Formal and **Automated** Exploitability Analysis of TLS Specification Violations

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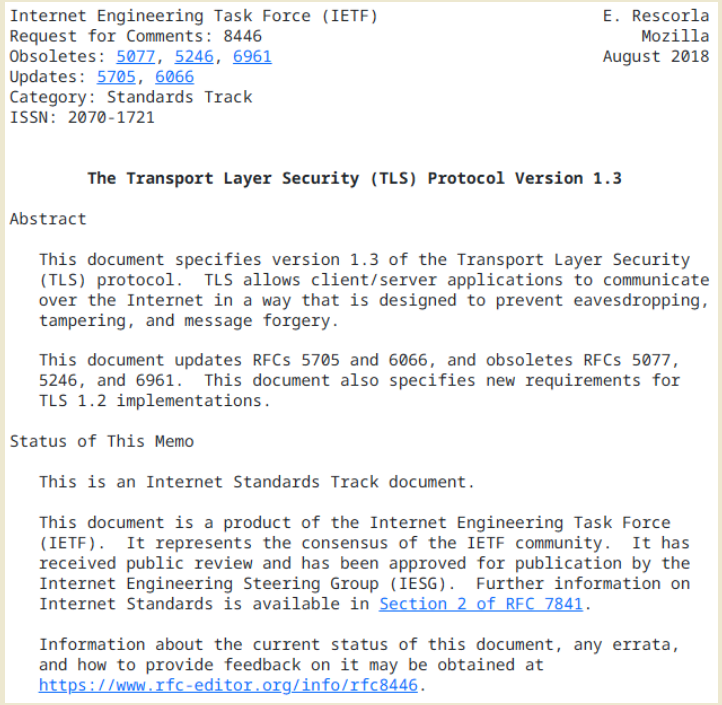
STAAR 10th Workshop, Ulsan, Korea

POSTECH

TLS Protocol

- TLS(Transport Layer Security) 프로토콜: 두 당사자 간 메시지 전송 시 데이터 보호/무결성을 보장하기 위한 보안 프로토콜



Internet Engineering Task Force (IETF) — E. Rescorla
Request for Comments: 8446 — Mozilla
Obsoletes: 5077, 5246, 6961 — August 2018
Updates: 5705, 6066
Category: Standards Track
ISSN: 2070-1721

The Transport Layer Security (TLS) Protocol Version 1.3

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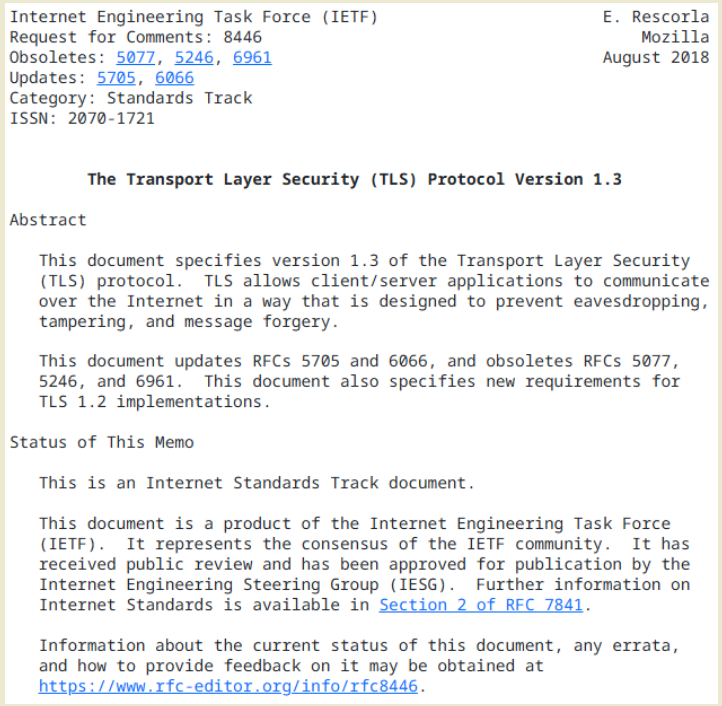
RFC 5246(TLS 1.2), 8446(TLS 1.3)

