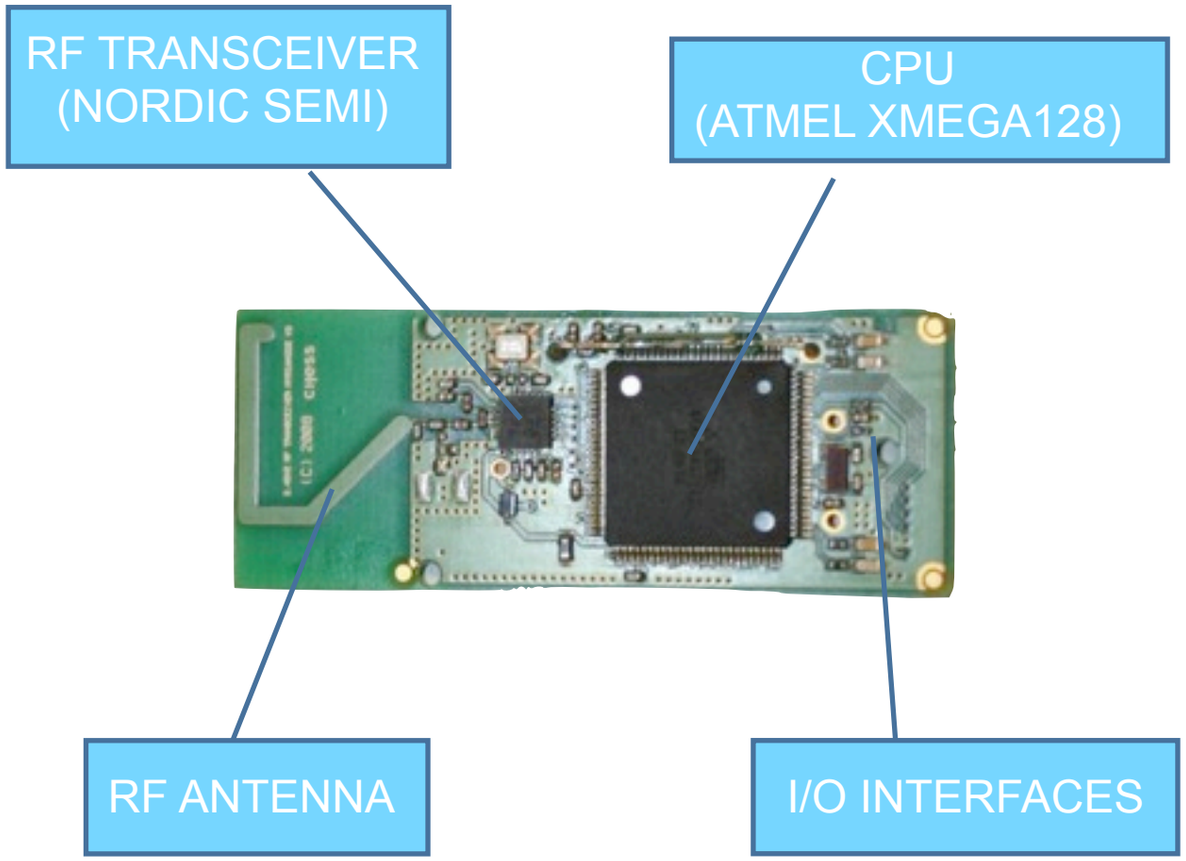
Model-Based Testing of a Wireless Sensor Network Node

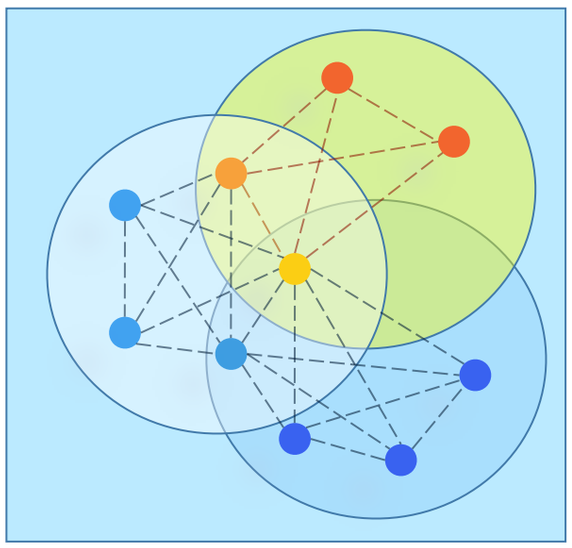
Axel Belinfante	Universiteit Twente
Jan Tretmans	Radboud Universiteit / ESI
Feng Zhu	Radboud Universiteit
Marcel Verhoef	Chess
Frits van der Wateren	Chess (WSN guru!)

What...

is our system under test?

A *MyriaNed*
Wireless
Sensor
Network
node...





- Shares data by gossiping
- Conserves energy by sleeping

Testing a Wireless Sensor Network Node

What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to
  network density

What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density

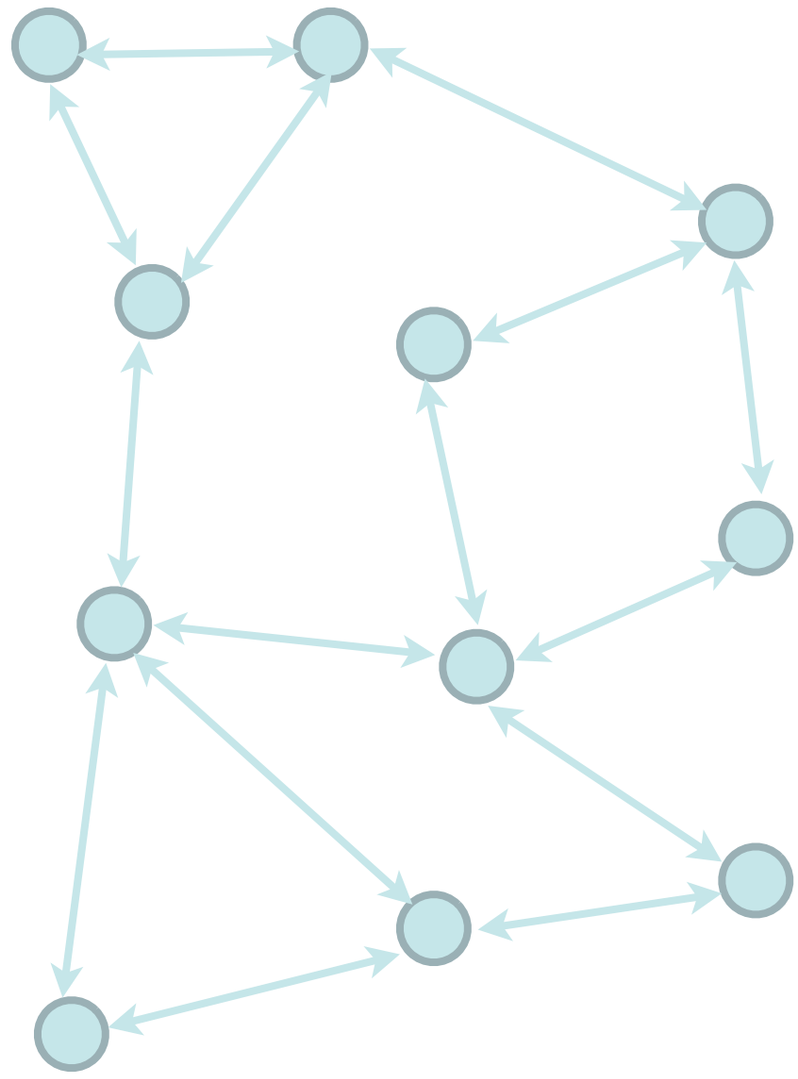
- 'clean' node
- 'new' data
- 'old' data
- GOSSIP →

Testing a Wireless Sensor Network Node

What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density

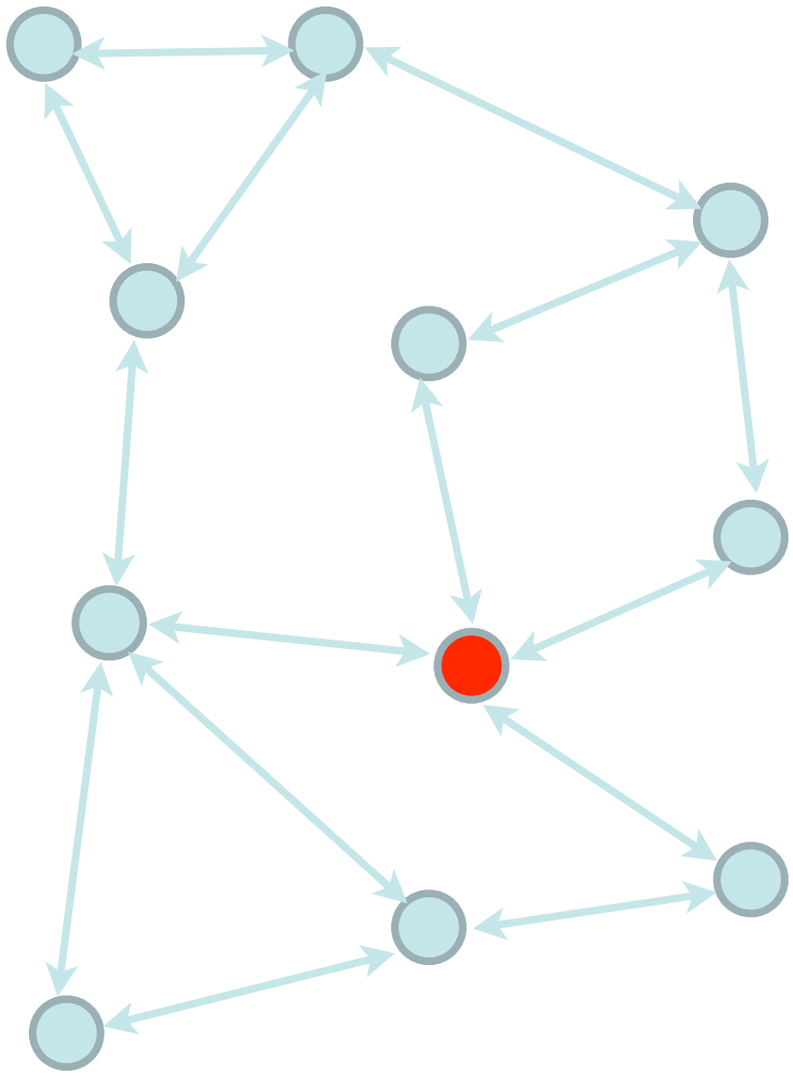


Testing a Wireless Sensor Network Node

What

about sharing data by gossipping?

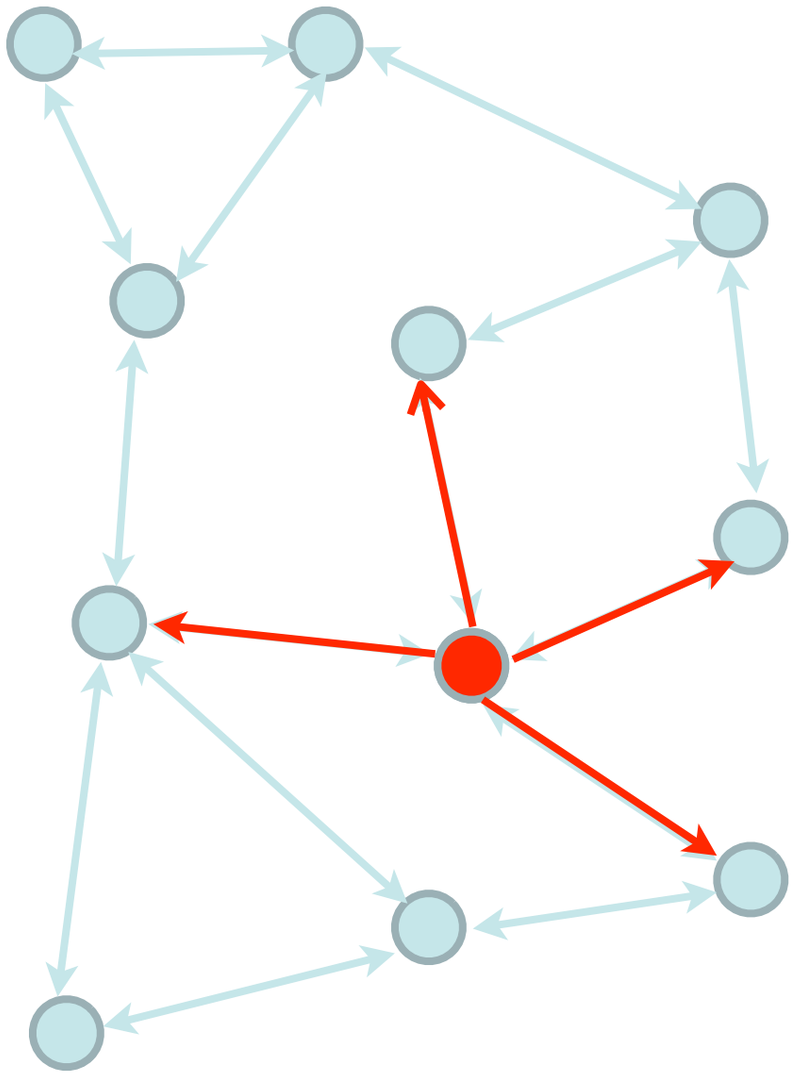
- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density



What

about sharing data by gossipping?

