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Property-Based Testing of Sensor Networks

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Sensor Network Testing is Important

- Integral to Software Development
- Sensor networks are pushing into the commercial domain
- Failure can affect the whole network
- Used in critical domains:
  - Health Care
  - Process Control

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Testing the Encoder and Decoder of a Protocol

- Functions: $encode()$ and $decode()$
- Does decoding an encoded message yield the original message?
- Test it!

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Property-Based Testing

- We specify:
  - Generic Structure of the Input
  - General properties for valid system behaviour
- A PBT tool automatically tests these properties
  - Generate wide range of input
  - Run the system under test with the generated input
  - Check the system against properties

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Example

```
prop_encode_decode() ->
  ?FORALL(I, input(),
   I == protocol:decode(protocol:encode(I))).


input() ->
  list(range(32, 127)).
```

- The input `I` is randomly **generated**
- The test code is run for each input
- The property is checked for each test instance

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Demo

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Testing Sensor Networks

- Implemented in C
  - Hardware dependent
- Distributed Systems
  - Network Topologies
  - Heterogeneous Hardware
- Functional and Non-Functional Properties
  - Energy Consumption
  - Timing

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Testing the Encoder and Decoder of a Protocol implemented in C

- Functions:

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

- Does decoding an encoded message yield the original message?
- Test it!

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Nifty

- NIF Interface Generator
- http://parapluu.github.io/nifty/

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Demo

```
prop_c_impl() ->
  ?FORALL(I, input(),
    begin
      %% Erlang List -> C string
      Message = nifty:list_to_cstr(I),
```

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

```
prop_c_impl() ->
  ?FORALL(I, input(),
    begin
      %% Erlang List -> C string
      Message = nifty:list_to_cstr(I),

      %% pointers for the encoded and decoded message
      Encoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),
      Decoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),
```

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

```
prop_c_impl() ->
  ?FORALL(I, input(),
    begin
      %% Erlang List -> C string
      Message = nifty:list_to_cstr(I),

      %% pointers for the encoded and decoded message
      Encoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),
      Decoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),

      %% encode
      0 = c_protocol:encode(Message, Encoded),

      %% decode
      0 = c_protocol:decode(nifty:dereference(Encoded), Decoded),
```

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

```
prop_c_impl() ->
  ?FORALL(I, input(),
    begin
      %% Erlang List -> C string
      Message = nifty:list_to_cstr(I),

      %% pointers for the encoded and decoded message
      Encoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),
      Decoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),

      %% encode
      0 = c_protocol:encode(Message, Encoded),

      %% decode
      0 = c_protocol:decode(nifty:dereference(Encoded), Decoded),

      %% C string -> Erlang List
      ProcessedMessage = nifty:cstr_to_list(nifty:dereference(Decoded)),
```

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

```
prop_c_impl() ->
  ?FORALL(I, input(),
    begin
      %% Erlang List -> C string
      Message = nifty:list_to_cstr(I),

      %% pointers for the encoded and decoded message
      Encoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),
      Decoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),

      %% encode
      0 = c_protocol:encode(Message, Encoded),

      %% decode
      0 = c_protocol:decode(nifty:dereference(Encoded), Decoded),

      %% C string -> Erlang List
      ProcessedMessage = nifty:cstr_to_list(nifty:dereference(Decoded)),

      %% cleanup
      nifty:free([Encoded, Decoded, Message, …]),
```

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

```
prop_c_impl() ->
  ?FORALL(I, input(),
    begin
      %% Erlang List -> C string
      Message = nifty:list_to_cstr(I),

      %% pointers for the encoded and decoded message
      Encoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),
      Decoded = nifty:as_type(nifty:pointer(), "c_protocol.char **"),

      %% encode
      0 = c_protocol:encode(Message, Encoded),

      %% decode
      0 = c_protocol:decode(nifty:dereference(Encoded), Decoded),

      %% C string -> Erlang List
      ProcessedMessage = nifty:cstr_to_list(nifty:dereference(Decoded)),

      %% cleanup
      nifty:free([Encoded, Decoded, Message, …]),

      %% result
      I =:= ProcessedMessage
    end).
```