TLS Protocol

- TLS 프로토콜 RFC에 대해 Formal Verification을 통해서, 스펙 수준에서 여러 보안 속성들을 엄밀하게 검증



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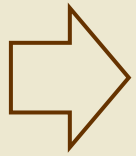
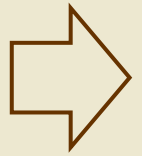




RFC 5246(TLS 1.2), 8446(TLS 1.3)

Formal Models

Correct / Failed

TLS Protocol

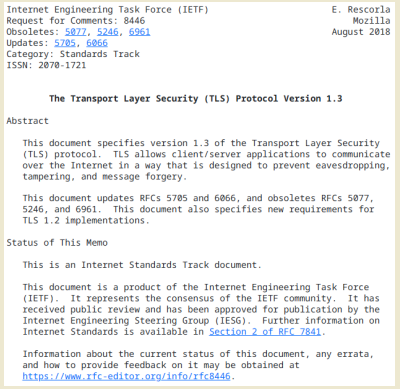
- TLS 프로토콜 구현 코드에 대해 Fuzzing, Combinatorial Testing, Differential Testing 등을 통해 오류 발견

TLS Implementation

Test Code

Correct / Failed

Formal 모델을 통한 테스트 및 취약점 탐지



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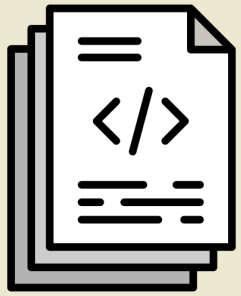
RFC Spec

MoudE3

Formal Model



Test Code

OpenSSL
Cryptography and SSL/TLS Toolkit

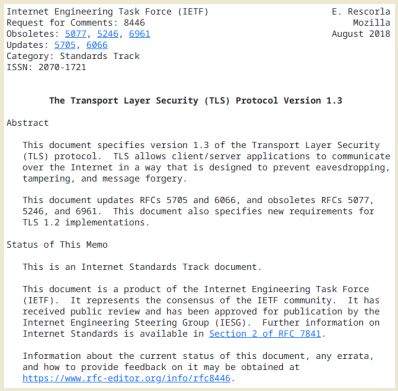
gnuTLS

wolfSSL

Mbed TLS

TLS Libraries

Formal 모델을 통한 테스트 및 취약점 탐지



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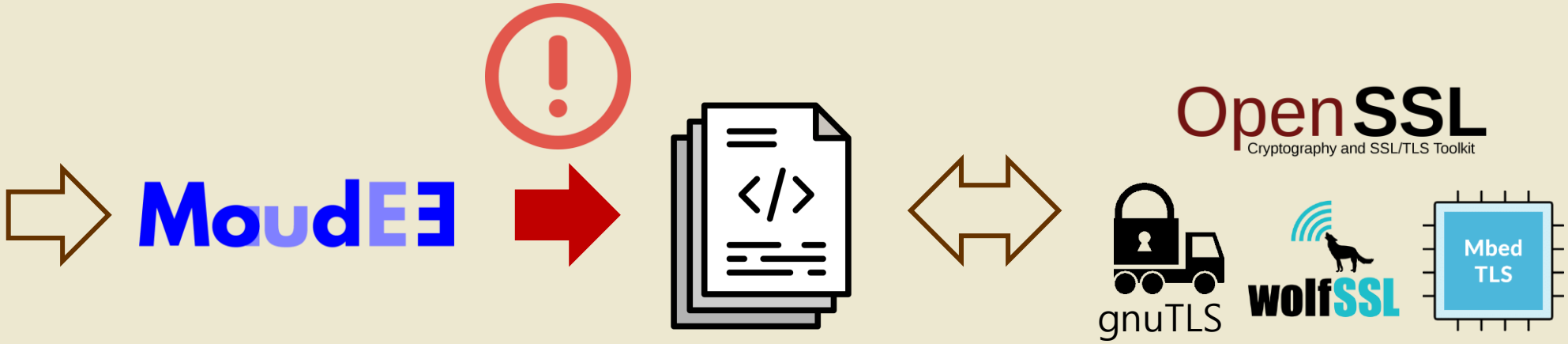


