Passive Approach for Robustness Testing of Communication Protocols

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Topics

- Robustness Testing
  - Why
  - What
- Proposed Approaches
- An Hybrid Approach
- Results

Why robustness testing?

- Testing software to ensure that the functional requirements were met … → Conformance testing

  … is necessary but not enough

☞ How does the system behave in presence of
  - erroneous or unexpected user inputs?
  - internal or external failures?
  - stressful environmental conditions?

→ Robustness testing

Robustness

- Definition

  "*the degree to which a software system or component can function* ***correctly*** *in the presence of* ***invalid inputs*** *or stressful environmental conditions*."

IEEE Std 610.12-1990 - Glossary of Software Engineering Terminology

Robustness testing

- Definition [CW03] :

  "*aimed to determine whether a system or component can have an acceptable behavior in the presence of* ***faults*** *or stressful environmental conditions*"

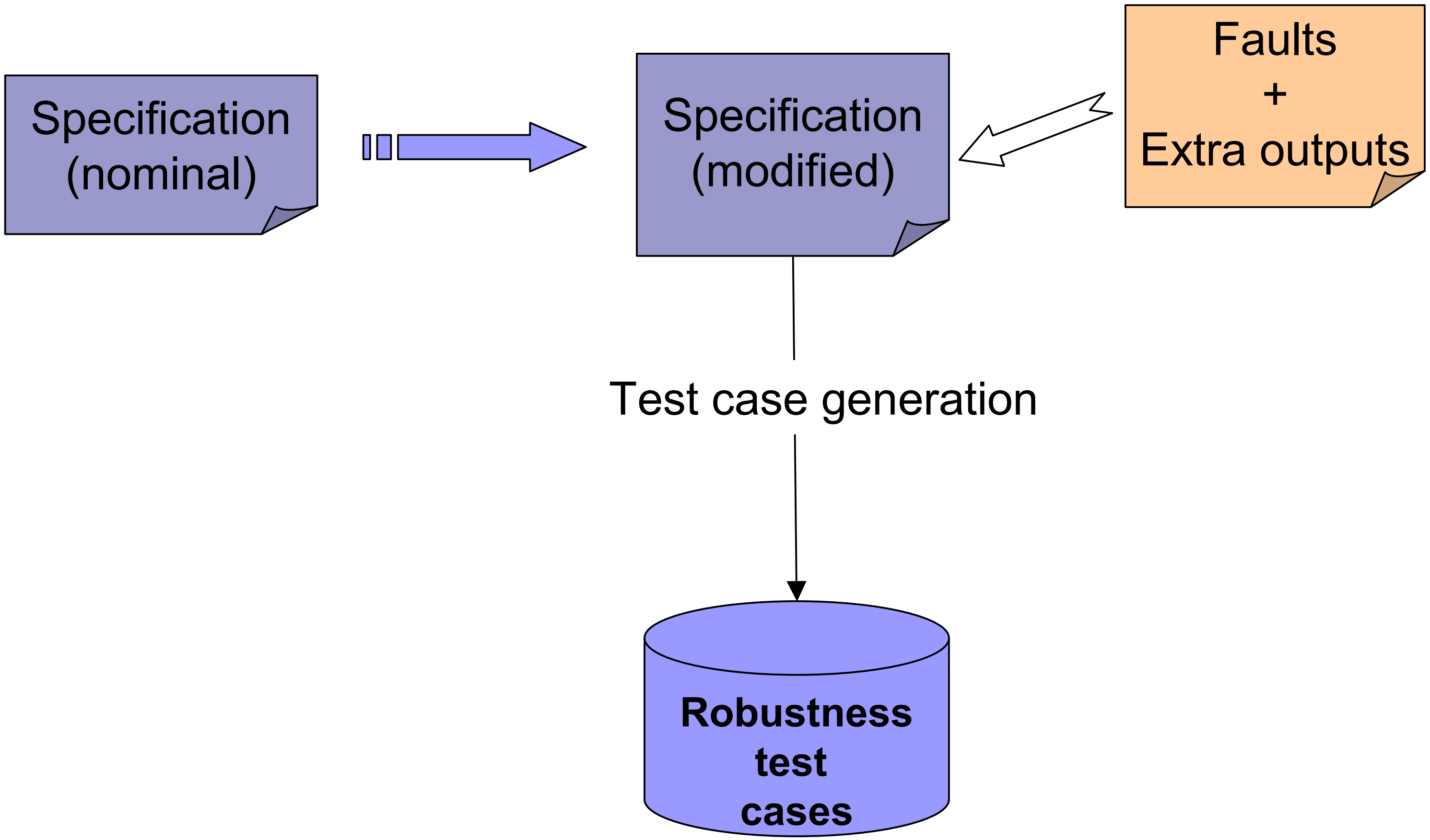
Robustness testing approaches

- Ad-hoc approaches
  - Hard to automate
- Based on models
- Based on fault injection

Model-based approaches

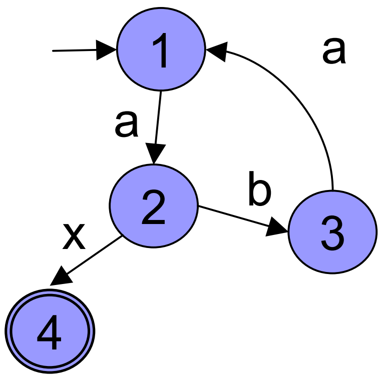
- Formalization of robustness testing is inspired on that of conformance testing
  - Conformance testing:
    - Goal: determining whether an implementation conforms to its specification
  - The specification is represented by a (behavior) model from which:
    - Test cases can be derived
    - Observed results can be analyzed