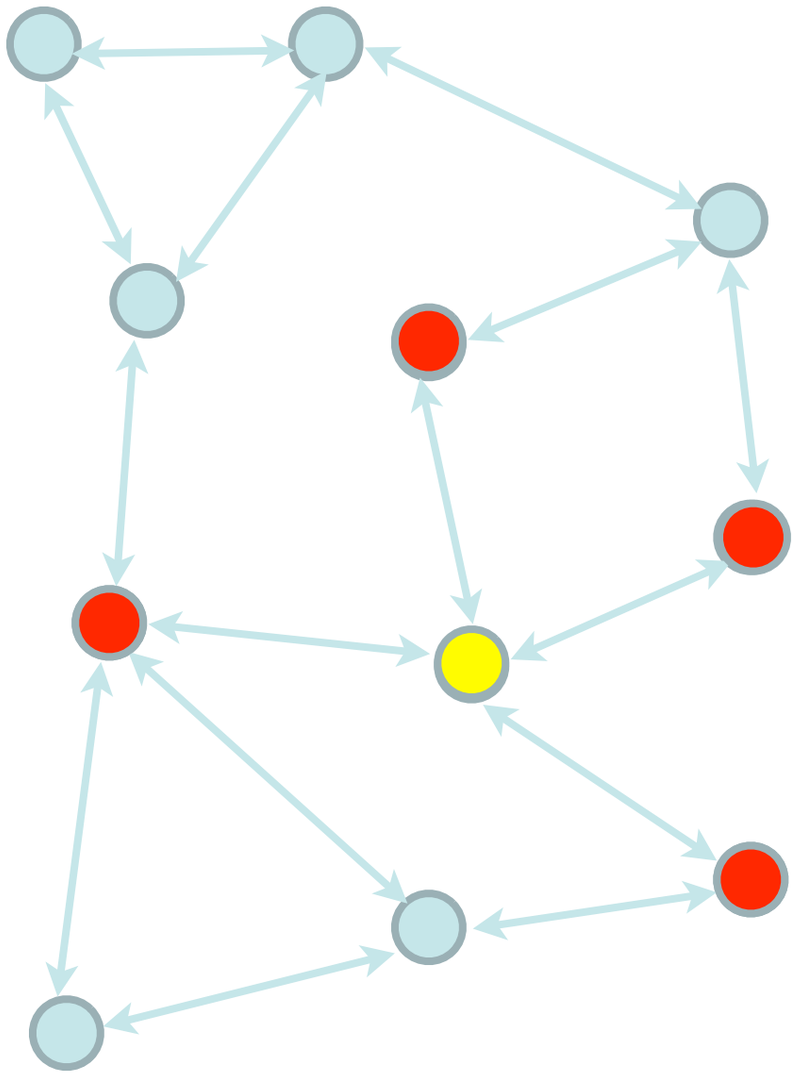
- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density



What

about sharing data by gossipping?

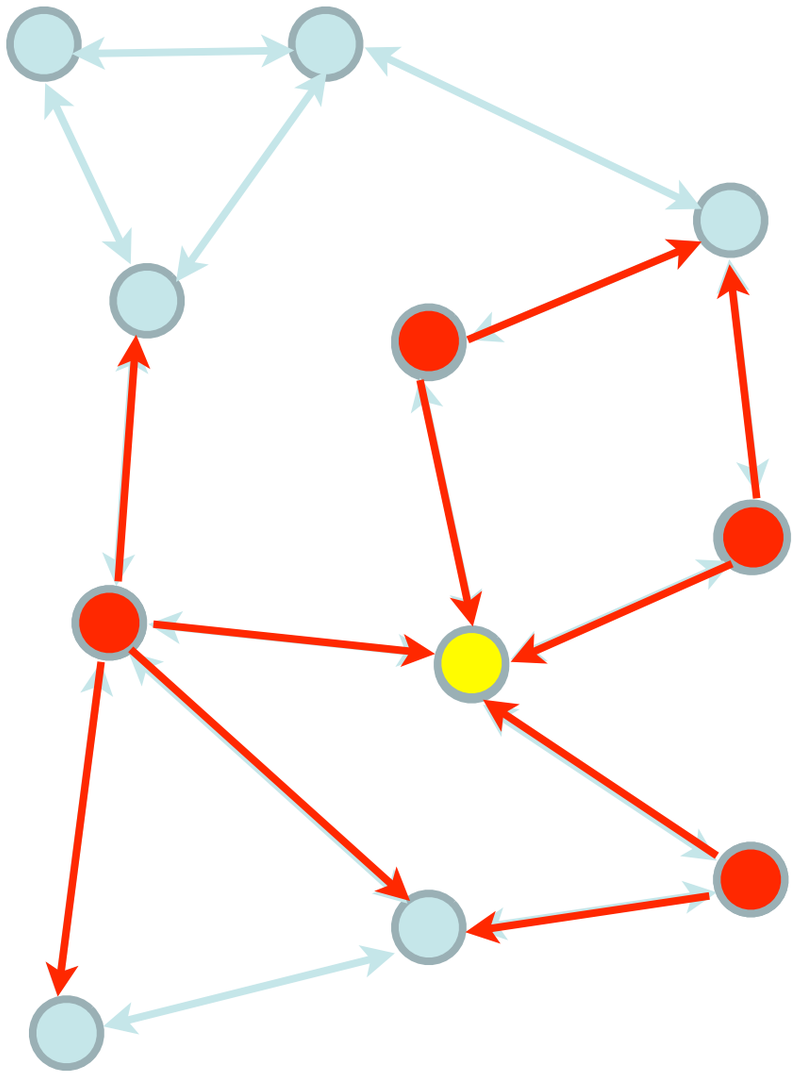
- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density



What

about sharing data by gossipping?

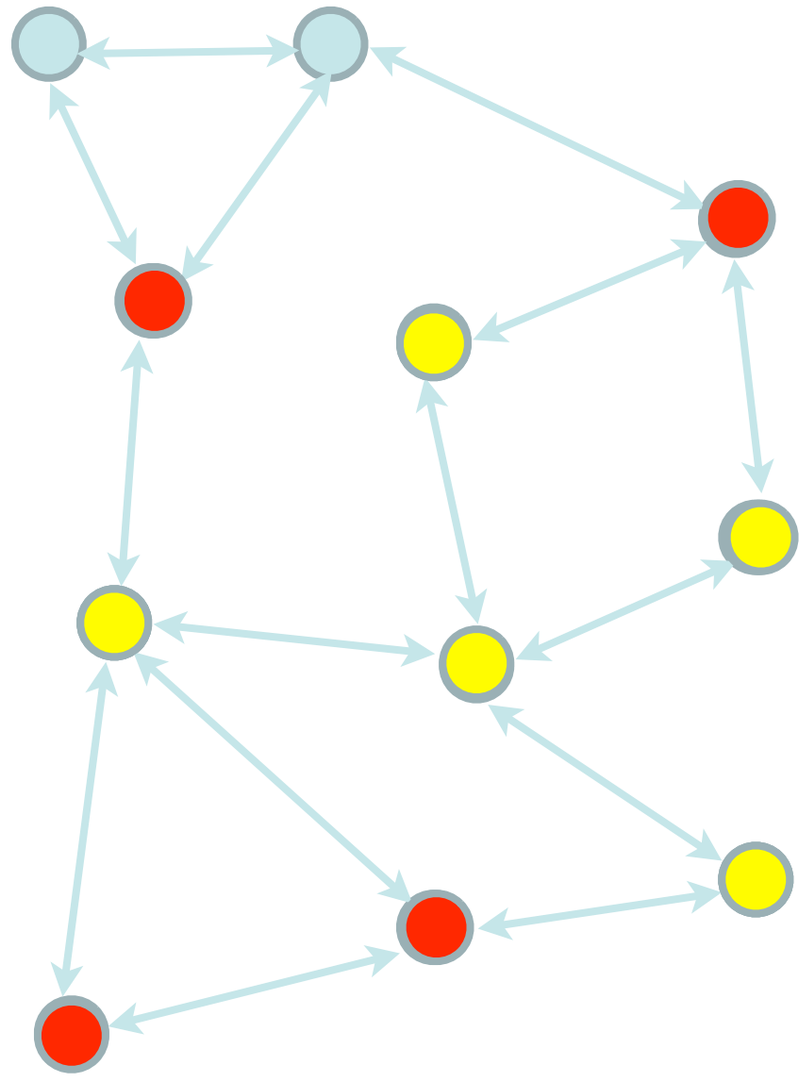
- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density



What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density

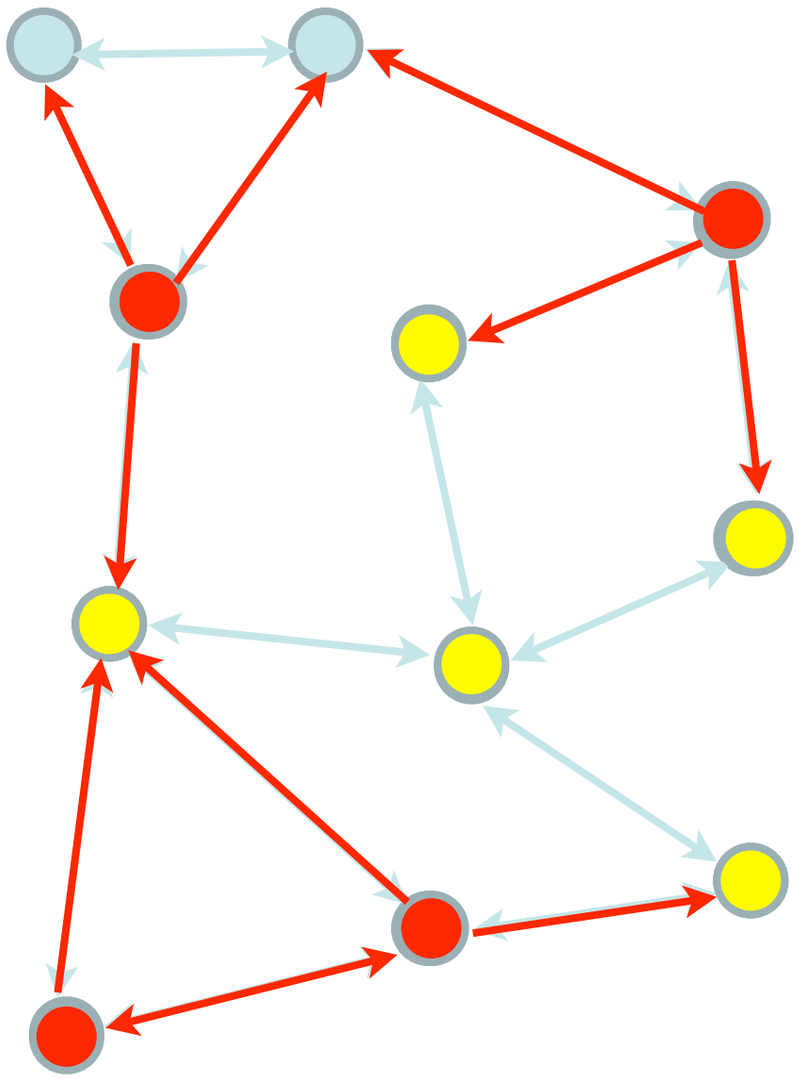


Testing a Wireless Sensor Network Node

What

about sharing data by gossipping?

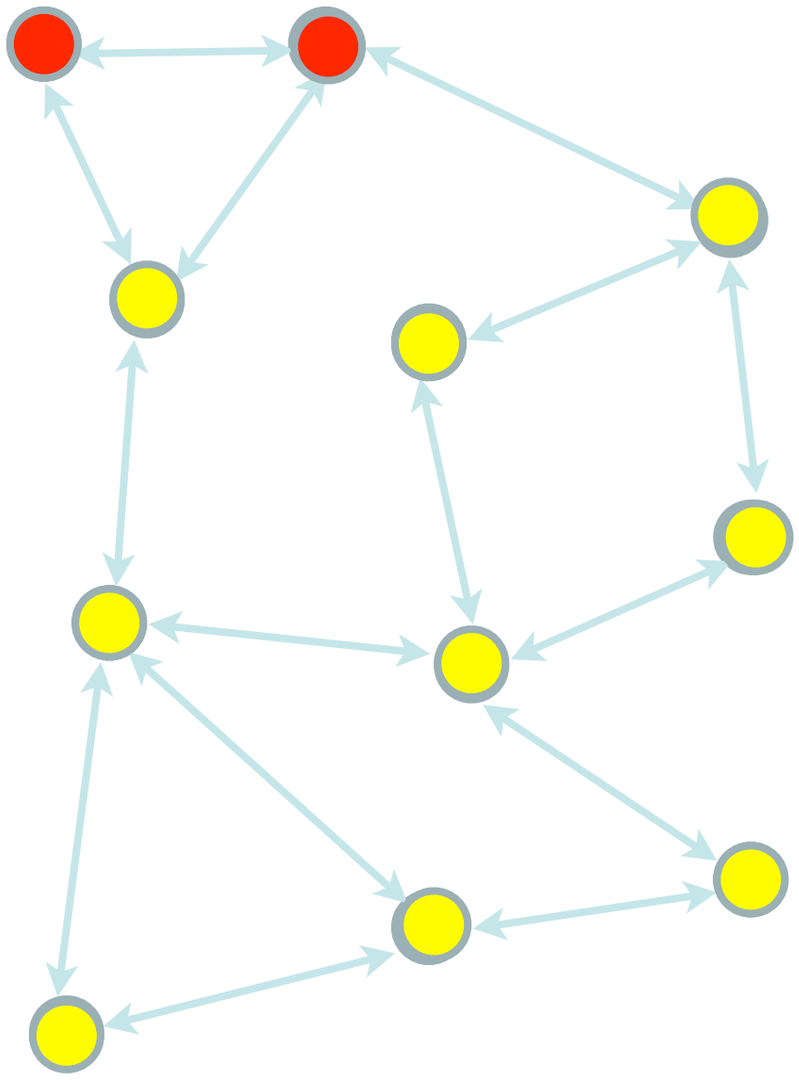
- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density