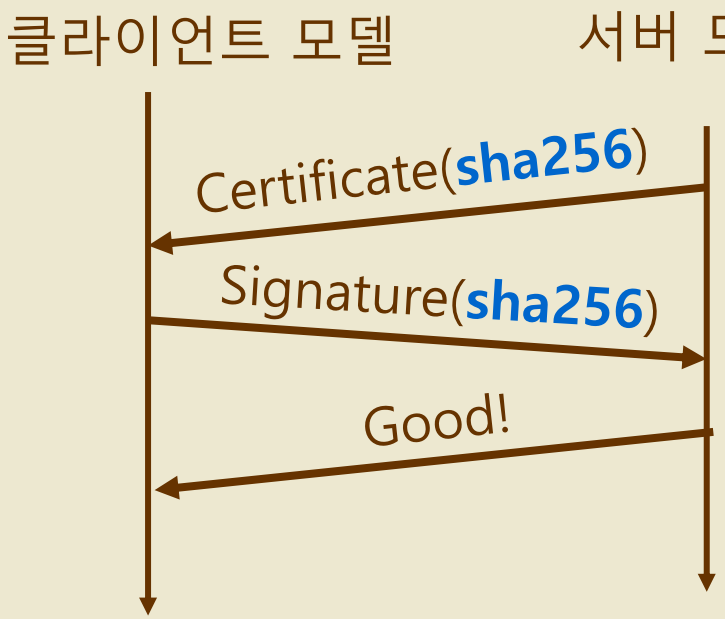
RFC Spec — Formal Model — Test Code — TLS Libraries

1. **효율적으로** RFC Spec을 위반하는지 테스트하는 시나리오 자동 생성
2. 버그를 넘어 **보안 취약점까지 탐지**하기 위한 테스트 시나리오 자동 생성

Formal Model 기반 테스트

RFC Requirement: 서버가 요구한 Hash 알고리즘으로 클라이언트는 서명해서 보내야 함.

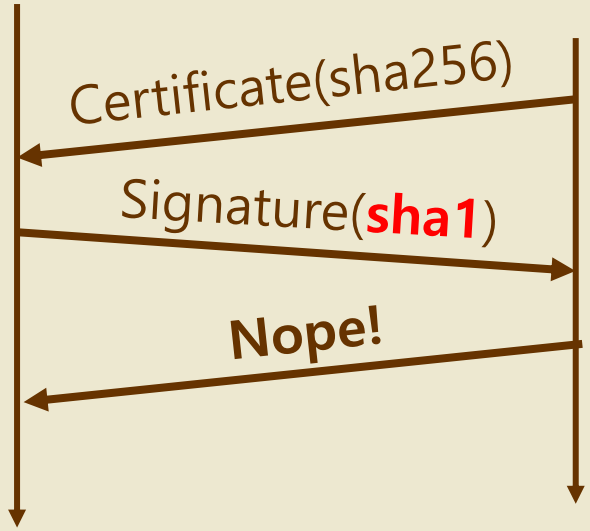
Formal Model 기반 테스트




```
rl [buildSignature]:
  < Client | sig : SA > => < Client | ... > Signature(SA)
```