Robustness test cases generation

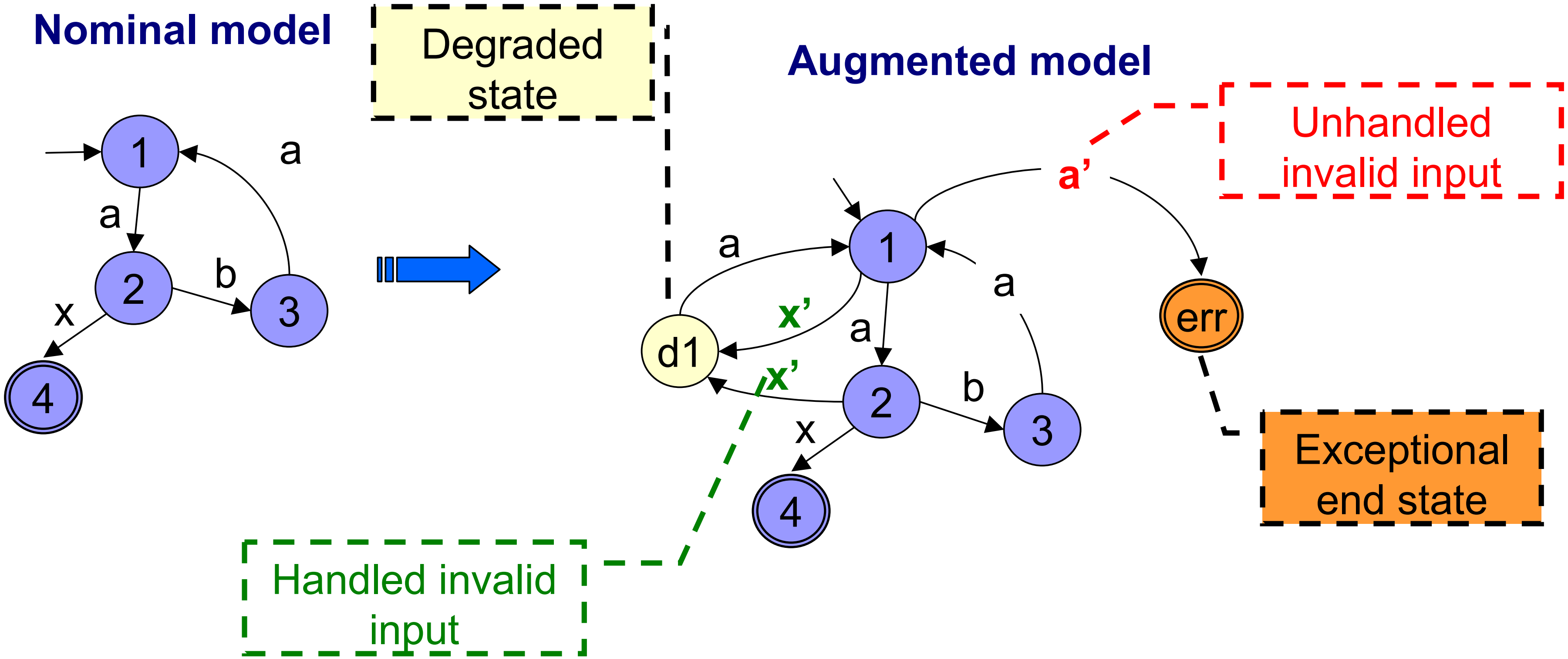


Illustrative example

Nominal model



Illustrative example



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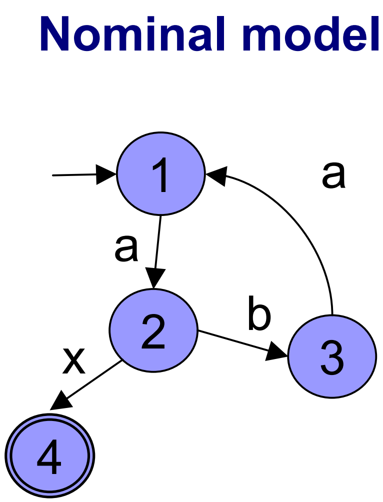
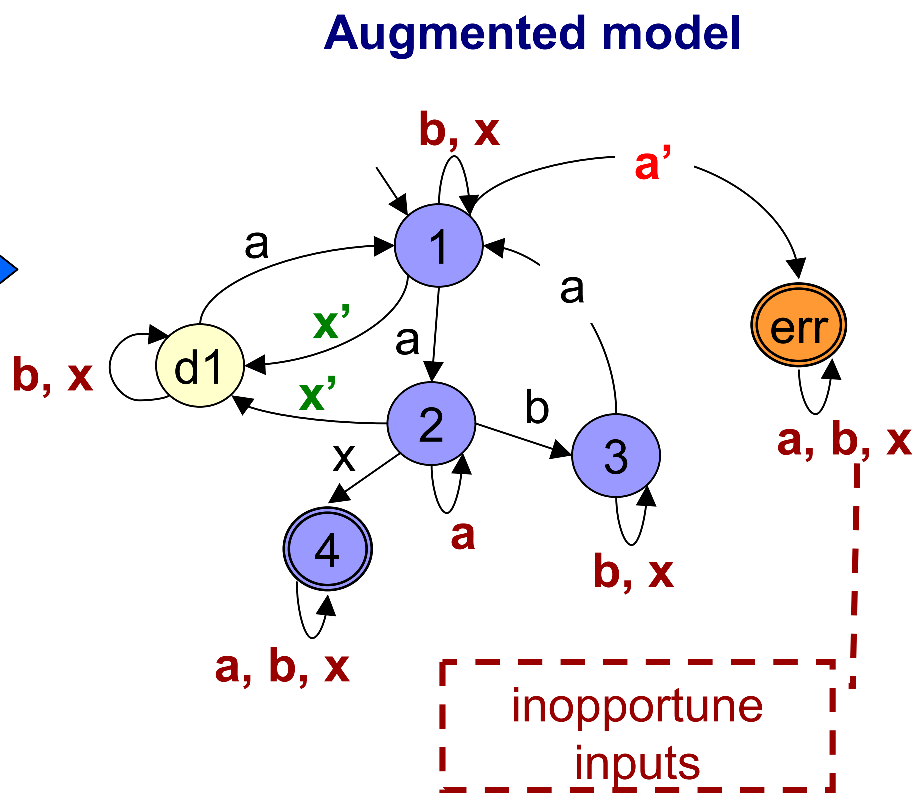