What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density

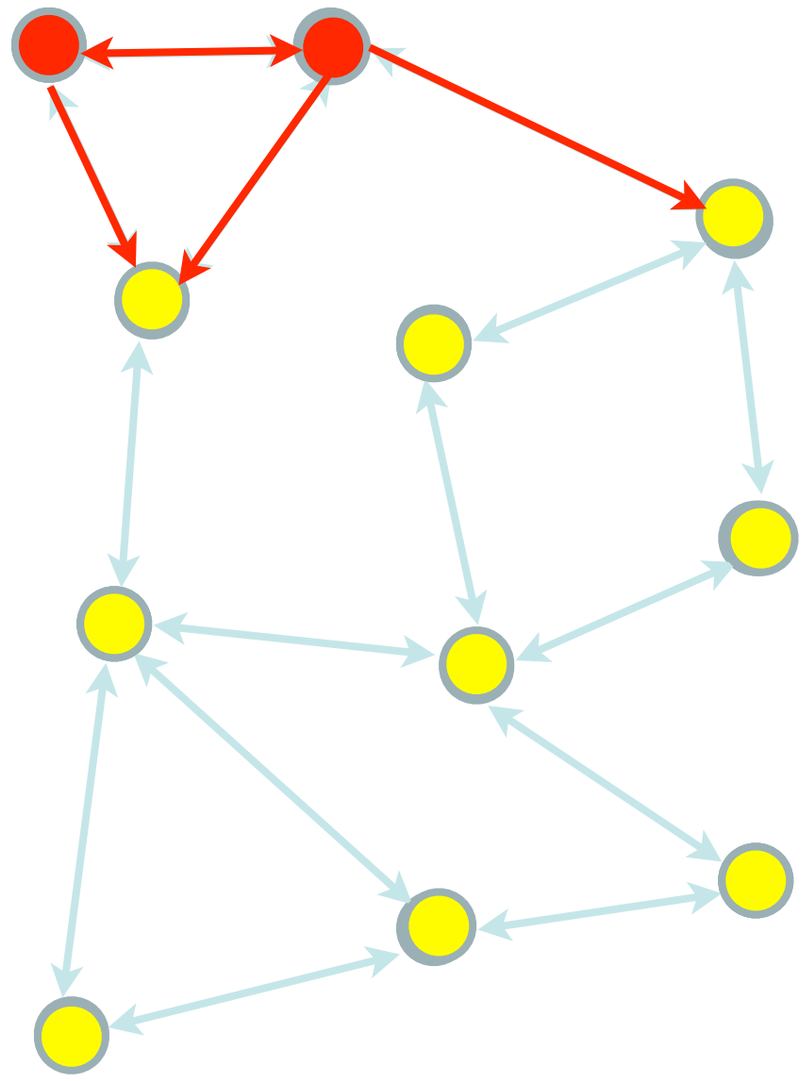


Testing a Wireless Sensor Network Node

What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density

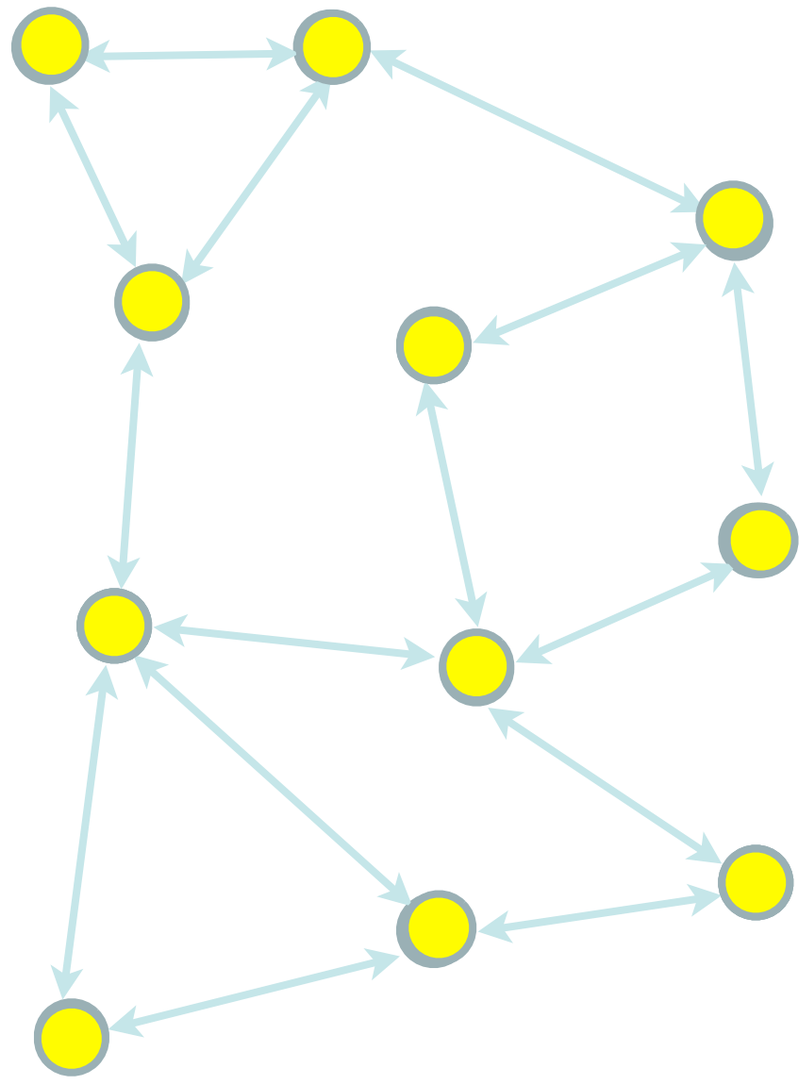


Testing a Wireless Sensor Network Node

What

about sharing data by gossipping?

- MyriaNed 'GOSSIP' protocol
- inspired on biology and human interaction
- **robust**,
  scalable,
  inherently self-configuring,
  supports mobility,
  automatic adaptation to network density



Testing a Wireless Sensor Network Node

What...

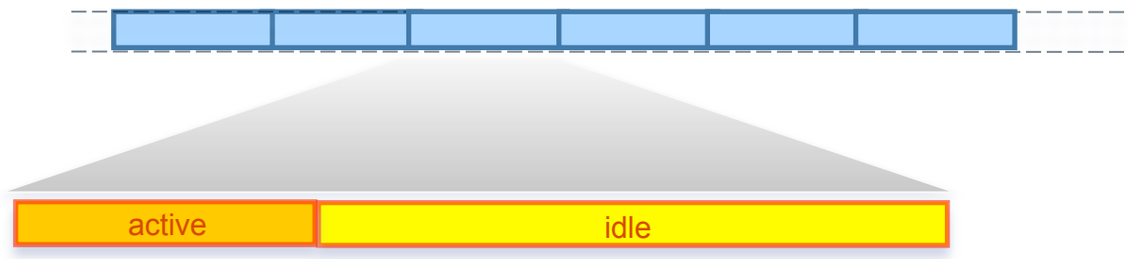
about conserving energy?

What...

about conserving energy?

- reduce duty cycle (cpu/radio)

➡ *synchronize* active periods

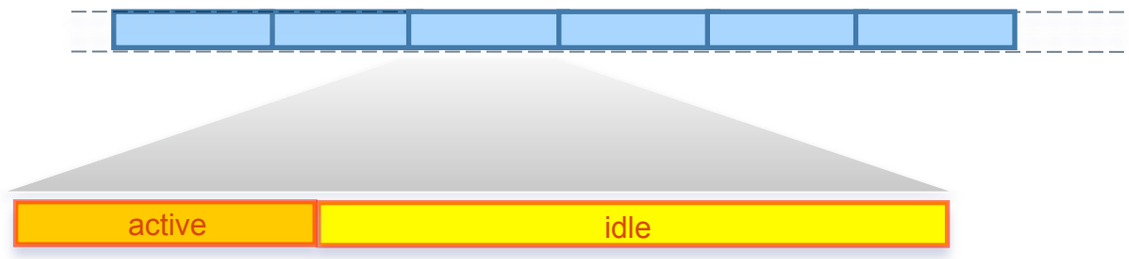


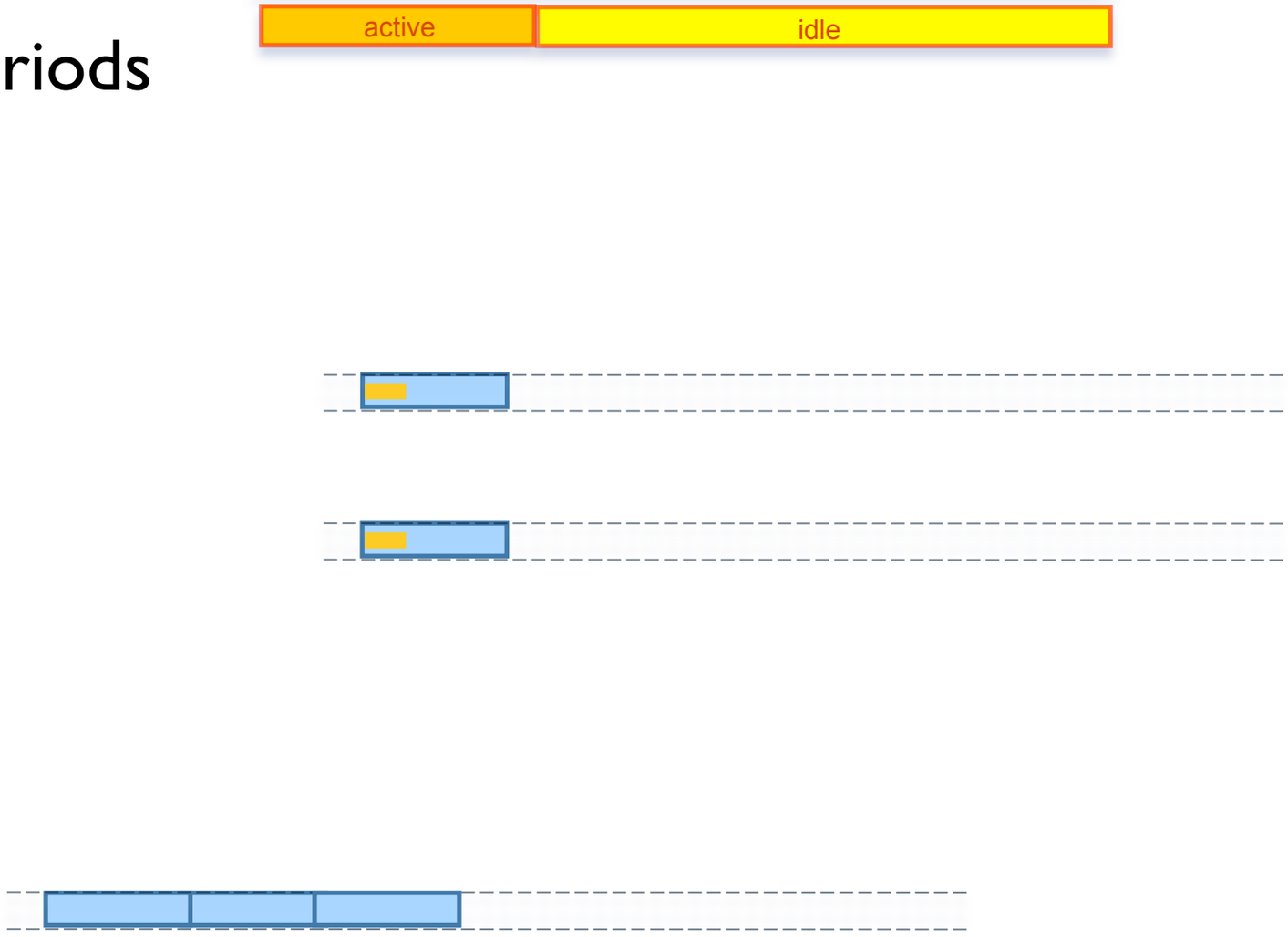
What...

about conserving energy?

- reduce duty cycle (cpu/radio)

➡ *synchronize* active periods





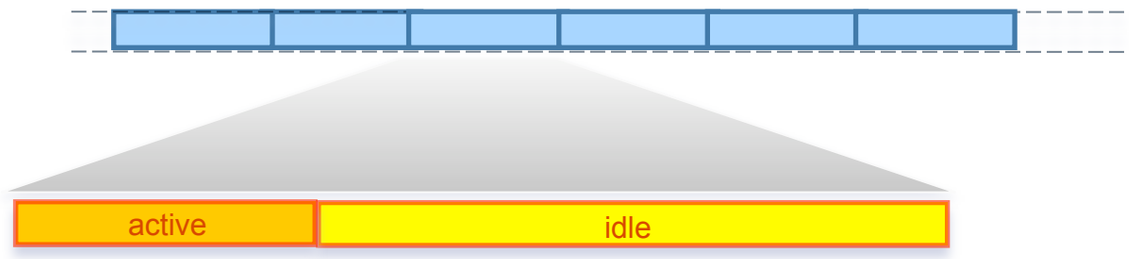
Testing a Wireless Sensor Network Node

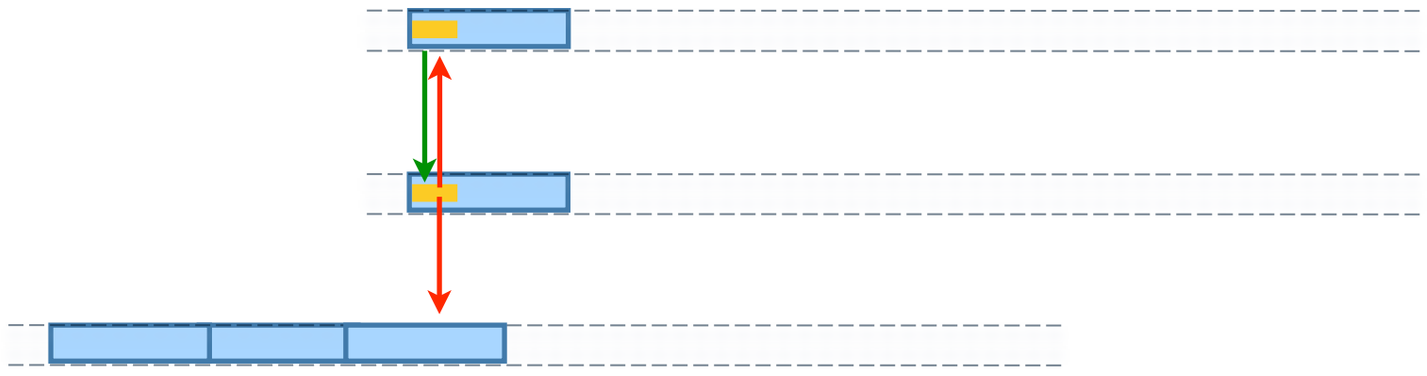
What...

about conserving energy?