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

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Demo

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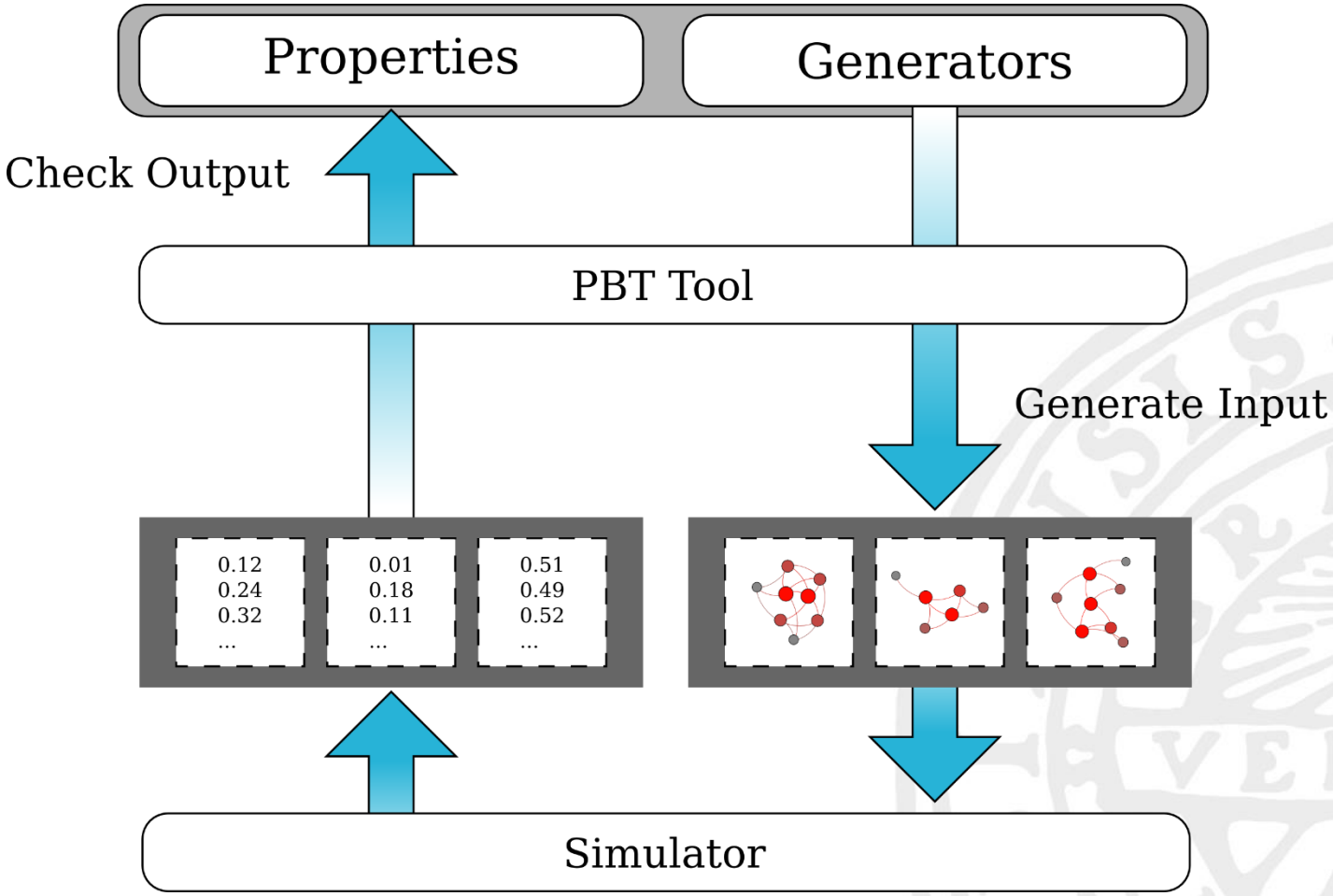
Framework



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Duty-Cycle of X-MAC

- Setup:
  - Random distribution of UDP server and client nodes
  - Client nodes sends periotically messages to server nodes
  - IPv6 and RPL
- Test:
  - Has X-MAC for any network a duty-cycle > 10%?