Difficulties with the model-based approaches

- Model size is too big for use
  - Need to carefully define test objectives
- Tester has limited control of faults
  - Faults to consider may depend on the application domain and on the system architecture
  - Environmental (context) faults (memory, processor, communication channel, device drivers) are not considered
- System behavior in the presence of faults cannot always be completely specified

Fault injection

- Definition

  Deliberate introduction of faults into a system to observe its behavior

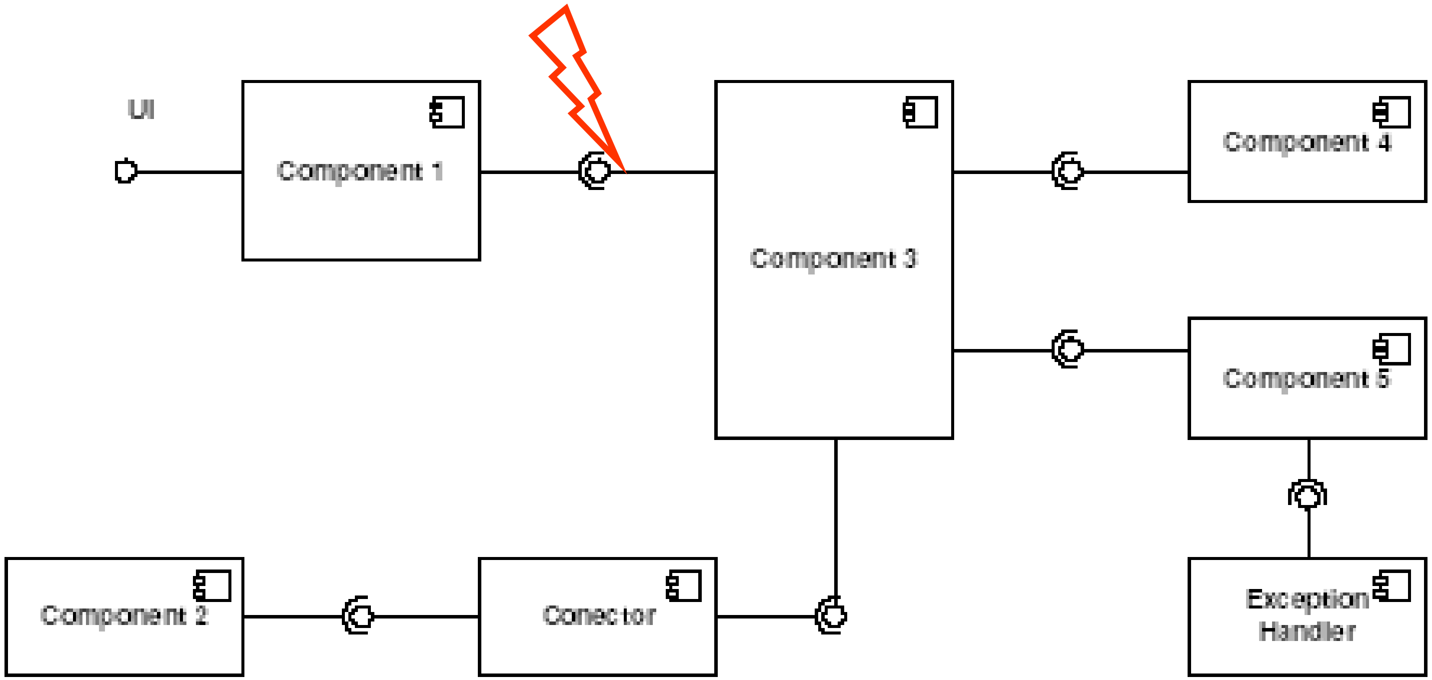
- Applicability
  - To verify whether the error detection and recovery mechanisms behave as expected.
  - To evaluate dependability measures such as reliability for a giving mission time, availability, performance degradation due to fault handling.
  - To understand the effects of real faults.

Fault injection approaches

- Faults can be injected:
  - Into a model ⇒ Simulation-based fault injection
  - Into a prototype or final system:
    - Hardware level ⇒ Hw-implemented fault injection (HWIFI)
    - Software level ⇒ Sw-implemented fault injection (SWIFI)

Robustness testing and fault injection

- Interface fault injection:
  - affects functions input/output parameters or protocol messages fields
  - Invalid values produced according to input/output domains or formats
- Some approaches and tools:
  - Ballista/Piranha, Mafalda, Fuzz, Riddle, PROTOS, Jaca


UI
Component 1
Component 3
Component 4
Component 5
Component 2
Conector
Exception Handler

Limitations of interface fault injection approaches

- Oracle is generally not based on the specification
  - "golden run" or reference implementation
  - Crash or not crash
- Knowledge about the system structure or behavior is not frequent
  - Exceptions: Avresky et al 1992; Echtle &Chen 1991; Sinha &Suri 1998; Loki 2000