- reduce duty cycle (cpu/radio)

➡ *synchronize* active periods





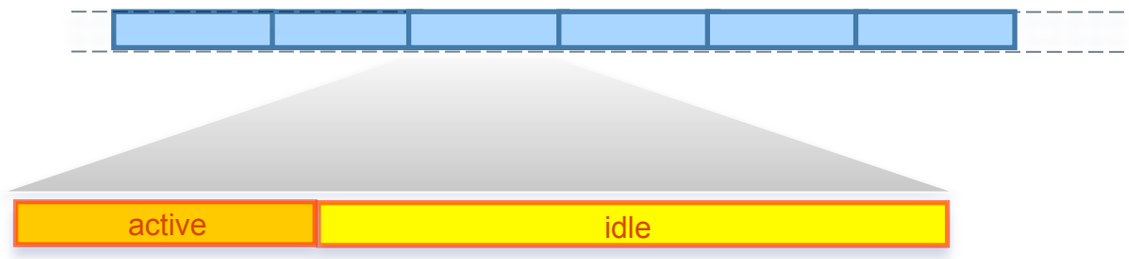
Testing a Wireless Sensor Network Node

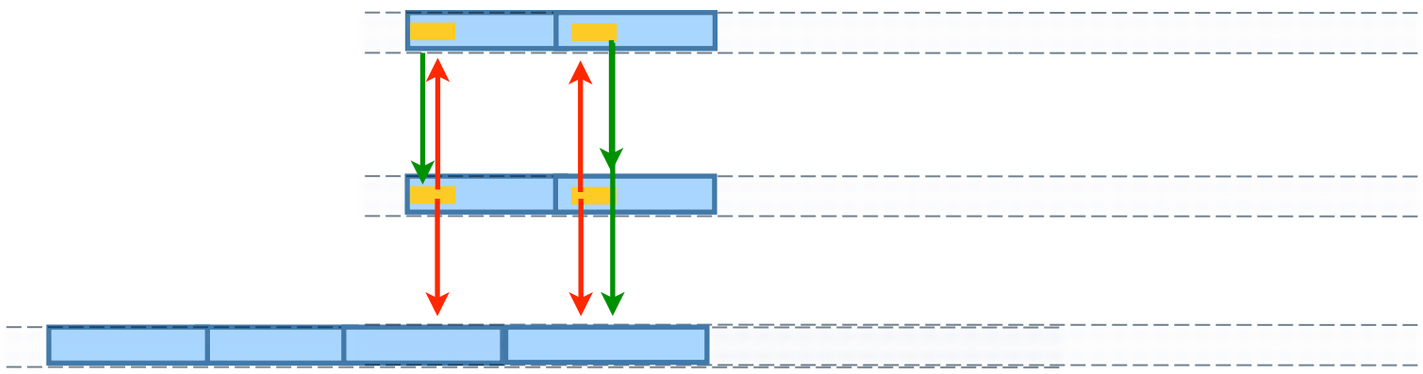
What...

about conserving energy?

- reduce duty cycle (cpu/radio)

➡ *synchronize* active periods





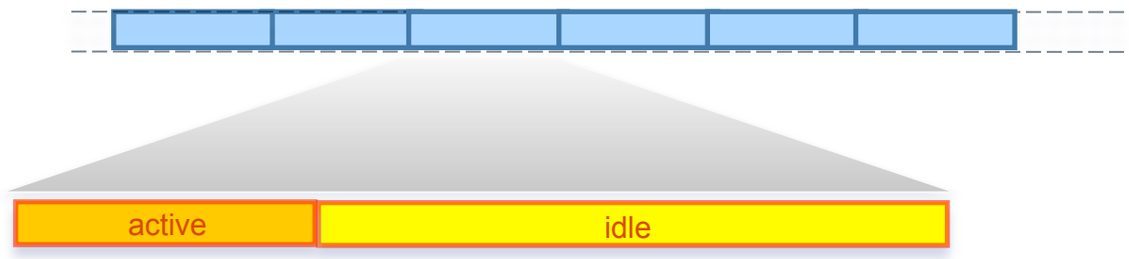
Testing a Wireless Sensor Network Node

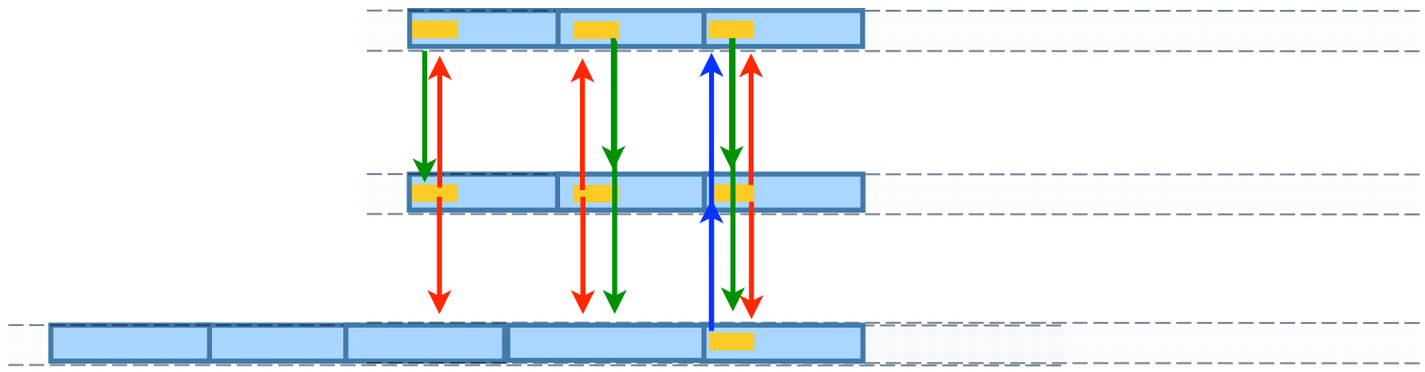
What...

about conserving energy?

- reduce duty cycle (cpu/radio)

➡ *synchronize* active periods





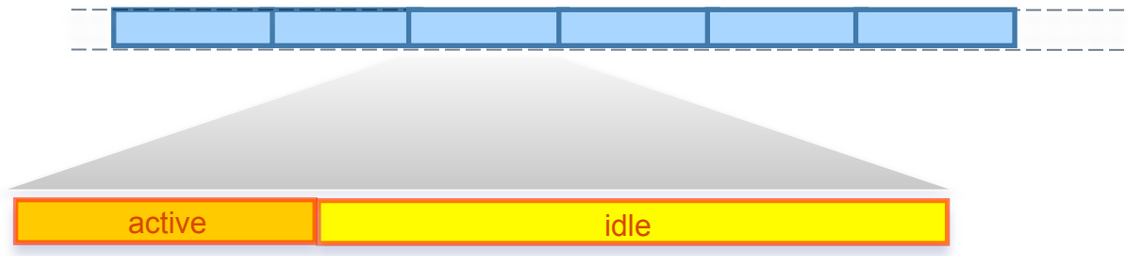
Testing a Wireless Sensor Network Node

What...

about conserving energy?

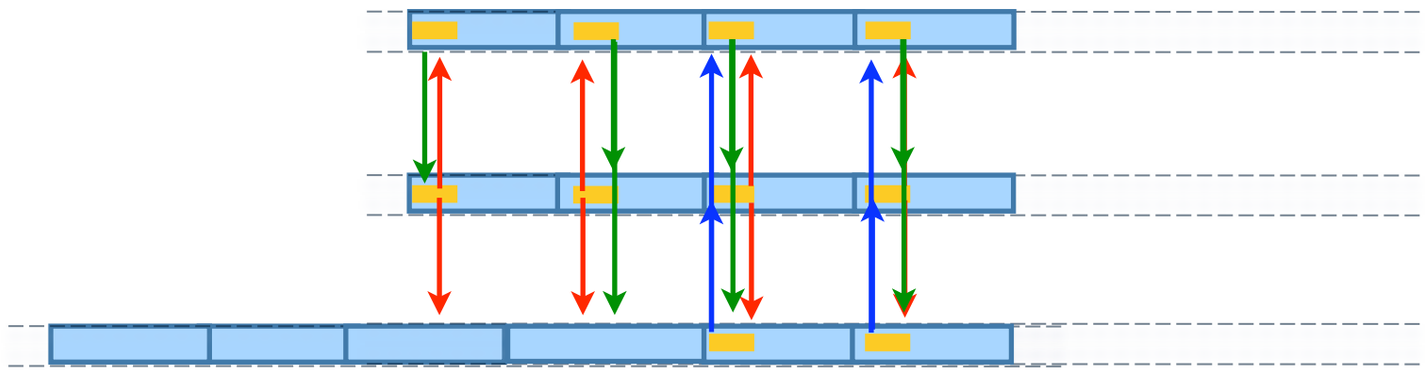
- reduce duty cycle (cpu/radio)

  ➡ *synchronize* active periods



- time slots are shared

  ➡ *collisions*

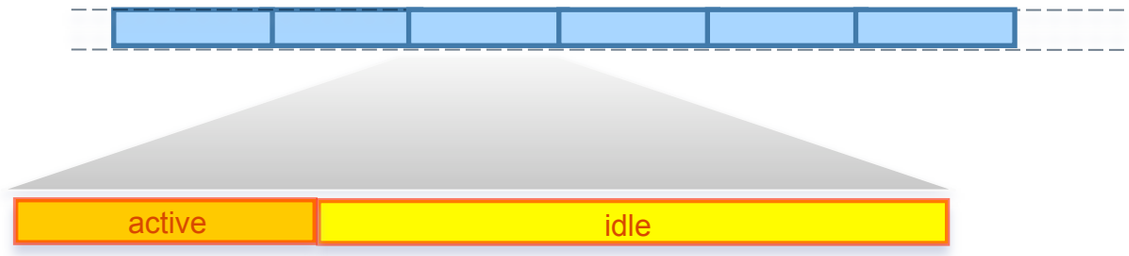


What...

about conserving energy?

- reduce duty cycle (cpu/radio)

  ➡ *synchronize* active periods

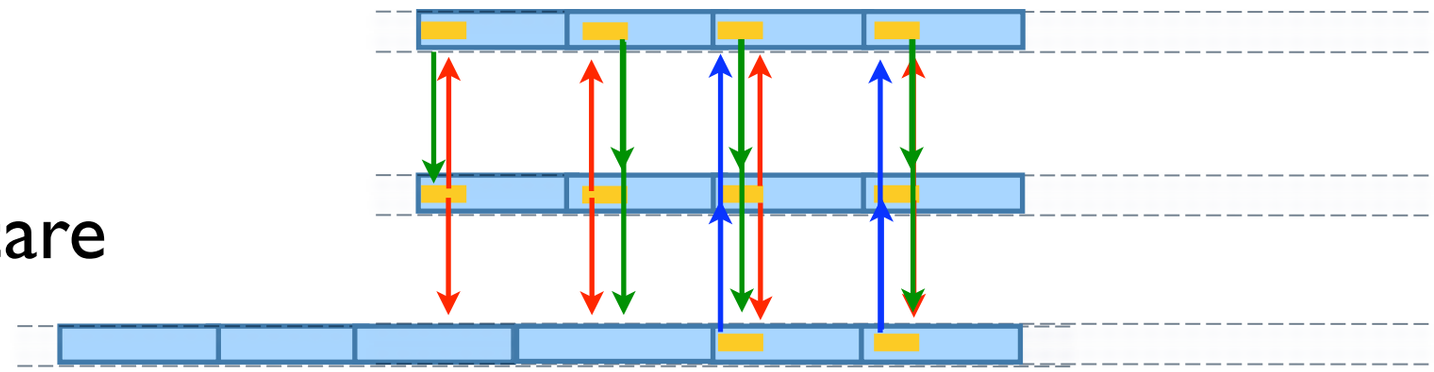


- time slots are shared

  ➡ *collisions*

- gMAC protocol takes care

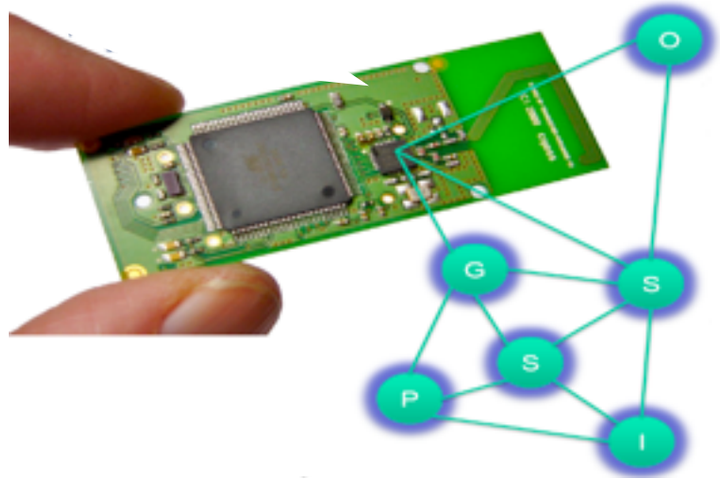
  - *employs* randomization



Testing a Wireless Sensor Network Node

Why... is *CHESS* interested in MBT of WSN nodes?

- MyriaNed has *potential*
- has to be 'first time right'
- correctness gMAC crucial!!
- use *all* methods available
- MBT offers unique debugging angle
- obtaining Model extracts knowledge from designers



Testing a Wireless Sensor Network Node

Why...

are *we* interested in MBT of WSN nodes?

Why...

are *we* interested in MBT of WSN nodes?

universities

Why...

are *we* interested in MBT of WSN nodes?

universities

MBT is our thing, baby...

Testing a Wireless Sensor Network Node

Why...

are *we* interested in MBT of WSN nodes?

universities

Why...

are *we* interested in MBT of WSN nodes?

universities

- case unlike previous cases
  yes, really!
  for multiple reasons

- time is *essential*
  *(*but *simulated time* suffices*)*

- non-determinism is *essential*

- product in *active development*

- guru-based process

- cool product,
  inspiring CHESS team!!!

MBT is our thing, baby...

yes, really!

Why...

are *we* interested in MBT of WSN nodes?

universities

- case unlike previous cases
  yes, really!
  for multiple reasons

- time is *essential*
  *(*but *simulated time* suffices*)*

- non-determinism is *essential*

- product in *active development*

- guru-based process

- cool product,
  inspiring CHESS team!!!

