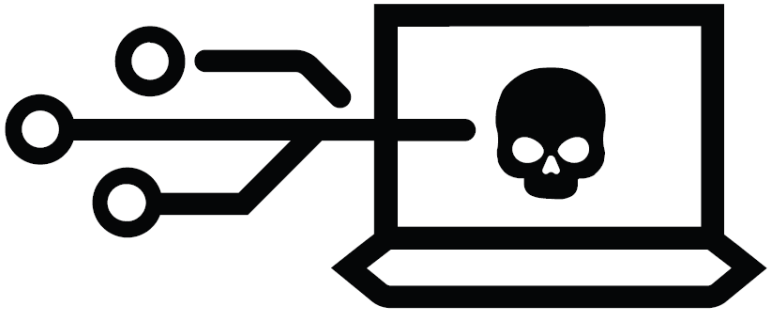
Constrained CIP Security Best Practices

Jakub Korbel, Jack Visoky
Rockwell Automation

Why the CIP Security Constrained Profile?

- More devices are being “connected” via Ethernet
  - Even sensors and other constrained devices
- Each of these present an attack surface that might be attractive to hackers
  - Example: Mirai Botnet
- Even if a device isn’t directly connected to the Internet it could still be targeted
  - Example: Jeep hack, Trisis malware
- Therefore security protections must be available for resource-constrained CIP devices



Resource Constrained CIP Security

- In April of 2021 ODVA published the CIP Security Resource-Constrained Profile
- Provides functionality for protocol protections, but tailored to more constrained devices
  - PSKs instead of certificates (except for initial commissioning)
  - Only 3 cipher suites
  - DTLS only
- This makes it much easier for a constrained device to implement security
- However, there are still some best practices to discuss

Why the changes – certificates

- Certificates bring a lot of complexity
  - X.509 parsing
  - File Object
  - Certificate Management Object
- Using PSKs is a lot simpler, better suited to these constrained devices
- However, an initial, default certificate can still be used – no need to parse it or support the objects, just serve it as part of the initial handshake
  - This helps bootstrap security and to provide device authenticity assurances
  - IEEE 802.1AR IDevID

Part of a certificate used on an EtherNet/IP device…seems complicated…

```
X509 Certificate:
Version: 3
Serial Number: 6e6e5112000000000f24
Signature Algorithm:
    Algorithm ObjectId: 1.2.840.10045.4.3.4 sha512ECDSA
    Algorithm Parameters: NULL
Issuer:
    CN=Rockwell Automation - Manufacturing Intermediary CA
5
    O=Rockwell Automation, Inc.
    C=US
  Name Hash(sha1): 02a938c1873ccc4c6c926b3a1a3e2080b3678e1f
  Name Hash(md5): 3ebb00acfb516fbc867fe59dfac3fea3

 NotBefore: 12/16/2015 12:19 PM
 NotAfter: 12/6/2055 12:19 PM

Subject:
    CN=1756-L85E (00b48f94)
    O=Rockwell Automation, Inc.
    C=US
  Name Hash(sha1): ec91018dbb124274ba596b0f46e7a939a6c5bc36
  Name Hash(md5): 31c2a3931fd0c6b7fd230d6dc07ea7d6

Public Key Algorithm:
    Algorithm ObjectId: 1.2.840.10045.2.1 ECC
    Algorithm Parameters:
    06 08 2a 86 48 ce 3d 03  01 07
        1.2.840.10045.3.1.7 ECDH_P256
Public Key Length: 256 bits
Public Key: UnusedBits = 0
    0000  04 18 ee 09 3c fd 6e cb  31 d3 89 ba 17 32 43 db
    0010  78 b0 3a 55 47 61 f7 a4  2e b1 92 92 88 a5 d2 8e
    0020  12 3a 73 d9 38 f6 46 ce  37 35 fa 11 aa ea 2f 20
    0030  cc 27 21 38 d6 78 be 44  9f d2 4b 6e 1b 91 96 73
    0040  4f
```

```
Certificate Extensions: 13
    1.3.6.1.4.1.95.3.2: Flags = 0, Length = 3

    0000  02 01 01
...
0000: 02 01
          ; INTEGER (1 Bytes)
0002:    01

    1.3.6.1.4.1.95.3.5: Flags = 0, Length = 3

    0000  02 01 0e
...
0000: 02 01
          ; INTEGER (1 Bytes)
0002:    0e

    1.3.6.1.4.1.95.3.6: Flags = 0, Length = 4

    0000  02 02 00 a8
....
0000: 02 02
          ; INTEGER (2 Bytes)
0002:    00
0003:    a8

    1.3.6.1.4.1.95.3.7: Flags = 0, Length = 7

    0000  03 05 00 02 00 00 00
.......
0000: 03 05
          ; BIT_STRING (5 Bytes)
0002:    00
0003:    02 00 00 00
```