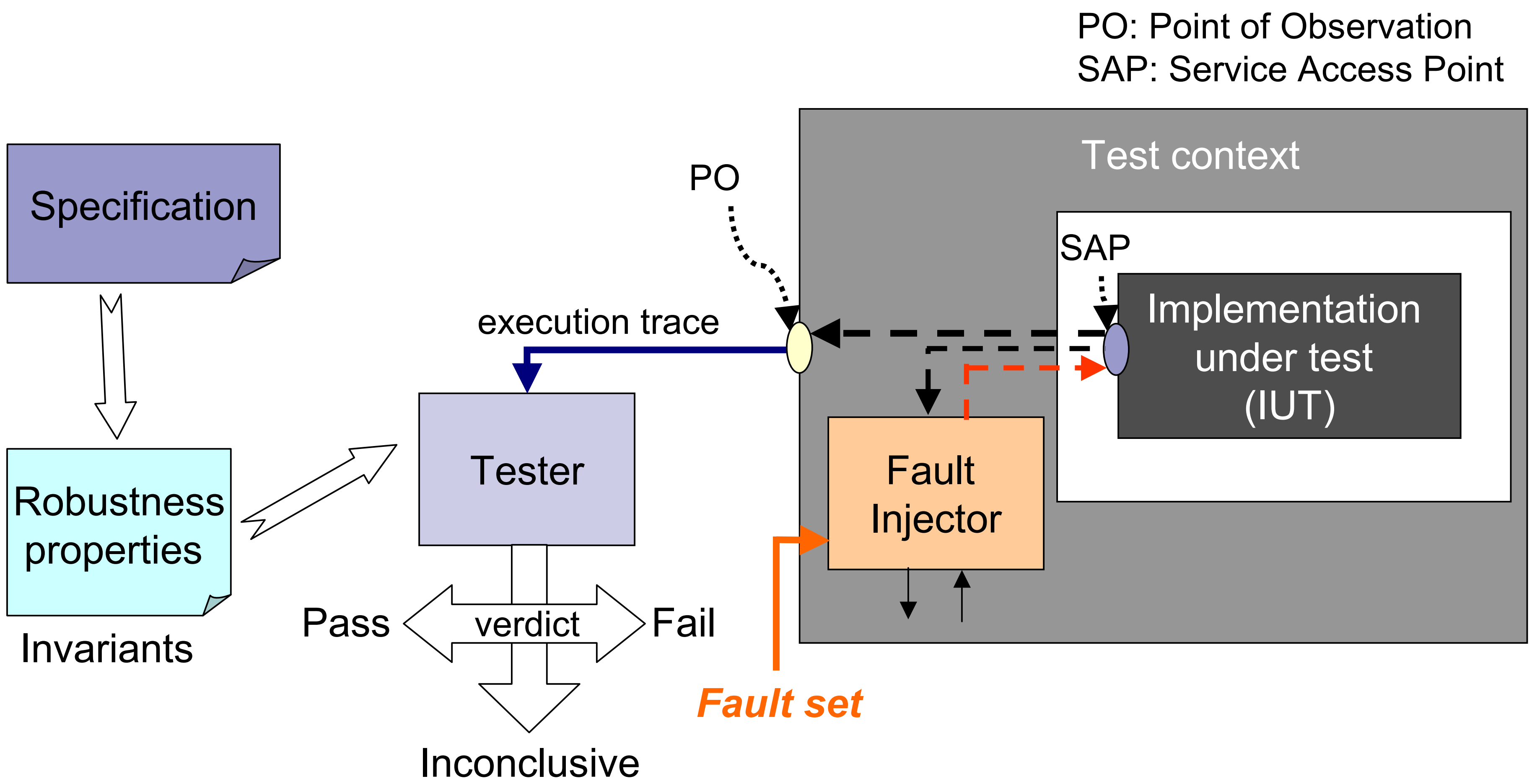
Proposed approach

- Hybrid approach combining
  - Fault injection
  - Passive testing

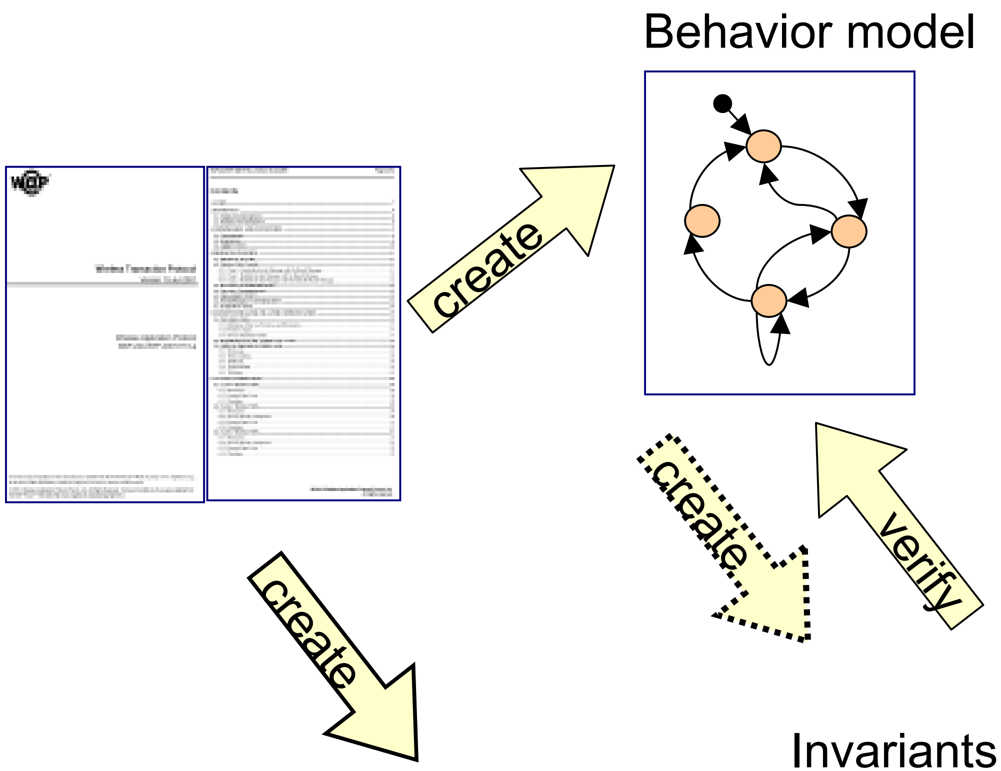
Passive testing approaches

- Based on trace acceptation
  - determines whether the observed trace satisfies the specification model
- Based on invariants