... this differs also from other cases discussed here

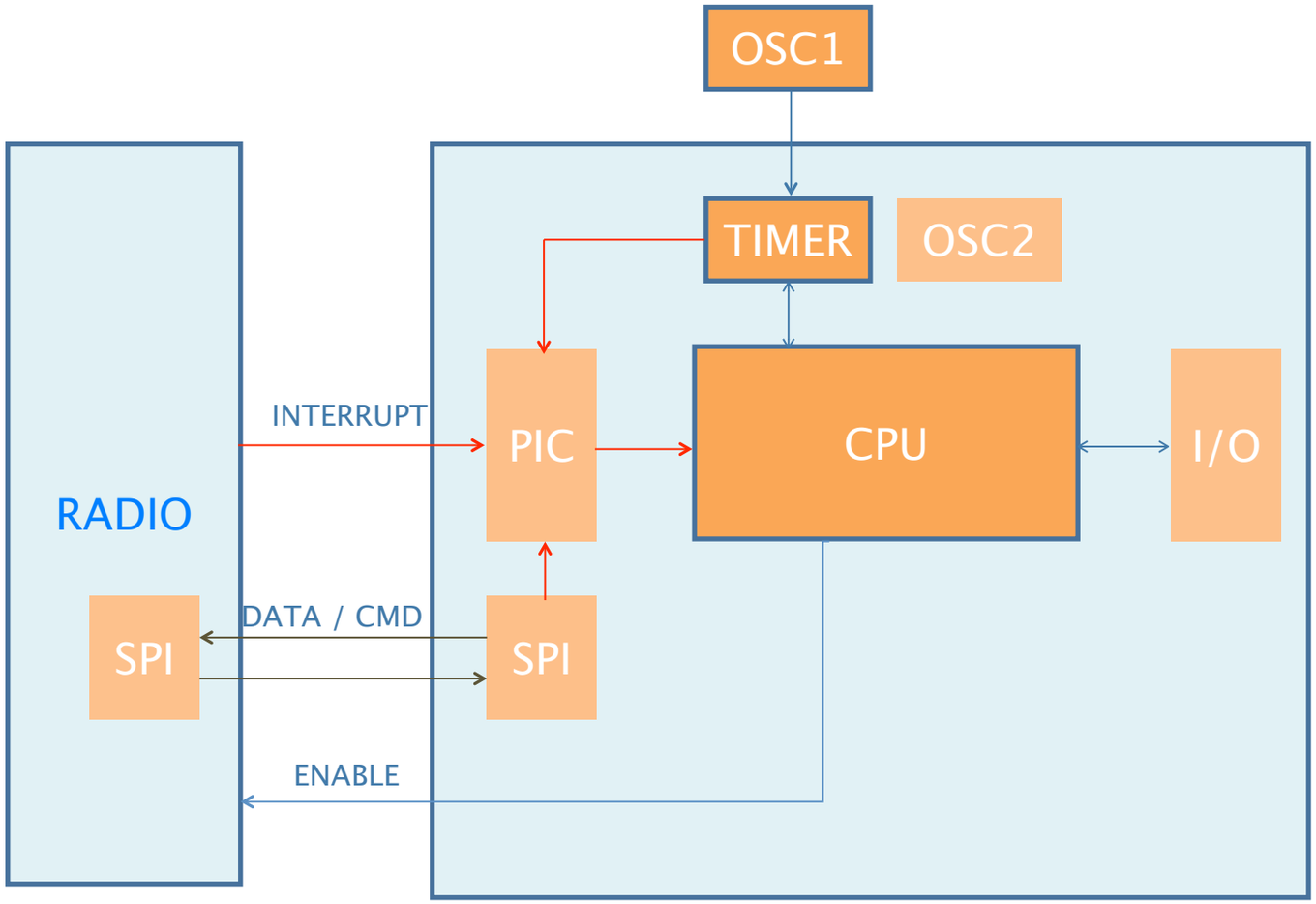
What,

again, is our system under test?

Testing a Wireless Sensor Network Node

What,

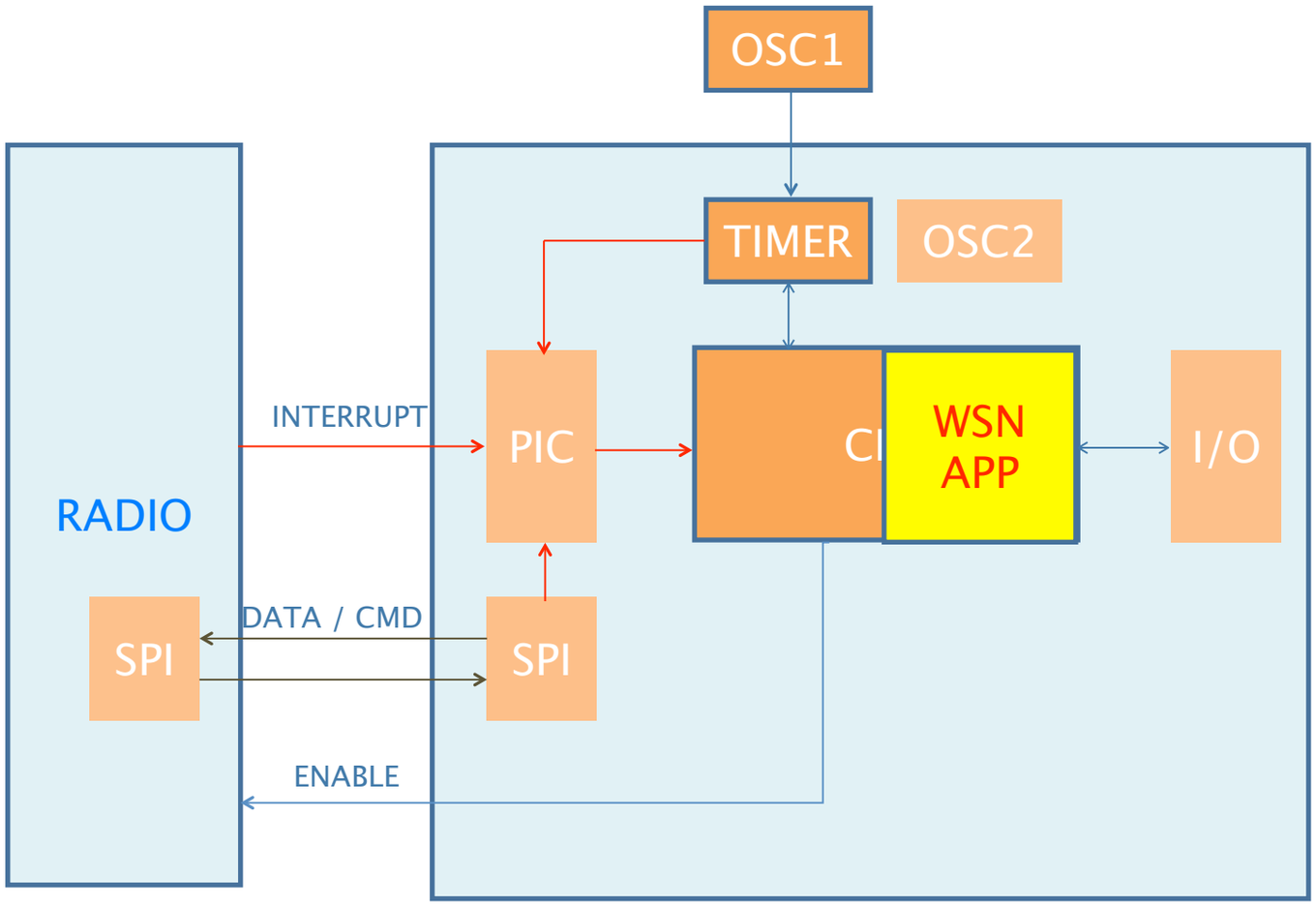
again, is our system under test?



Testing a Wireless Sensor Network Node

What,

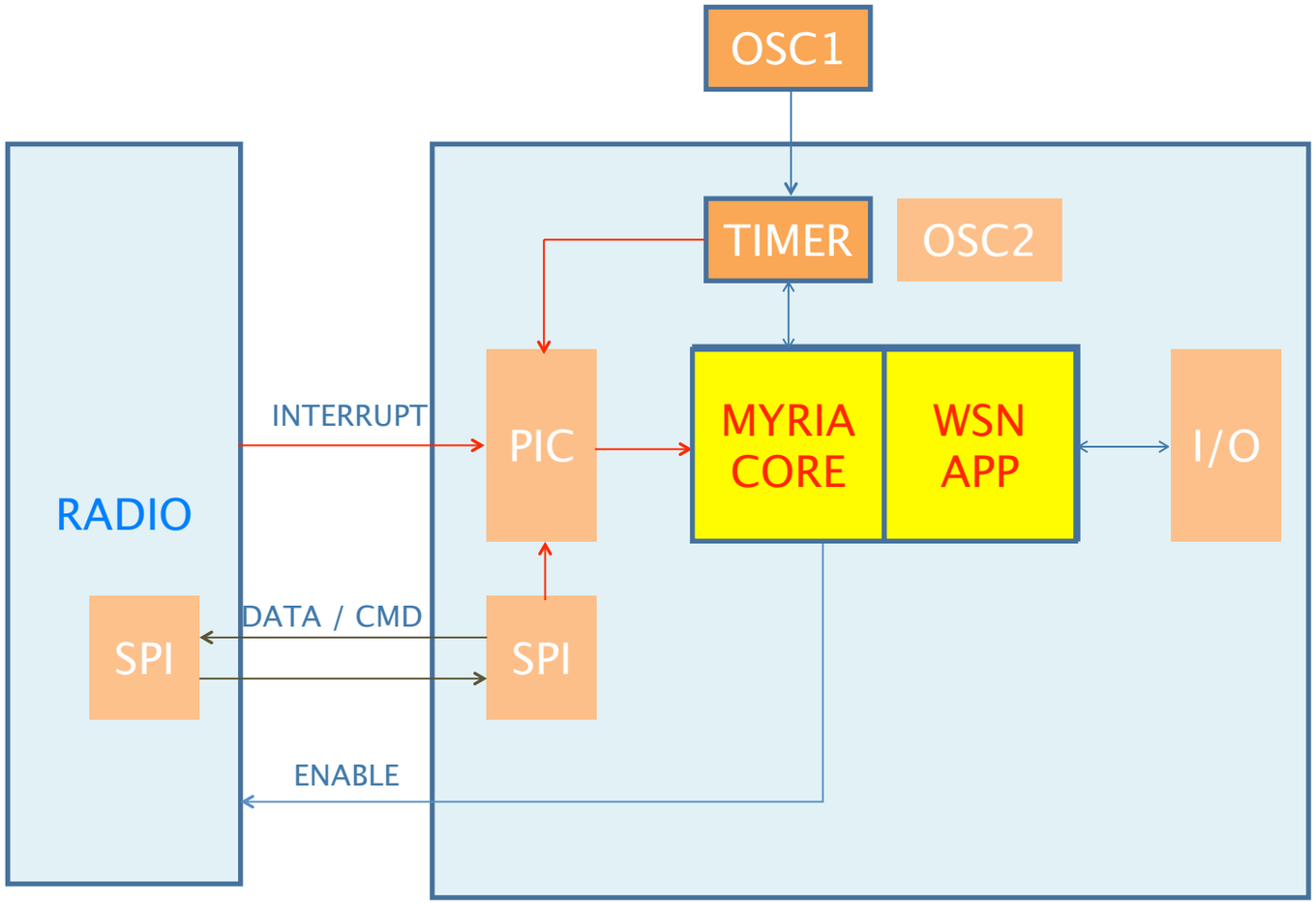
again, is our system under test?



Testing a Wireless Sensor Network Node

What,

again, is our system under test?

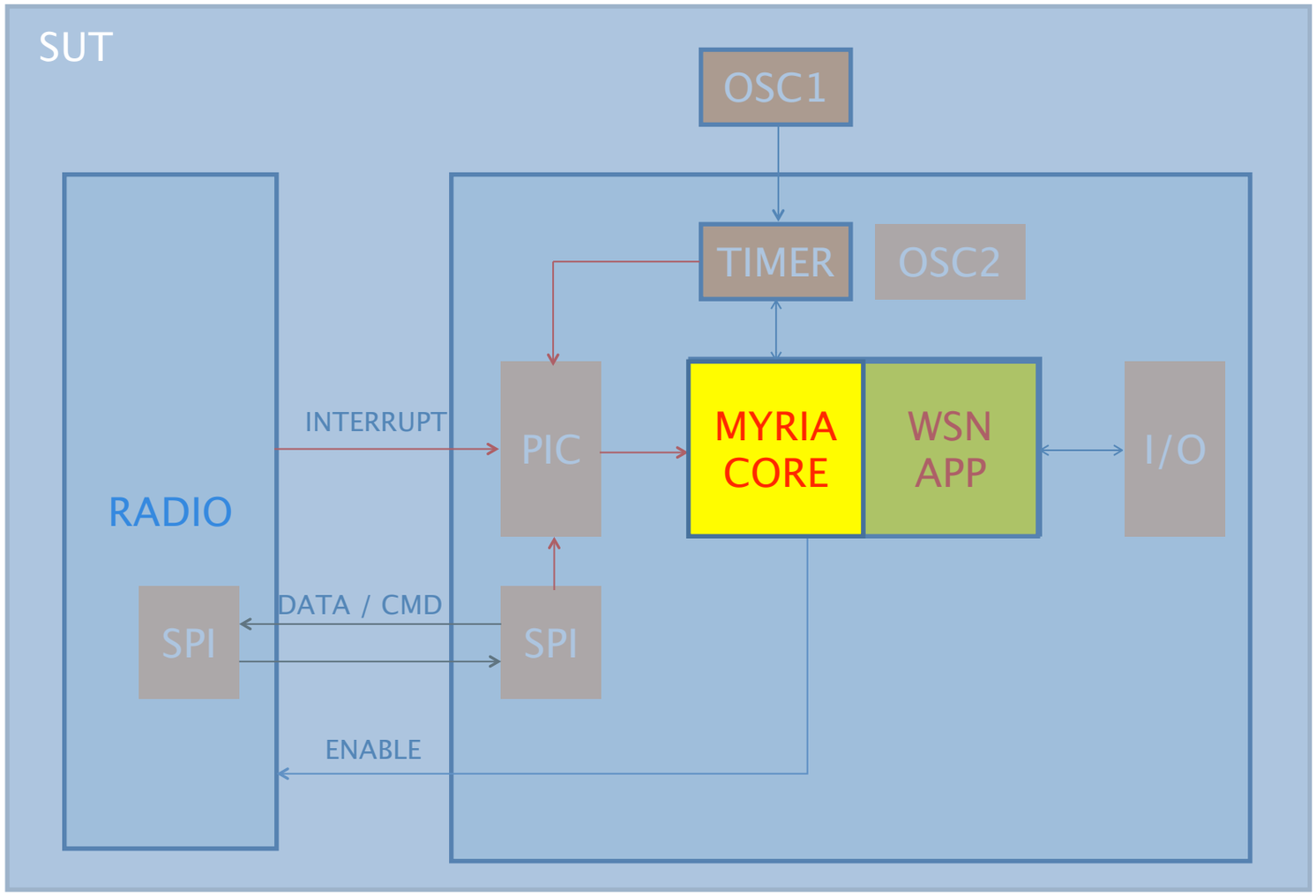


System Software

Testing a Wireless Sensor Network Node

What,

again, is our system under test?