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Property

```
prop_xmac() ->
  ?FORALL(Motes, motes(),
```

- Generates a random configuration of motes
- Motes:
  - Position (x,y, 0)
  - Mote with ID 2 is server
  - Other motes are clients

```
mote() ->
  tuple([float(0, 100),
         float(0, 100),
         0.0]).

motes() ->
  ?SUCHTHAT(Motes, list(mote()),
            length(Motes)>=2).
```

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Property

```
prop_xmac() ->
  ?FORALL(Motes, motes(),
    begin
      Handler = nifty_cooja:start("…", "…xmac.csc", []),
      Mote_IDs = add_motes(Handler, Motes),
```

- Start and initialize the simulation

```
add_mote(Handler, {Pos, Type}) ->
  {ok, ID} = nifty_cooja:mote_add(Handler, Type),
  ok = nifty_cooja:mote_set_pos(Handler, ID, Pos),
  ok = nifty_cooja:mote_hw_listen(Handler, ID),
  ID.
```

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Property

```
prop_xmac() ->
  ?FORALL(Motes, motes(),
    begin
      Handler = nifty_cooja:start("…", "…xmac.csc", []),
      Mote_IDs = add_motes(Handler, Motes),
      ok = nifty_cooja:simulation_step(Handler, 120000),
```

- Run the simulation

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Property

```
prop_xmac() ->
  ?FORALL(Motes, motes(),
    begin
      Handler = nifty_cooja:start("…", "…xmac.csc", []),
      Mote_IDs = add_motes(Handler, Motes),
      ok = nifty_cooja:simulation_step(Handler, 120000),
      DutyCycle = duty_cycle(Handler, Mote_IDs),
      R = check_duty_cycling(DutyCycle, 0.1),
```

- Retrieve and check the duty cycle

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Property

```
prop_xmac() ->
  ?FORALL(Motes, motes(),
    begin
      Handler = nifty_cooja:start("…", "…xmac.csc", []),
      Mote_IDs = add_motes(Handler, Motes),
      ok = nifty_cooja:simulation_step(Handler, 120000),
      DutyCycle = duty_cycle(Handler, Mote_IDs),
      R = check_duty_cycling(DutyCycle, 0.1),
      ok = nifty_cooja:exit(),
      R
    end).
```