Abstract test architecture



Invariants analysis approach



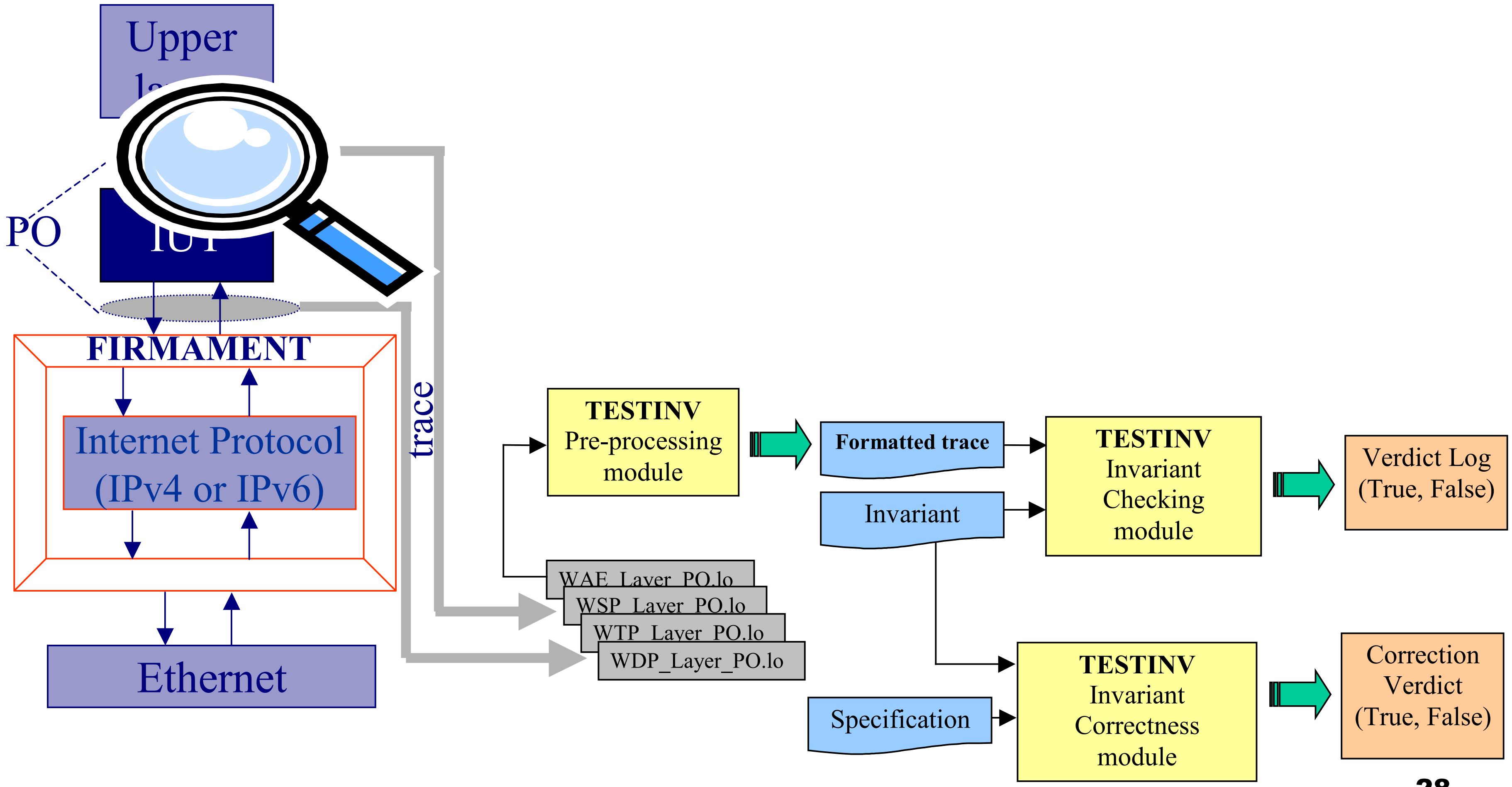
Invariants = properties of interest

Invariants in the form of regular expressions

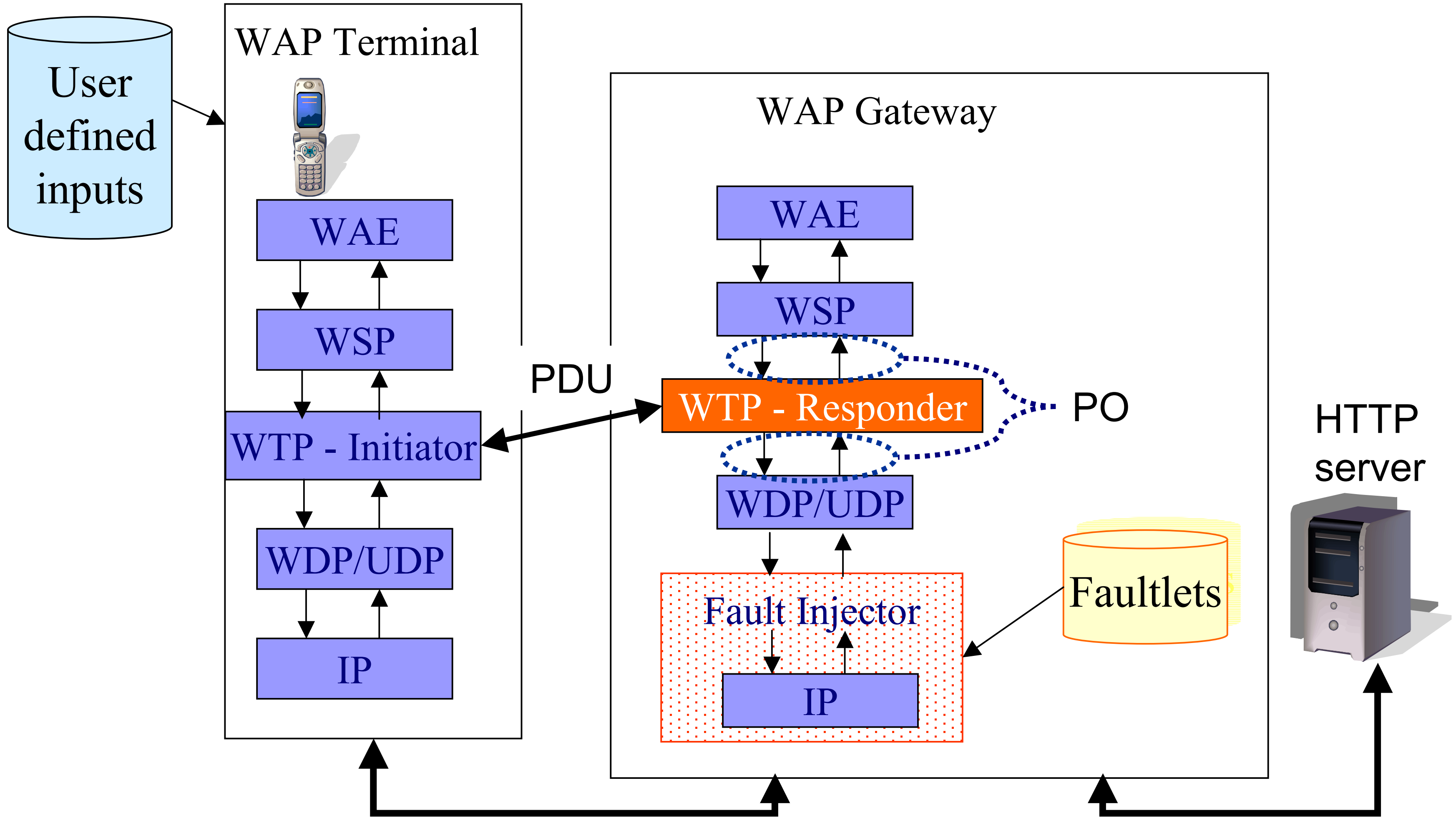
*I1 = RcvInvoke(TID = N)/?, *, TR-Invoke.res/{Ack (TID = N)}*