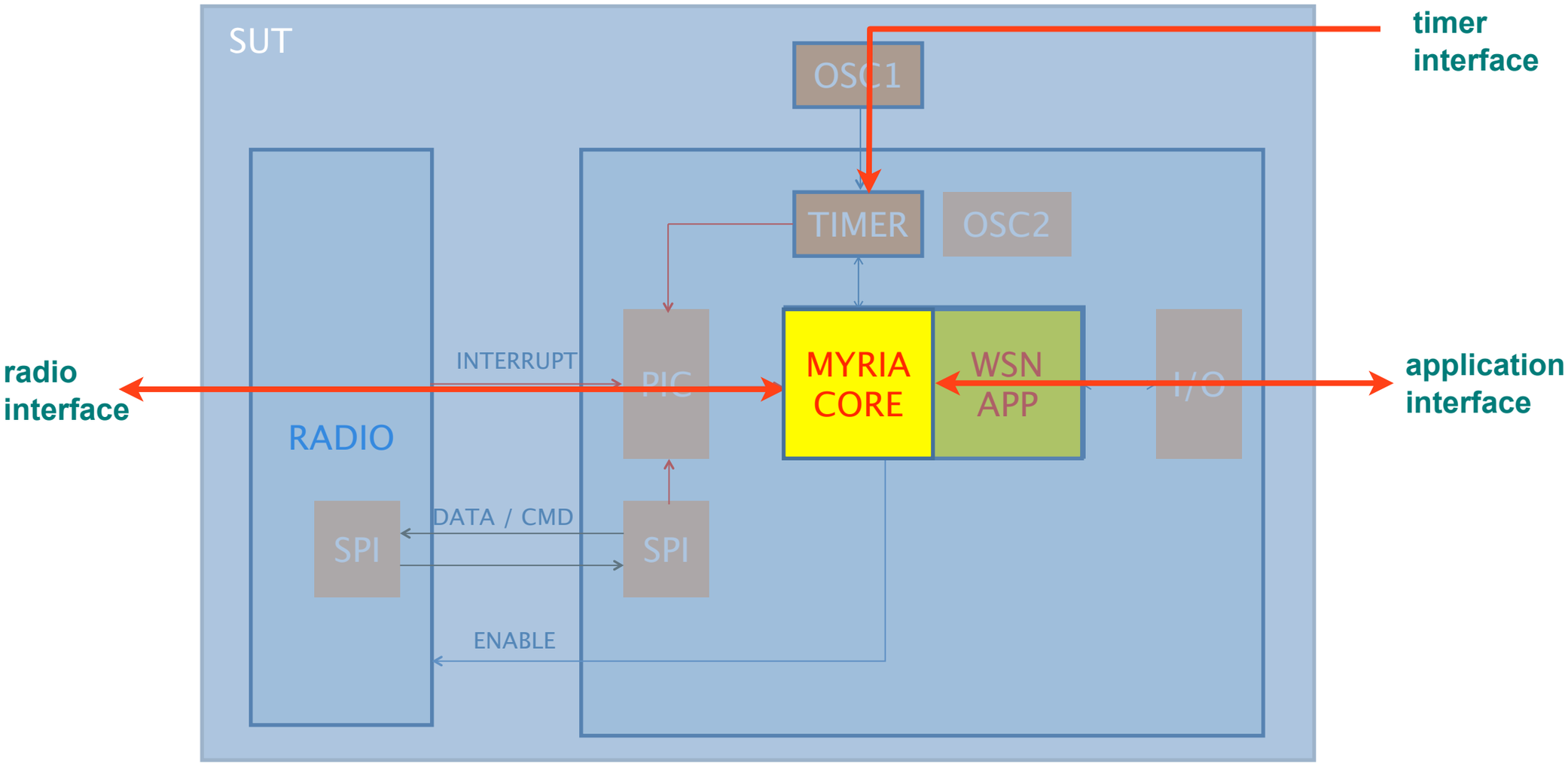


System Software, accessed via software test harness

Testing a Wireless Sensor Network Node

What,

again, is our system under test?



System Software, accessed via software test harness

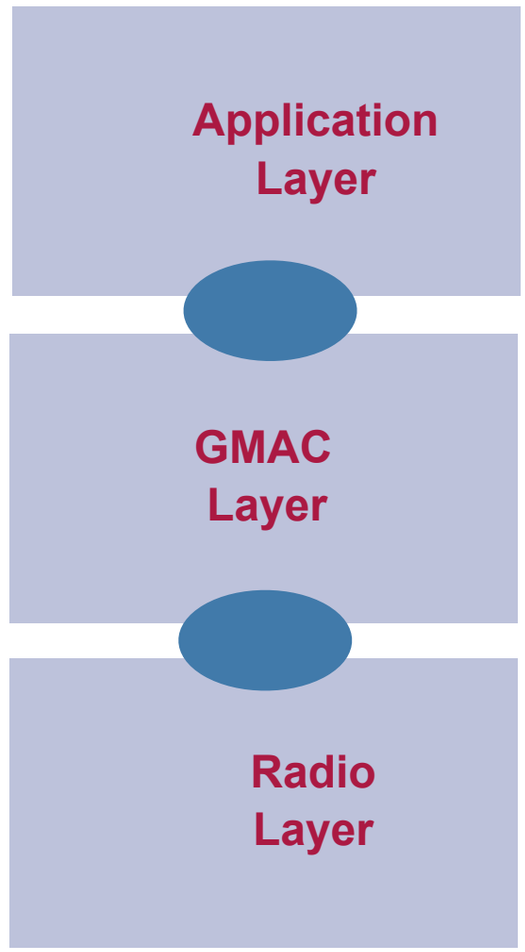
Testing a Wireless Sensor Network Node

How

do we test gMac?

How

do we test gMac?

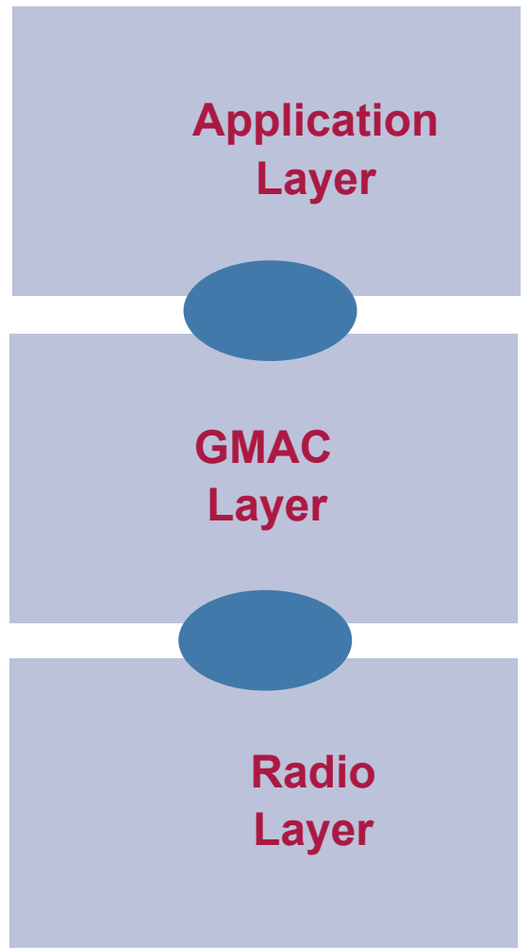


Testing a Wireless Sensor Network Node

How

do we test gMac?

- focus on gMAC software
- test for conformance
- single node
- simulated time

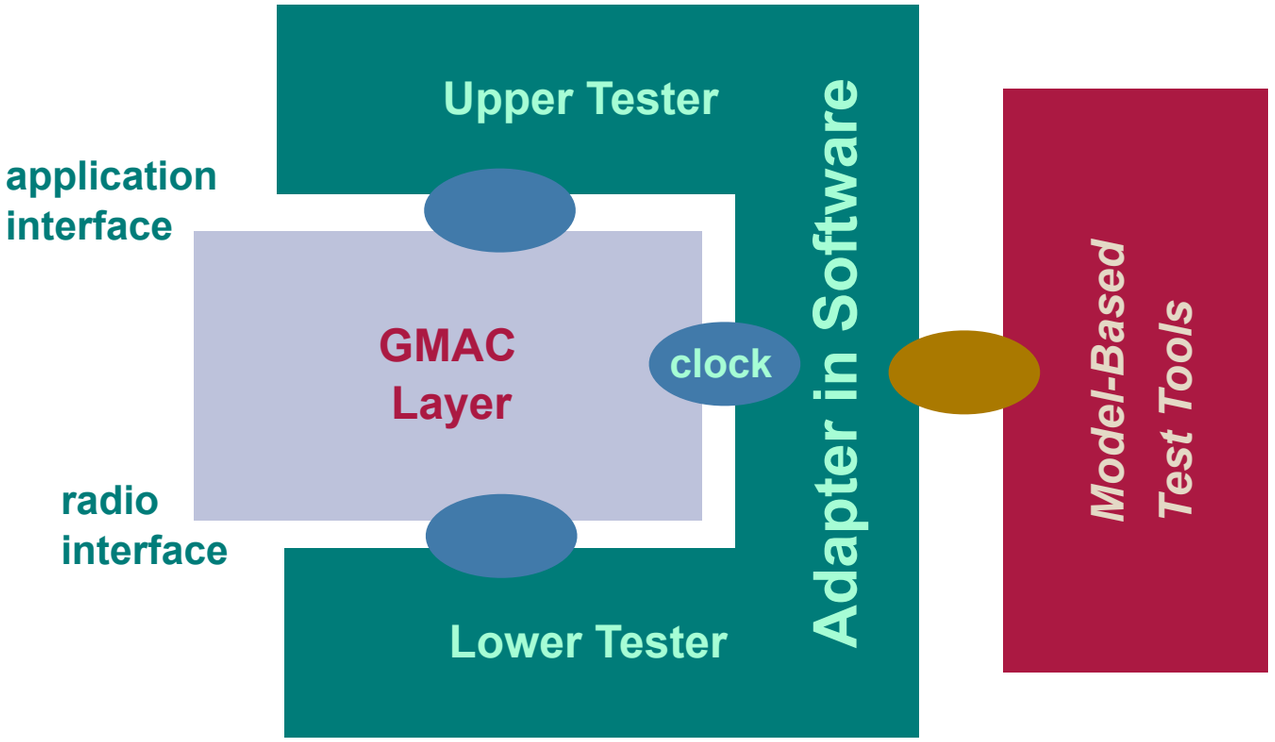


Testing a Wireless Sensor Network Node

How

do we test gMac?

- focus on gMAC software
- test for conformance
- single node
- simulated time

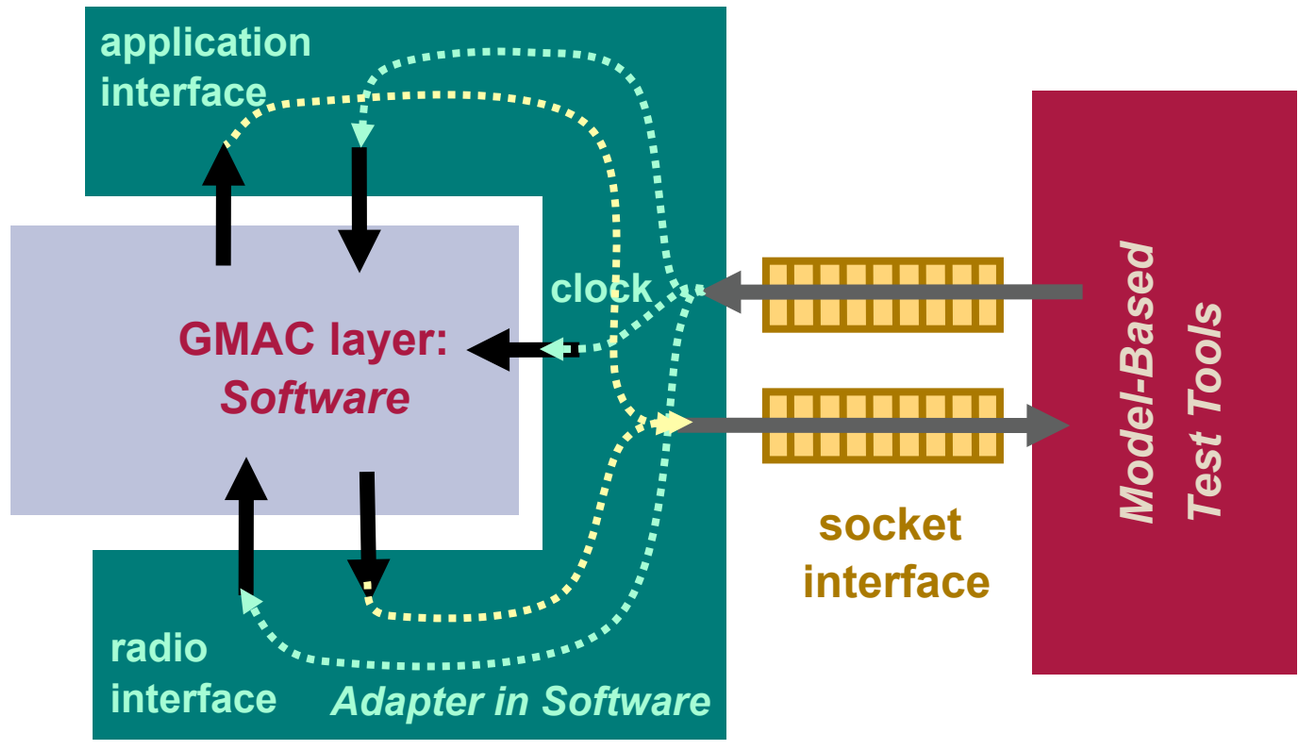


Testing a Wireless Sensor Network Node

How

do we test gMac?

- focus on gMAC software
- test for conformance
- single node
- simulated time



Testing a Wireless Sensor Network Node

What...

test tools did we choose to use?

What...

test tools did we choose to use?

TorXakis

JTorX

Uppaal-Tron

What...

test tools did we choose to use?

	TorXakis	JTorX	Uppaal-Tron
	Radboud Univ	Univ Twente	Univ Aalborg

Testing a Wireless Sensor Network Node

What...

test tools did we choose to use?

	TorXakis	JTorX	Uppaal-Tron
	Radboud Univ	Univ Twente	Univ Aalborg
time	symbolic data	network of timed automata (ta2torx)	(uppaal)

Testing a Wireless Sensor Network Node

What...

test tools did we choose to use?

	TorXakis	JTorX	Uppaal-Tron
	Radboud Univ	Univ Twente	Univ Aalborg
time	symbolic data	network of timed automata (ta2torx)	network of timed automata (uppaal)
scenarios	model	- model - interactive	model

Testing a Wireless Sensor Network Node

What...

