly using Tamarin)

Over-The-Air programming (OTA) involving

- Secure bootloader
- Image dissemination (e.g. LWM2M)
- Image verification (signature check)
- Image swapping w/ scratch area

Summary

- Security is a crucial concern for IoT software
- IoT platforms pose new challenges for software security
  - Attack surface, resource constraints, device characteristics
- aSSIsT goal is to develop techniques for
  1. Software analysis for vulnerabilities
  2. V&V for (security) protocol implementations
  3. Platform run-time protection mechanisms
- For use by developers of software for IoT
- For hardening existing IoT platforms
  - Contiki-based, …
  - Low power wireless protocols