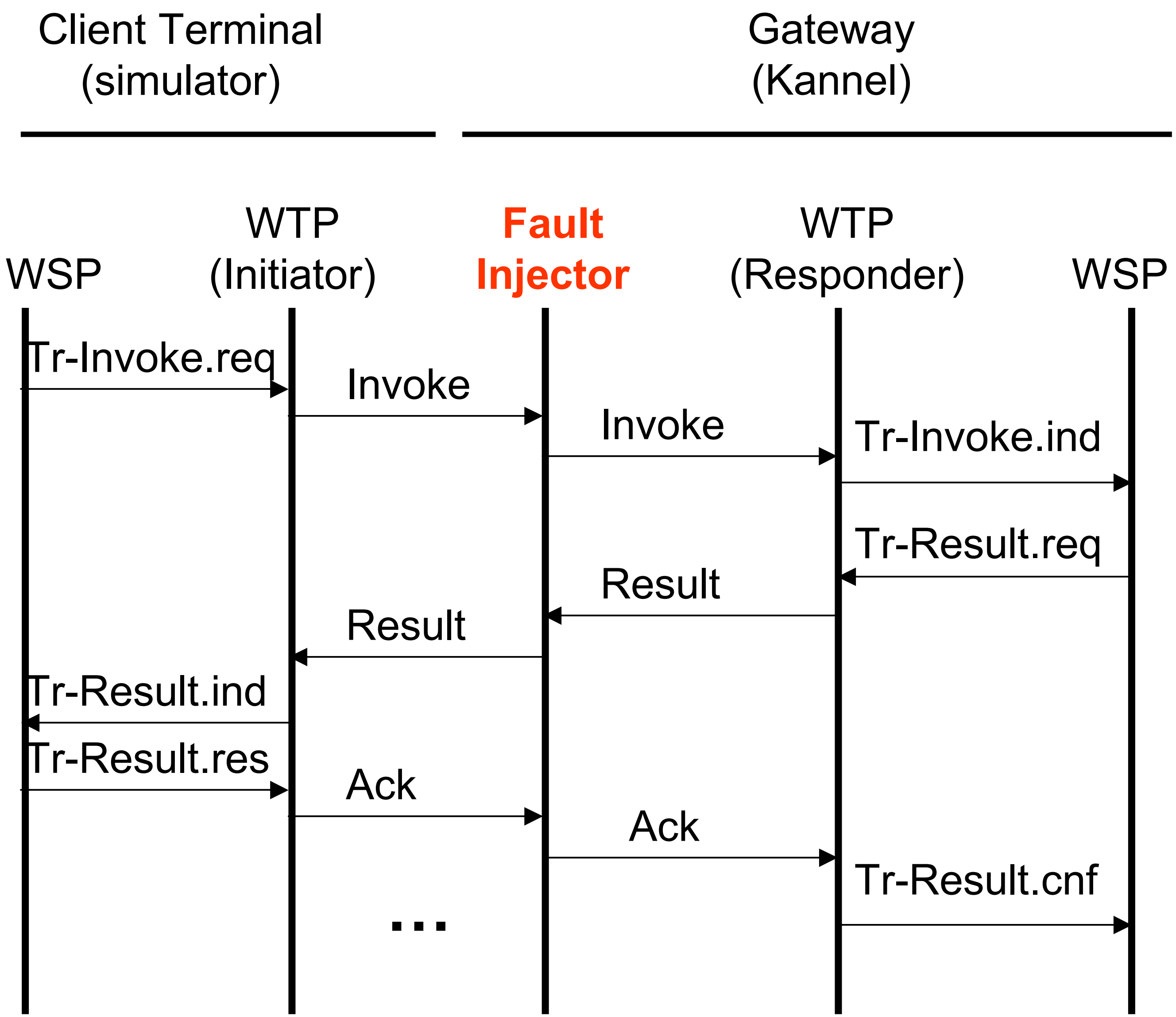
*I2= RcvInvoke(TID = N) / TR.Invoke.ind, *, TR-Invoke.res /* {Ack (TID = N) }