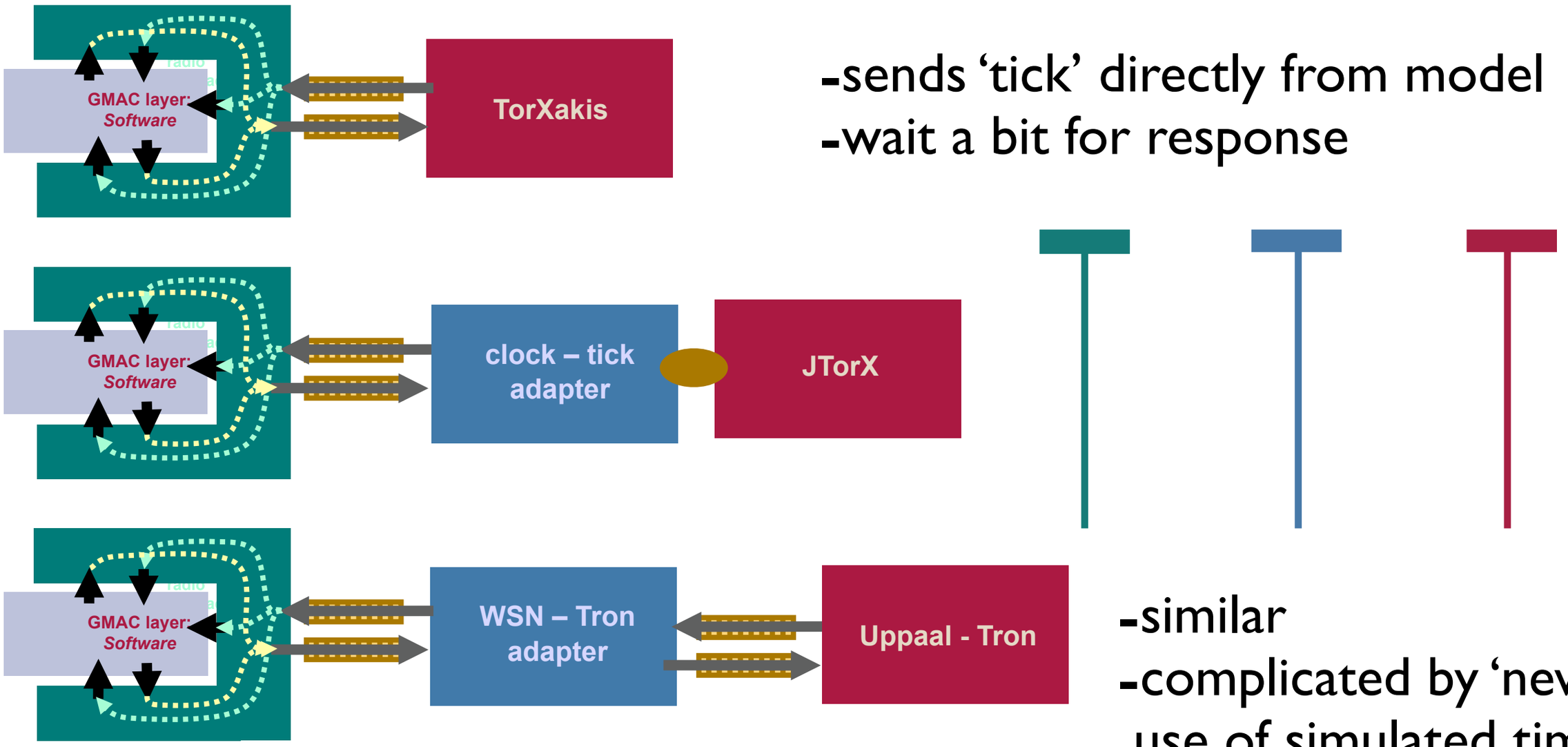
test tools did we choose to use?

	TorXakis	JTorX	Uppaal-Tron
	Radboud Univ	Univ Twente	Univ Aalborg
time	symbolic data	network of timed automata (ta2torx)	(uppaal)
scenarios	model	- model - interactive	model

all three can model non-determinism, underspecification

Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?

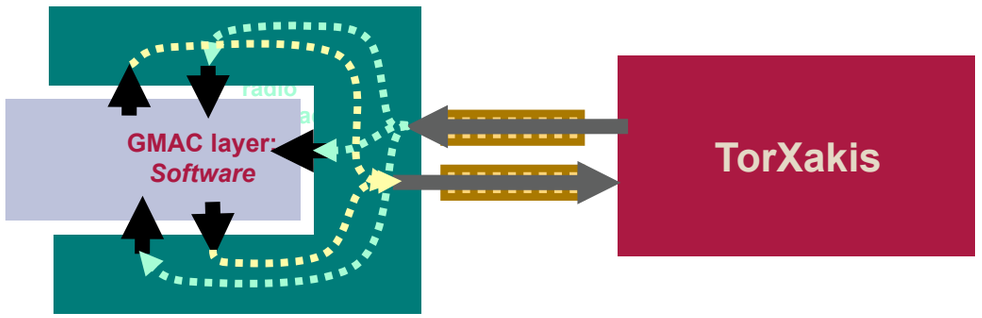


-sends ‘tick’ directly from model
-wait a bit for response

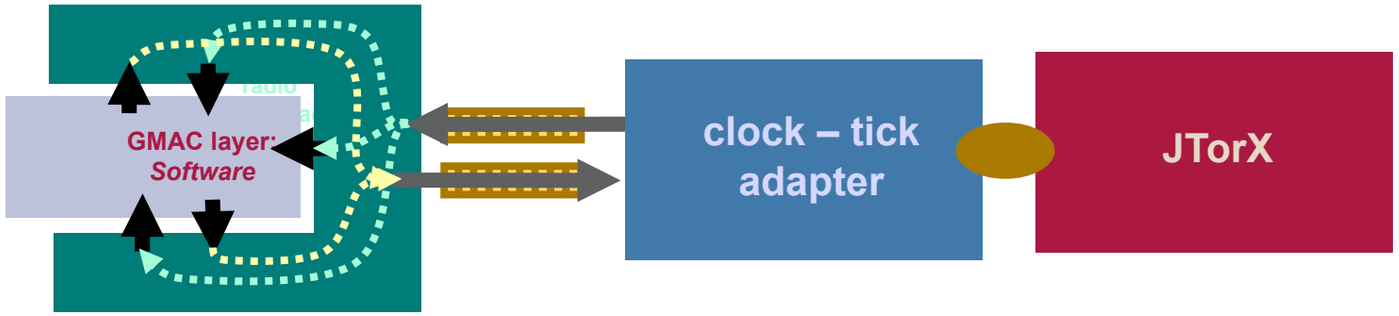
-similar
-complicated by ‘new’ use of simulated time

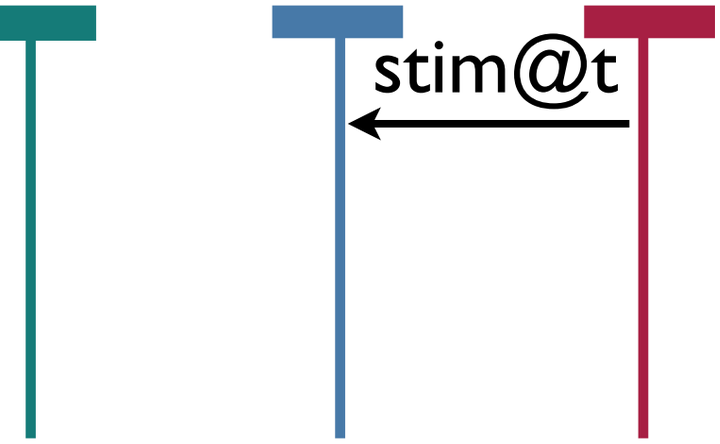
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

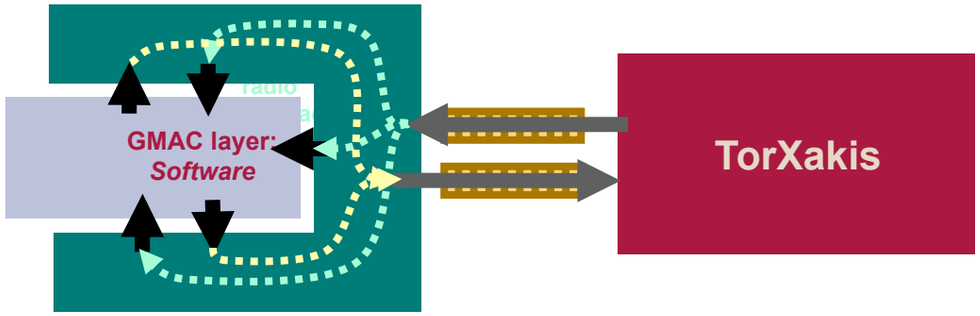




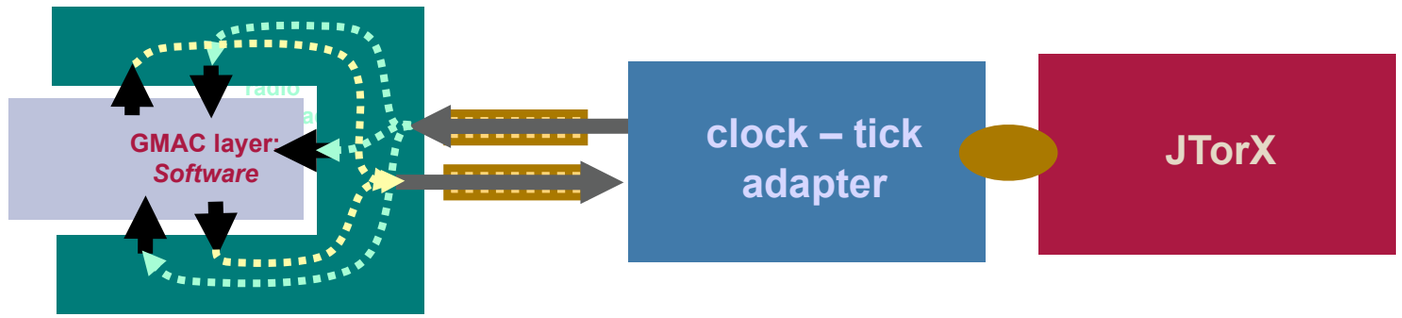
-similar
-complicated by 'new' use of simulated time

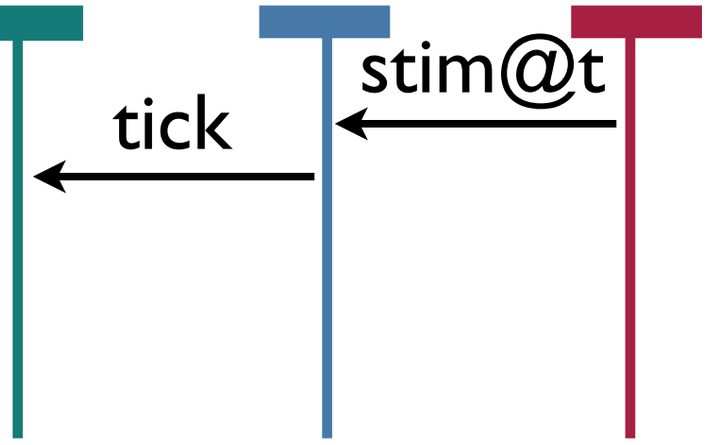
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

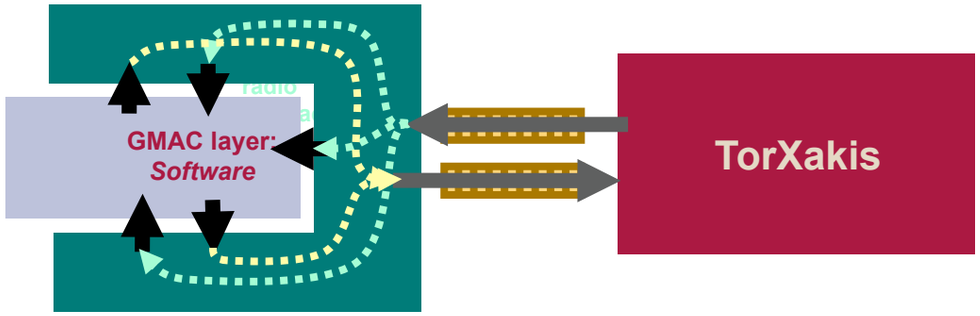




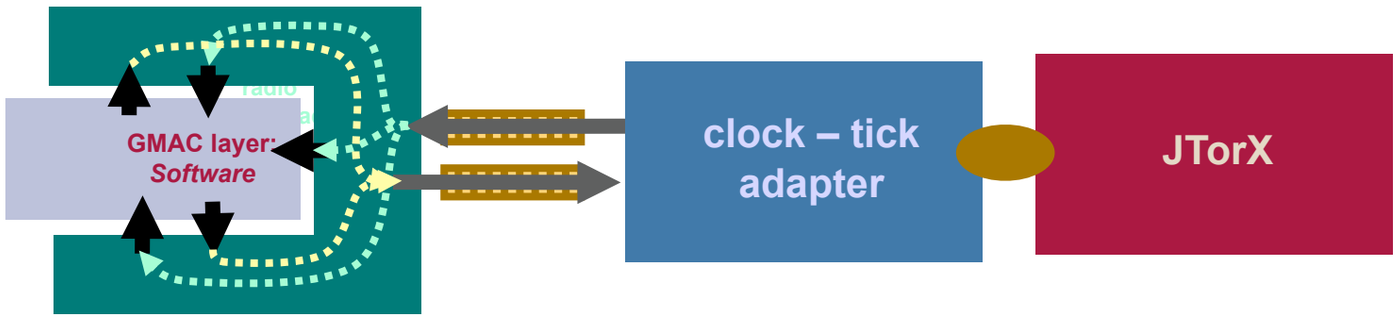
-similar
-complicated by 'new' use of simulated time

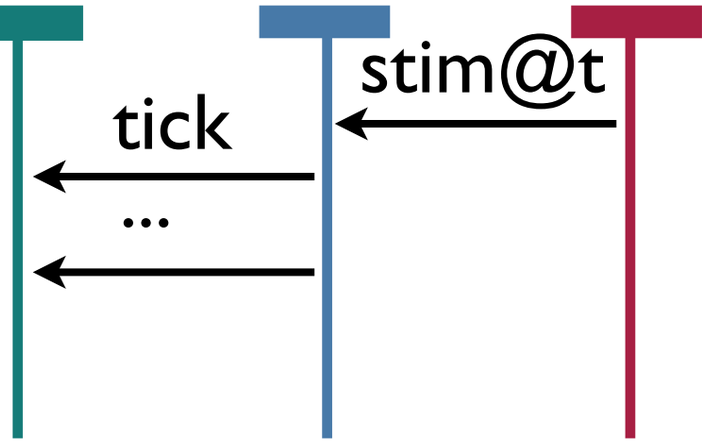
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