Formal Model 기반 테스트

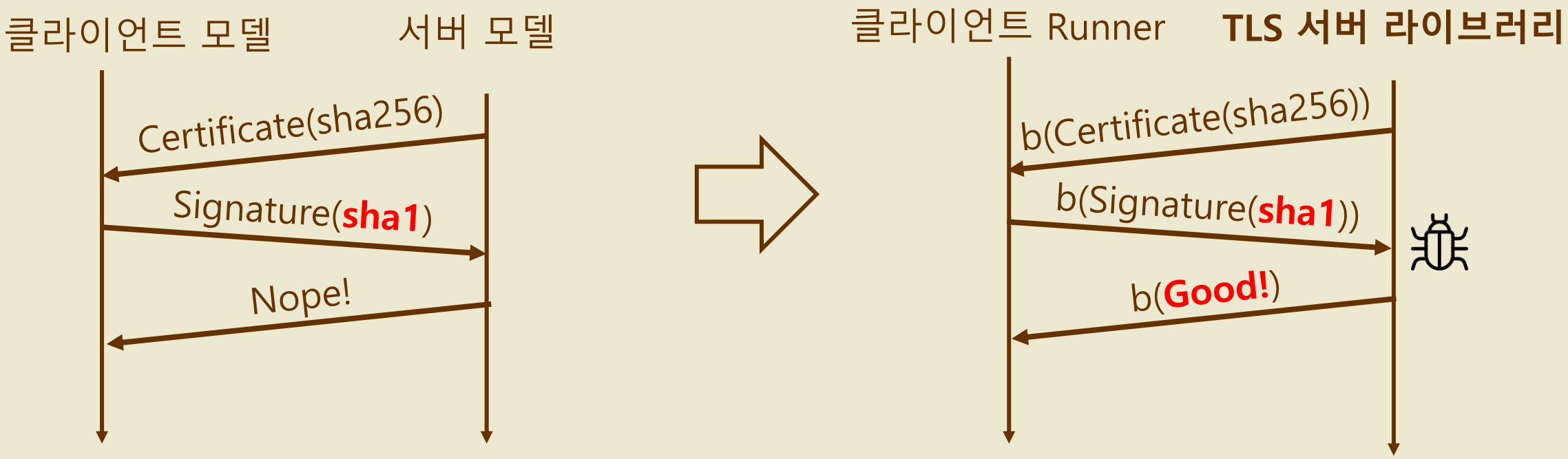
클라이언트 모델 서버 모델



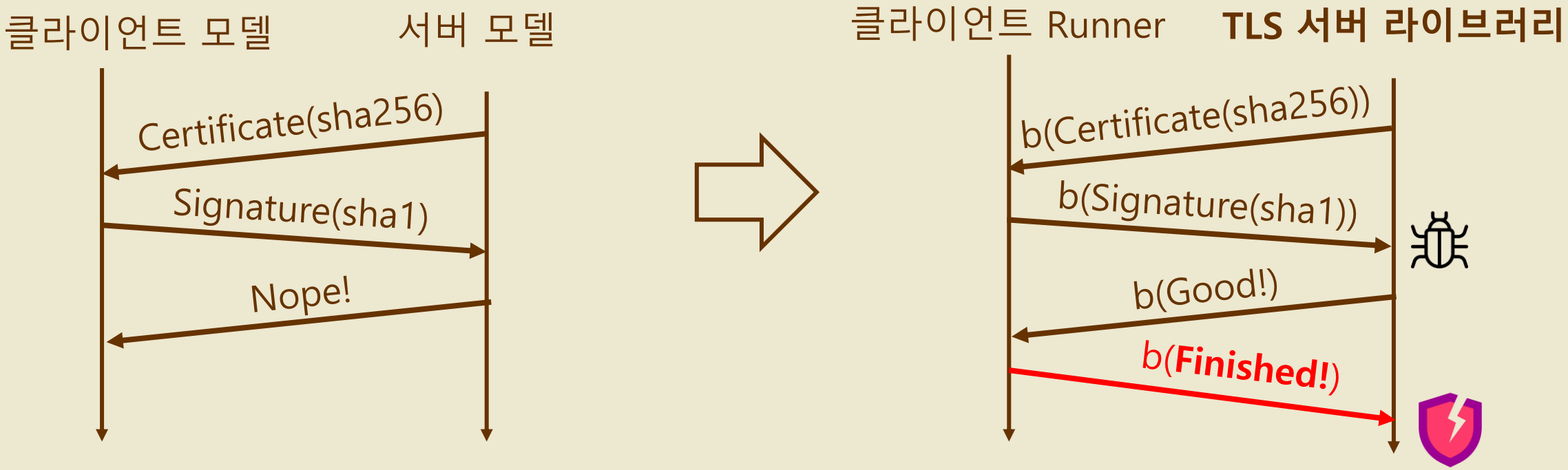

```
rl [buildSignature]:
  < Client | sig : SA > => < Client | ... > Signature(SA)

rl [buildModifiedSignature1]:
  < Client | sig : SA > => < Client | ... > Signature(sha1)

rl [buildModifiedSignature2]:
  < Client | sig : SA > => < Client | ... > Signature(md5)

. . .
```