Why the changes – ciphers

Just 3 ciphers needed for the Resource Constrained Profile

Cipher	Properties
TLS_ECDHE_PSK_WITH_NULL_SHA256	Authenticity only, no confidentiality. Just uses the SHA-256 HMAC
TLS_ECDHE_PSK_WITH_AES_128_GCM_SHA256	AES GCM for authenticity and confidentiality. Highly optimized for hardware acceleration
TLS_ECDHE_PSK_WITH_CHACHA20_POLY1305_SHA256	ChaCha20 and Poly1305. Highly optimized for devices without hardware acceleration

Why ECDHE Ciphers?

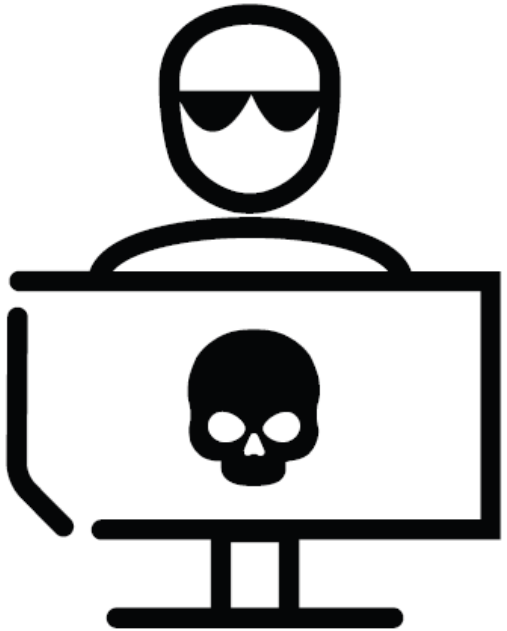
- Note that each cipher is Elliptic Curve Diffie Hellman Ephemeral
- This means that an ephemeral key pair is generated during the handshake
- This does add cost/complexity in terms of code space and memory usage ☹
- However, it also provides perfect forward secrecy ☺
  - Prevents compromise of data transmitted if static keys are ever compromised
- SIG felt this was important enough to pay the cost, minimum for security
- However it is something that could be discussed in the future if further constraints are needed

But How?

- The CIP Security Resource-Constrained Profile defines the technologies, but does not provide guidance on implementation details
- Here are some practices discovered and established during Rockwell Automation‘s implementation of the profile

Security Implications

- Trade-offs come at a cost!
  - Pay attention to your threat model
- Certificates are complex, but they provide a unique identity for every device in the system
  - PSKs don’t



What are some downsides to PSKs?

- Non-repudiation – anyone with the PSK can deny they did something
- Spoofing – cannot distinguish one member with the PSK from another
- Reflection – in some cases connections can be reflected or redirected
- Note with sufficiently small groups (like of 2) many of these threats disappear, but that is often not the case when using PSKs