Test configuration

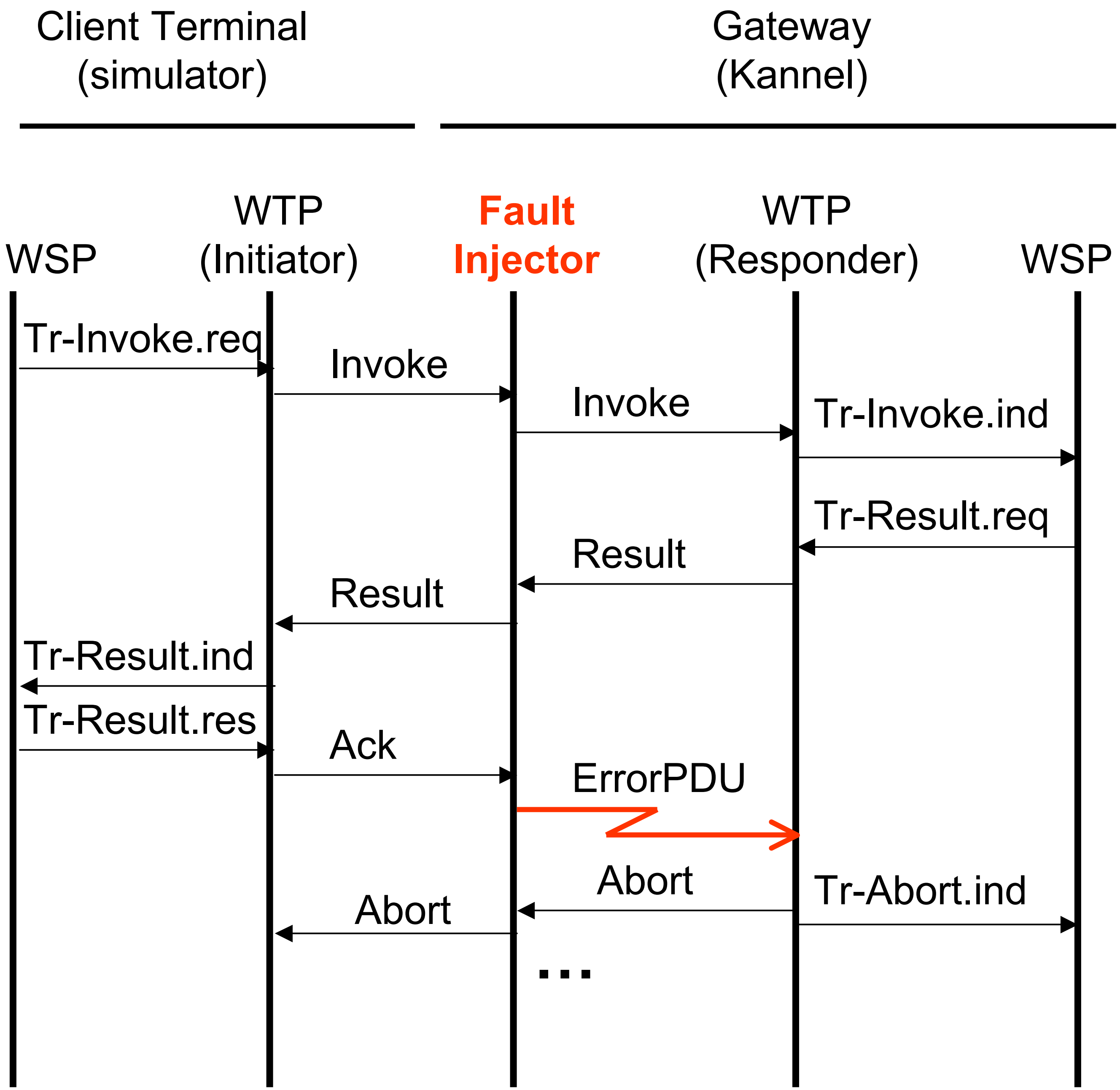


The WAP stack





No faults injected



Fault injected

An experiment that failed

Experiments	Runs	Result seen by Nokia browser	Observ.
E1- Test packet corruption. Change PDU Type	R1- Ack (0x3) →Invoke (0x1)	Requested page	
	R2- Ack (0x3) →Invalid (0x00)	Requested page	
	R3- Ack (0x3) →Result (0x2)	Error message: “Server aborted connection”	
	R4- Ack (0x3) →Invalid (0xff)	—	Browser blocked

Example of observed trace with failure (1)

```
2007-10-11 01:21:50 [6] INFO: (ORIGINATE STATE: LISTEN ; NEXT STATE:
INVOKE_RESP_WAIT)
2007-10-11 01:21:50 [6] INFO: FROM WDP: Event Name: RcvInvoke(TID=78, class=2,
Uack=1, TIDNew=0, RID=0)
2007-10-11 01:21:50 [6] INFO: TO WSP: Primitive Name: TR-Invoke.ind(class=2)
2007-10-11 01:21:50 [6] INFO:

2007-10-11 01:21:50 [6] INFO: (ORIGINATE STATE: INVOKE_RESP_WAIT ; NEXT STATE:
RESULT_WAIT)
2007-10-11 01:21:50 [6] INFO: FROM WSP: Primitive Name: TR-Invoke.res
2007-10-11 01:21:50 [6] INFO:

2007-10-11 01:21:50 [6] INFO: (ORIGINATE STATE: RESULT_WAIT ; NEXT STATE:
RESULT_RESP_WAIT)
2007-10-11 01:21:50 [6] INFO: FROM WSP: Primitive Name: TR-Result.req
2007-10-11 01:21:50 [6] INFO: TO WDP: PDU Name: Result(TID=78, RID=0)
2007-10-11 01:21:50 [6] INFO:

2007-10-11 01:21:50 [0] ERROR: pdu unpacking returned NULL
2007-10-11 01:21:50 [6] INFO: TO WDP: PDU Name: Abort(TID=78, abort-type=0,
abort-reason=1)
2007-10-11 01:21:50 [6] INFO:

2007-10-11 01:21:50 [6] INFO: TO WSP: Primitive Name: TR-Abort.ind(abort-
reason=1)
2007-10-11 01:21:50 [6] INFO:
2007-10-11 01:24:32 [0] ERROR: SIGINT received, let's die.
```

Abort PDU

TR-Abort

Wapbox hangs

Run aborted by the user

Wapbox log:

2007-10-11 01:21:50 [6] DEBUG: WTP: **Destroying WTPRespMachine 0x820def0 (23)**

2007-10-11 01:21:50 [6] DEBUG: WTP: **Created WTPRespMachine 0x8209c90 (24)**

2007-10-11 01:21:50 [6] DEBUG: WTP: resp_machine 24, state LISTEN, event RcvInvoke.