현재 상태와 **Inconsistent한 메시지를 생성**하는 Rules을 자동 생성 후,
Maude Strategy를 이용하여 해당 Rules만 실행

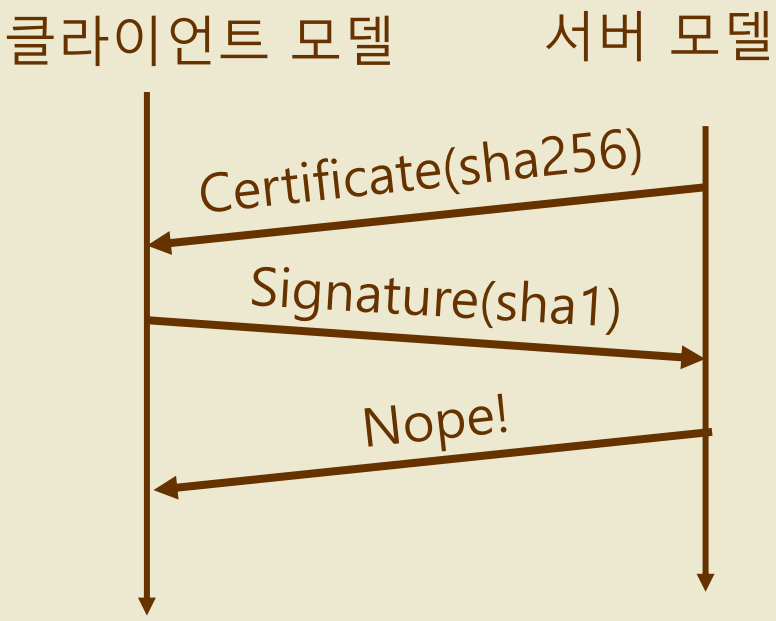
Formal Model 기반 테스트



Formal Model 기반 테스트



RFC 위반 버그에서 보안 취약점까지




```
crl [processSignature]:
  < Server | sig : SA1 > Signature(SA2) => < Server | ... > Good!
 if SA1 == SA2 .

crl [processSignature]:
  < Server | sig : SA1 > Signature(SA2) => < Server | ... > Nope!
 if SA1 =/= SA2 .
```

RFC 위반 버그에서 보안 취약점까지

클라이언트 모델 **서버 모델**


```
crl [processSignature]:
  < Server | sig : SA1 > Signature(SA2) => < Server | ... > Good!
 if SA1 == SA2 .

crl [processSignature]:
  < Server | sig : SA1 > Signature(SA2) => < Server | ... > Nope!
 if SA1 =/= SA2 .

crl [processModifiedSignature]:
  < Server | sig : SA1 > Signature(SA2) => < Server | ... > Good!
 if true .
```

잘못된 메시지가 왔을 때, **해당 메시지**로 상태를 강제 업데이트하는
Rules 자동 생성 및 해당 Rules 실행

실험 결과

- 신규 RFC 위반 **버그**: 20개
  - WolfSSL: 12개
  - gnuTLS: 4개
  - mbedTLS: 6개

- 신규 **CVE** 발급: 7개
  - WolfSSL: 5개
    - CVE-2025-11936, CVE-2025-11936, CVE-2025-11934, CVE-2025-11933, CVE-2025-12889
  - gnuTLS: 1개 (embargo)
  - mbedTLS: 1개 (embargo)