- cleanup

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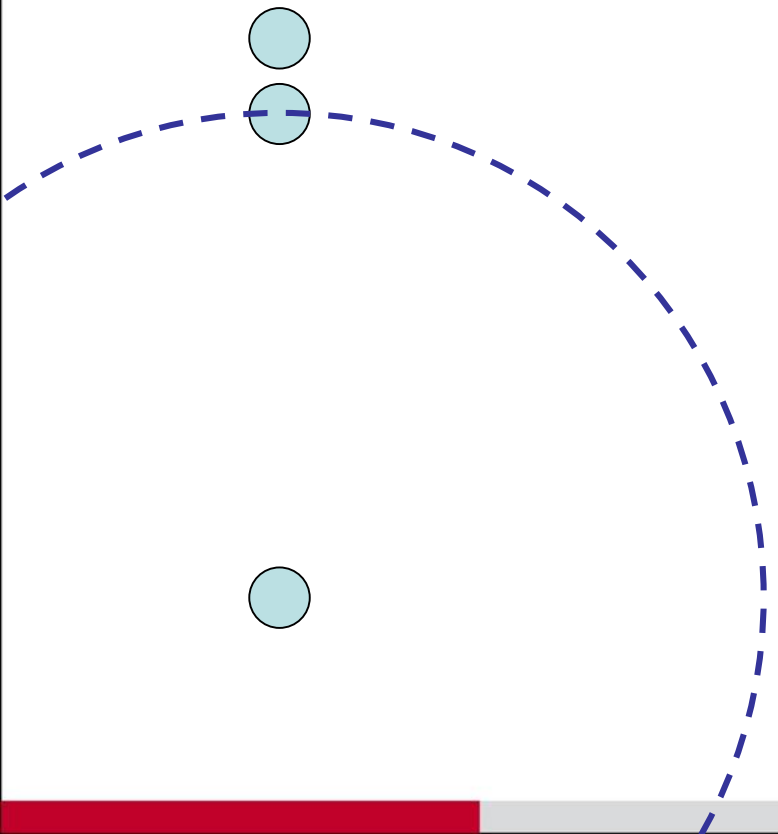
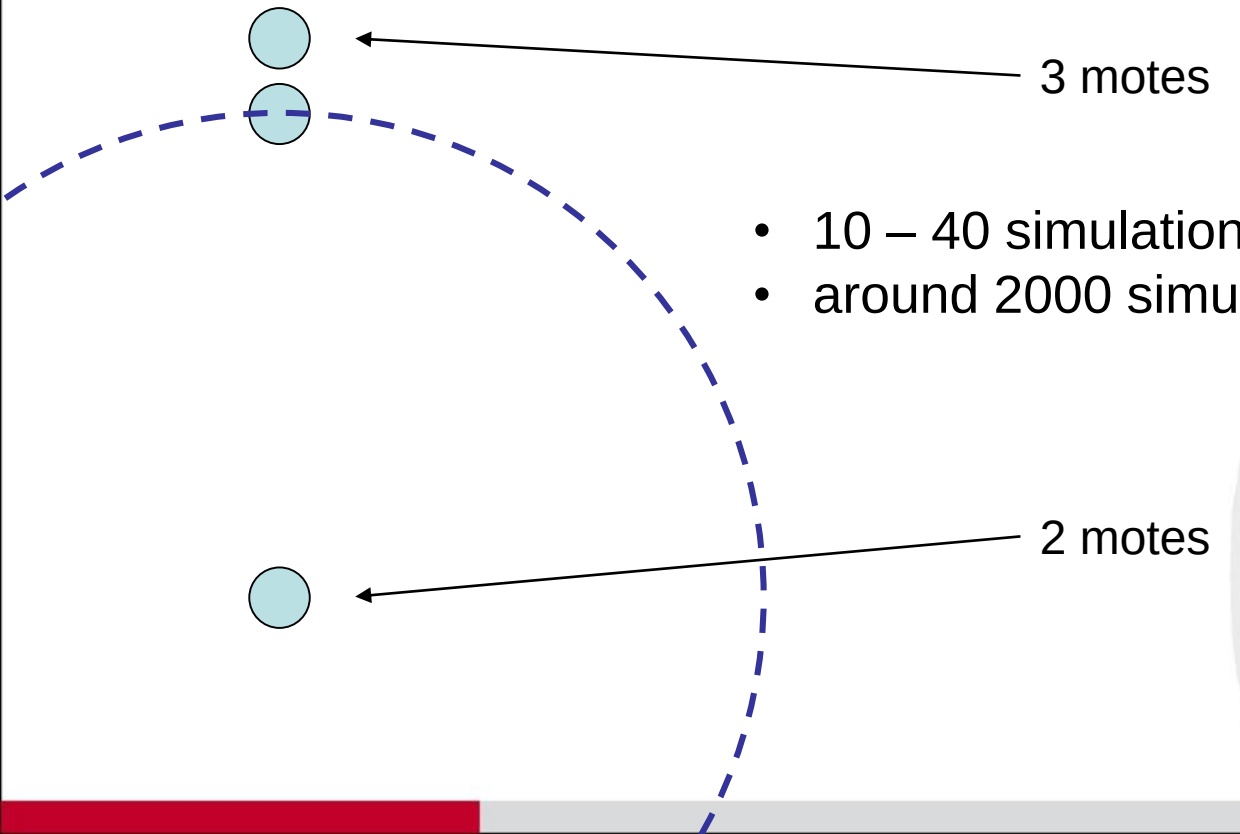
Results

- Counterexample with around 15 motes which can be shrunk down to 6 motes



Results

- Counterexample with 15 motes which was shrunk down to 6 motes



- 10 – 40 simulations to find counterexample
- around 2000 simulations for shrinking

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Results

- PropEr shrinks based on the used generators

- The Network topology is infered by the placement
- Shrinking influences the network topology only indirect

- Generators that produce graphs perform much better

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Testing the Encoder and Decoder of a Protocol on a Sensor Node

- Functions:

```
extern int encode(char*, char**);
extern int decode(char*, char**);
```

- Does decoding an encoded message yield the original message?
- Test it!