…

2007-10-11 01:21:50 [6] DEBUG: WTP: **Destroying WTPRespMachine 0x8209c90 (24)**

. . .

2007-10-11 01:21:50 [1] DEBUG: WSP: machine 0x81e90e8, state CONNECTING_2, event TR-Abort.ind

2007-10-11 01:21:50 [1] DEBUG: ----------1)handle_session_event

2007-10-11 01:21:50 [1] DEBUG: WSP 2: New state NULL_SESSION

2007-10-11 01:21:50 [1] DEBUG: **Destroying WSPMachine 0x81e90e8**

2007-10-11 01:24:32 [0] ERROR: SIGINT received, let's die.

Another experiment that failed

- Experiment 5: wrong packet size.
  - Run 2: change PDU size to small value (=2)
    - Failure: no Abort message generated as was expected!

```
2007-10-11 03:53:21 [6] INFO: (ORIGINATE STATE: LISTEN ; NEXT STATE:
INVOKE_RESP_WAIT)
2007-10-11 03:53:21 [6] INFO: FROM WDP: Event Name: RcvInvoke(TID=306,
class=2, Uack=1, TIDNew=0, RID=0)
2007-10-11 03:53:21 [6] INFO: TO WSP: Primitive Name: TR-Invoke.ind(class=2)
2007-10-11 03:53:21 [6] INFO:

2007-10-11 03:53:21 [6] INFO: (ORIGINATE STATE: INVOKE_RESP_WAIT ; NEXT STATE:
RESULT_WAIT)
2007-10-11 03:53:21 [6] INFO: FROM WSP: Primitive Name: TR-Invoke.res
2007-10-11 03:53:21 [6] INFO:

2007-10-11 03:53:21 [6] INFO: (ORIGINATE STATE: RESULT_WAIT ; NEXT STATE:
RESULT_RESP_WAIT)
2007-10-11 03:53:21 [6] INFO: FROM WSP: Primitive Name: TR-Result.req
2007-10-11 03:53:21 [6] INFO: TO WDP: PDU Name: Result(TID=306, RID=0)
2007-10-11 03:53:21 [6] INFO:

2007-10-11 03:53:21 [0 PANIC wap/wap_events.c:161: wap_event_assert:
Assertion `event != NULL' failed.
```

Crash of the wapbox

Wapbox log:

```
2007-10-11 03:53:21 [6] DEBUG: WTP 1: New state RESULT_RESP_WAIT
...
2007-10-11 03:53:21 [0] DEBUG: A too short PDU received
2007-10-11 03:53:21 [0] DEBUG: Dumping WAPEvent 0x820bad0
2007-10-11 03:53:21 [0] DEBUG:   type = T-DUnitdata.ind
2007-10-11 03:53:21 [0] DEBUG: WAPAddrTuple 0x820bb40 =
   <127.0.1.1:32787> - <0.0.0.0:9201>
2007-10-11 03:53:21 [0] DEBUG: user_data =
2007-10-11 03:53:21 [0] DEBUG:  Octet string at 0x820bd38:
2007-10-11 03:53:21 [0] DEBUG:    len:  1
2007-10-11 03:53:21 [0] DEBUG:    size: 2
2007-10-11 03:53:21 [0] DEBUG:    immutable: 0
2007-10-11 03:53:21 [0] DEBUG:    data: 18                          .
2007-10-11 03:53:21 [0] DEBUG:  Octet string dump ends.
2007-10-11 03:53:21 [0] DEBUG: WAPEvent dump ends.
2007-10-11 03:53:21 [0] PANIC: wap/wap_events.c:161: wap_event_assert:
   Assertion `event != NULL' failed.
```

Simple invariants used

S1. RcvInvoke/TR-Invoke.ind,*,TR-Result.req/{Result}

S2. RcvInvoke/TR-Invoke.ind,*,RcvAck/{TR-Result.cnf, NULL}

S3. RcvErrorPDU/{Abort, TR-Abort.ind}

S4. ?/?, *, RcvAbort/{TR-Abort.ind}

S5. ?/?, *, TimerTO_R/{Result,TR-Abort.ind}

S6. ?/?, *, TimerTO_A/{Ack,TR-Abort.ind, NULL}

S7. ?/?, *, TR-Abort.req/{Abort}

S8. RcvInvoke/Ack, *, RcvAck/{TR.Invoke.ind}

S9. RcvInvoke/Ack, *, RcvInvoke/{Ack, NULL}

S10. ?/?, *, NULL/{CRASH, HANG}

Alphabet of the machine: ≈ 20 WTP events + Hang + Crash + NULL

Discussion about observed results

- Only control flow was considered in the invariant analysis
- Observed anomalous behavior:
  - Lack of resources created new sources of failures:
    - IUT did not tolerate some OS exceptions
  - Lack of information in the specification
    - Ex.: Initiator continues to send requests for new transactions even when the Responder keeps retransmitting the same results

Conclusions

- Hybrid approach for robustness testing, combining formal and fault injection techniques:
  - Fault injection:
    - Allows better coverage of environment faults than in traditional testing
  - Passive testing:
    - Allows more precise result analysis than simply observing crash or hangs, as is usual in FI
  - Possibility to test an IUT in its context → useful in later stages of system testing or even in the field

Current work

- Approach is in use for testing robustness against attacks:
  - Cryptographic protocol testing
  - Instead of communication faults, attacks are injected
  - Attack scenarios derived from real successful attacks reported in the literature
  - Attacker is implemented by a fault injector
  - Goal: reveal vulnerabilities in the protocol implementation
  - Invariants used to represent security properties

Future works

- Algorithm for the transformation of attack scenarios into executable scenarios for the fault injector (Attacker)
- Application of the approach to a case study
- Use of sequence alignment algorithms for results analysis

Thanks!

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