Tasking

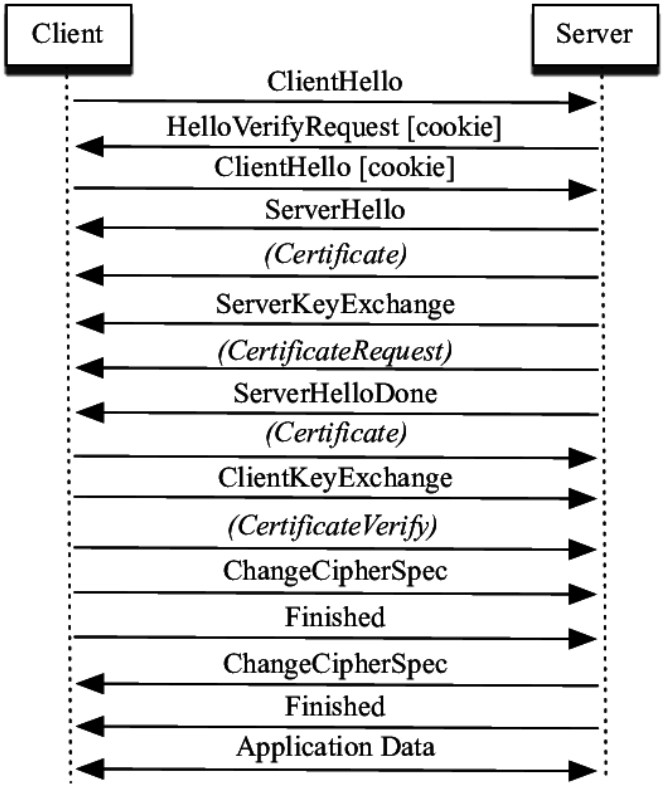
- Cooperative multitasking == tasks are reqlinquishing CPU control themselves, single stack is sufficient
  - Did someone say “event loop”?
- Pre-emptive multitasking == scheduler relinquishes task‘s CPU control usually as a reaction to ISR (context switch after finished assigned time slice), a stack per task is needed
  - Did someone say “POSIX threads”?

Pre-emptive Multitasking

Tasking

- Task architecture has a big impact on the performance and footprint of security in a resource-constrained environment
- Cooperative multitasking can be suitable if developers have full control over running firmware
  - With single core and **well-behaving tasks** finishing operations in small chunks, Cooperative multitasking can present significant performance benefit over pre-emptive multitasking.
- Pre-emptive multitasking is a must when users can launch **misbehaving tasks**, so that the system won‘t halt. It also does not require developers to split large calculations or allows them to perform **blocking operations**.

What is a DTLS Handshake?



Handshake Stack and Heap consumption

- Handshake and also hash/crypto operations can be very **stack and heap-consuming**, check it out yourself here.
  - Handshake consumes more stack/heap memory than keeping a connection alive
  - DTLS consumes more memory than TLS, but remember TLS leverages connection and stream properties of TCP
  - ECC client side is more memory consuming than RSA, but this might change with certificate chains, where the sum of key sizes offsets ECC‘s stack and heap-heavy operations
  - Even with size tweaking compile-time options, the stack sizes just for handshake grew often to 10K

Handshake

- Handshake operations are also **performance intensive**, especially for ECDH**E**
- CIP I/O cannot wait till the Ephemeral key generation (RNG) of ECDHE finishes
  - **Pre-emption** can be the solution, but it can result in multiplying RAM consumption for task stacks.
  - **Splitting the calculations** can be the solution in Cooperative scheme, but it requires support in the TLS library.
  - **Hardware acceleration** can help in combination
    - More and more cryptochips are being made, some can even help ECC operations.

Best practices

- To get to smaller memory footprint and better performance in highly constrained environments, such as <256KiB of RAM and <300MHz CPU Speed:
  - Use cooperative multitasking.
  - Use cryptoacceleration, if available.
  - Prefer PSKs, but understand the impact on security and establishment of trust.
  - Benchmark (or read the documentation of) cryptographic libraries for memory footprint and handshake performance.
  - Pick cipher-suites that provide enough security and can sustain the traffic needed by your product function.
    - (Or just conform to Volume 8, CIP Security Resource Constrained Profile ☺)

Conclusions

- CIP Security Resource Constrained Profile provides robust security while fitting into tightly constrained environments
- It is important to be aware of security limitations with PSKs
- Task architecture really matters for constrained environments and security, think about how constrained your environment is and pick your tasking model

Conclusions

- Be careful of how the handshakes are done, this has a big impact on performance and memory usage
- If in practice this profile is still too burdensome to highly constrained devices the SIG can consider PSKs which don't provide Perfect Forward Secrecy
  - This is likely a reasonable trade-off, bringing some security to constrained devices is better than "perfect" security that doesn't get used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