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Nifty for ContikiOS

- Contiki OS (http://www.contiki-os.org/) interface generator
- http://parapluu.github.io/nifty-contiki/

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Nifty for ContikiOS

```
0 = contiki_protocol:encode(Handler, 1, Message, Encoded)
```

Simulation Handler

Mote ID

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Contiki's Socket API

- C-API for handling TCP sockets in Contiki
- Non-Blocking (return values over an event handler)

- Test:
  - Are the correct events triggered?

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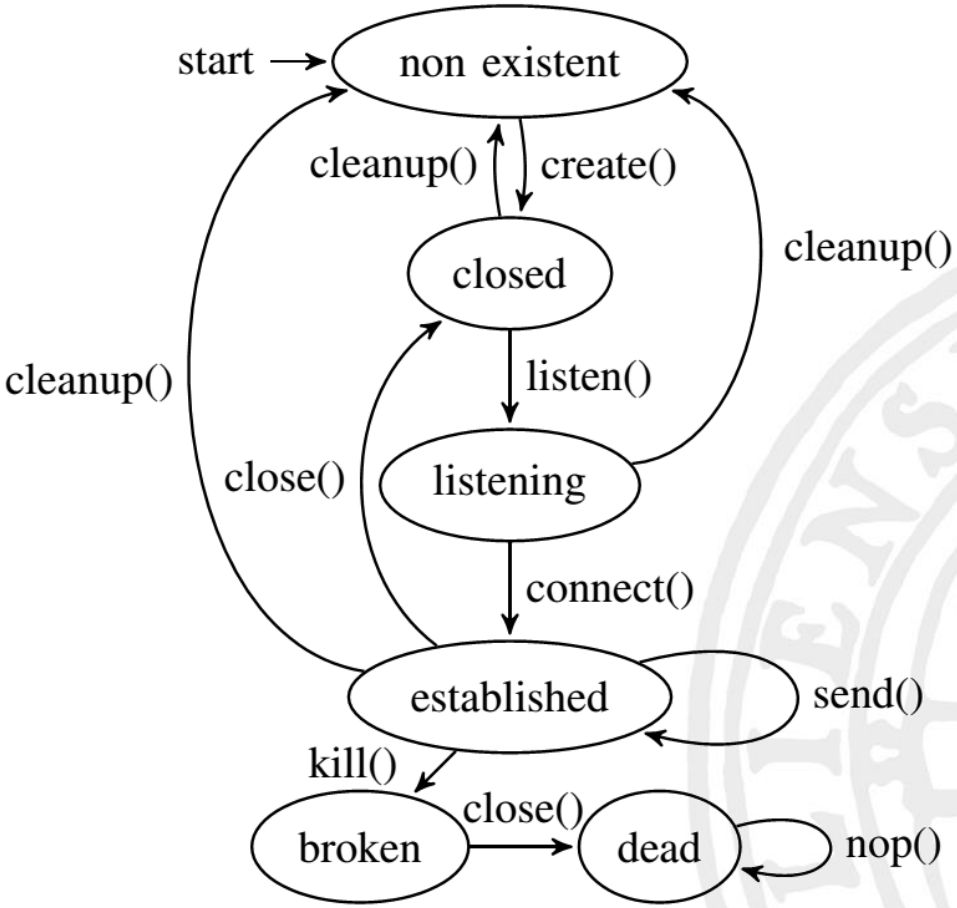
Input

- Input:
  - List of function calls to the socket interface
- A complete random order of the function calls makes not much sense.
- We use an Finite State Machine to restrict the possible combinations of calls.

FSM for operations on 2 Sockets



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Results

1. Reception of an empty message after connect() that was never sent
2. Double ”closed” event on socket that was remotely closed
3. Missing ”closed” event after a sequence of 14 commands, which was shrunk to 8 commands

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Results

```
create  -> listen  -> connect ->
cleanup -> create  -> listen  ->
connect -> close (on socket that
                  listened)
```

- Any change on the sequence will make the bug not show