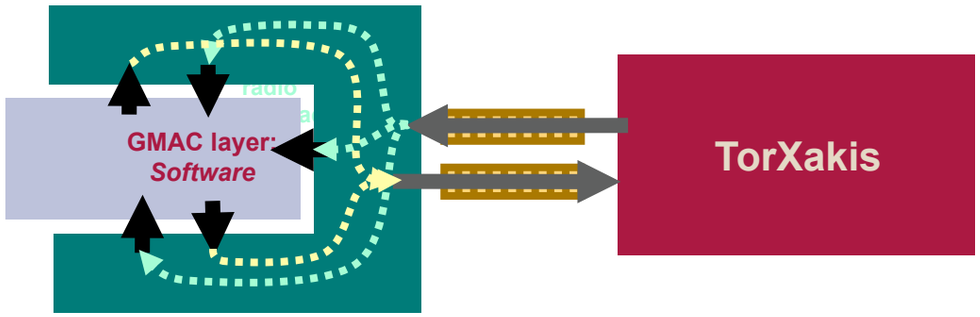




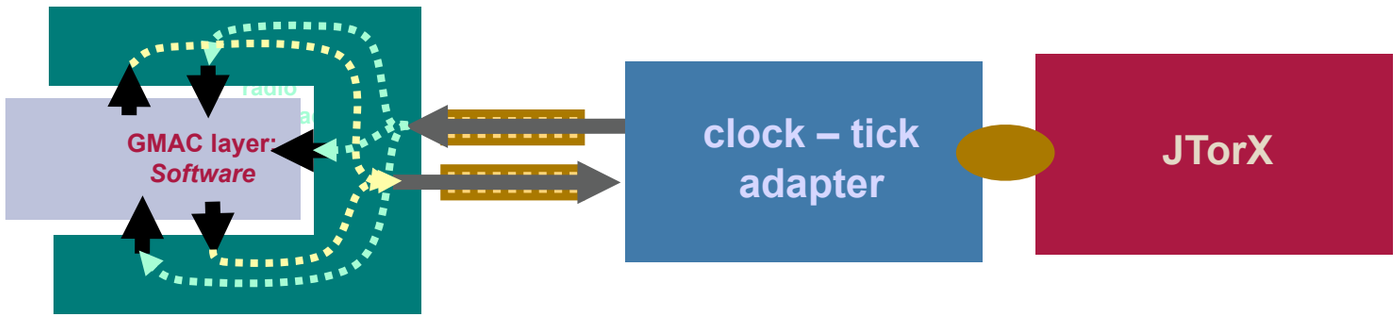
-similar
-complicated by 'new' use of simulated time

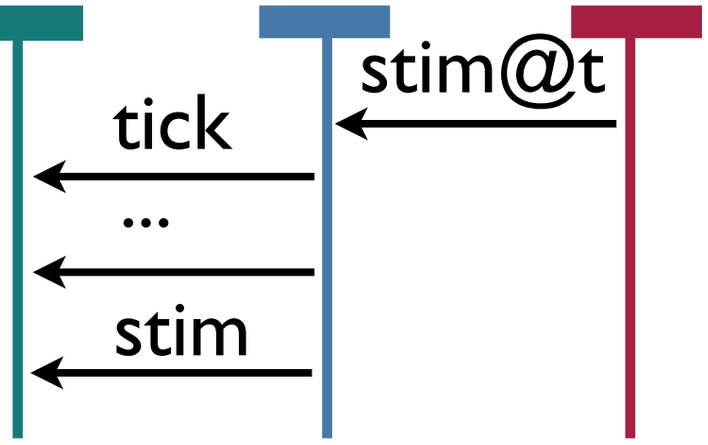
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

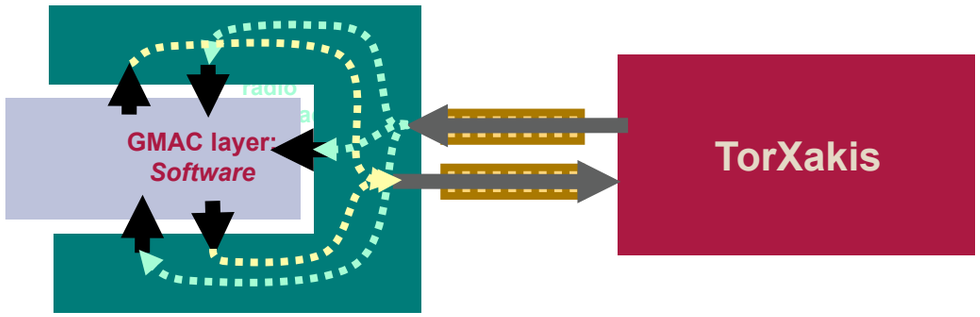




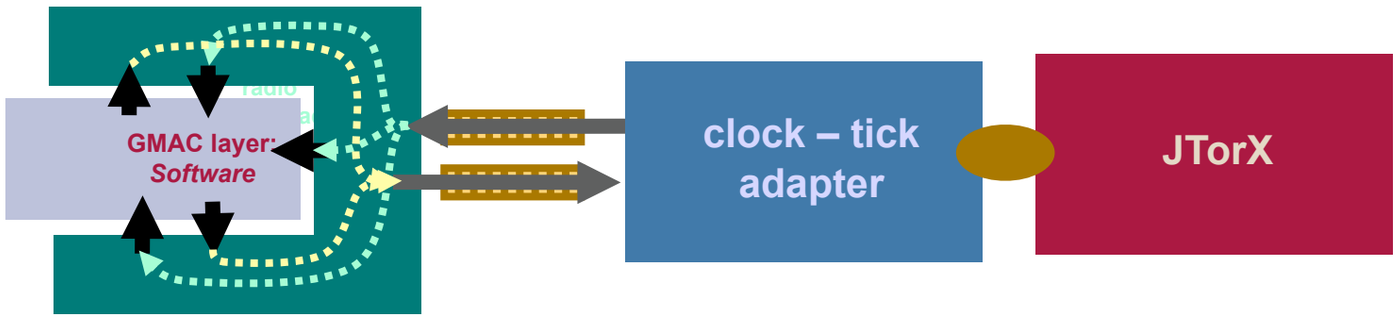
-similar
-complicated by 'new' use of simulated time

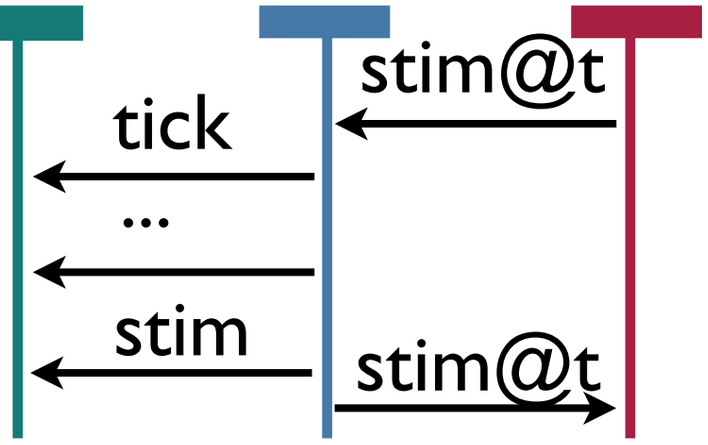
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

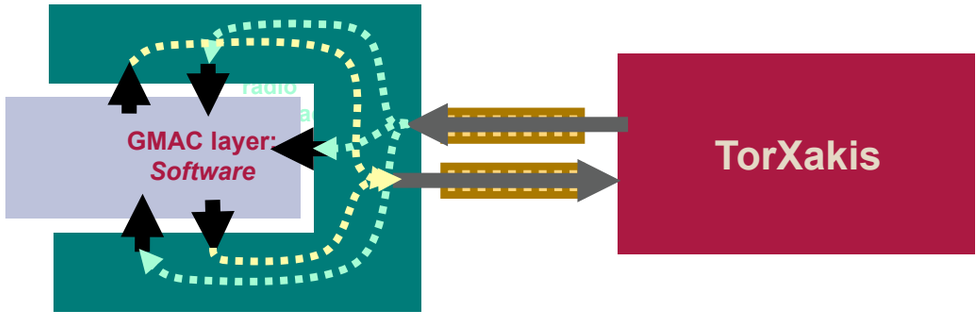




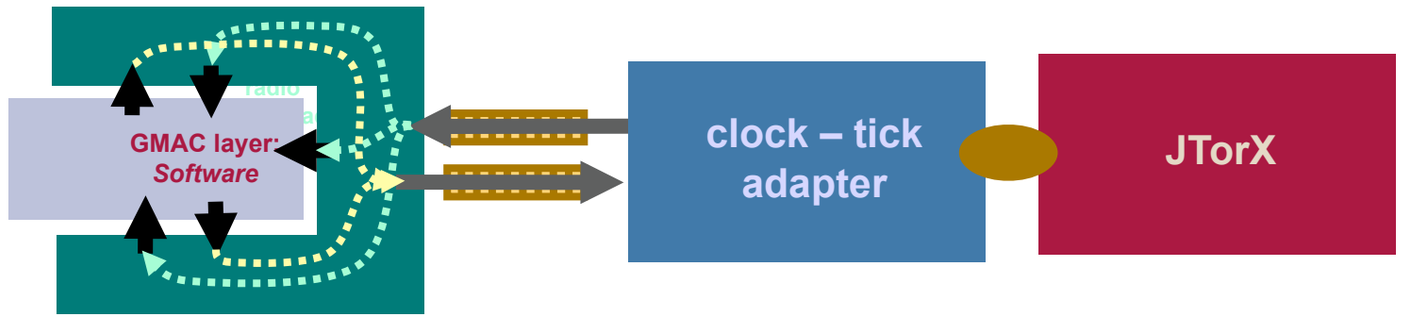
-similar
-complicated by 'new' use of simulated time

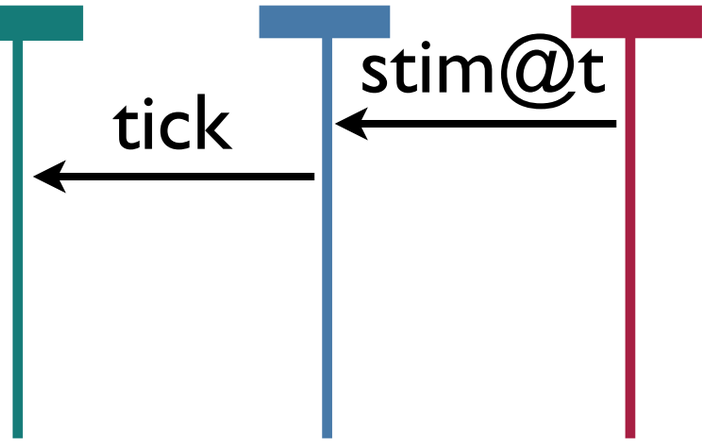
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

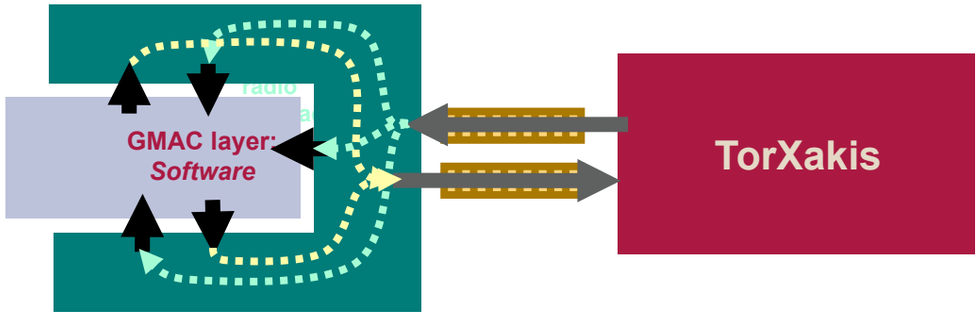




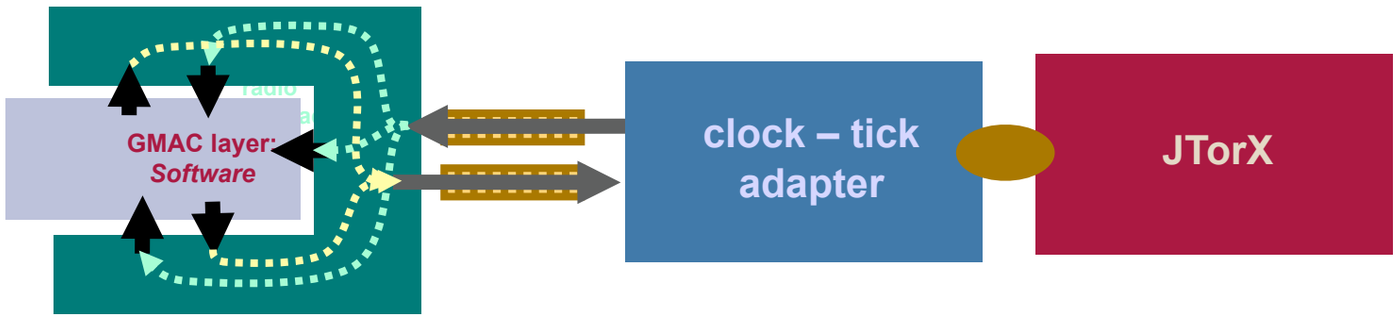
-similar
-complicated by 'new' use of simulated time

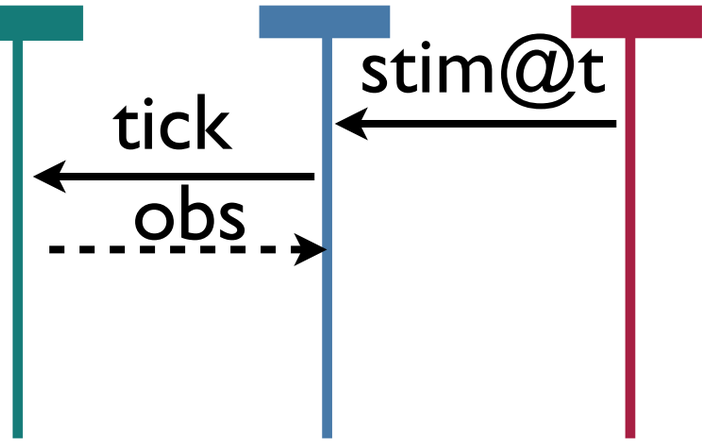
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

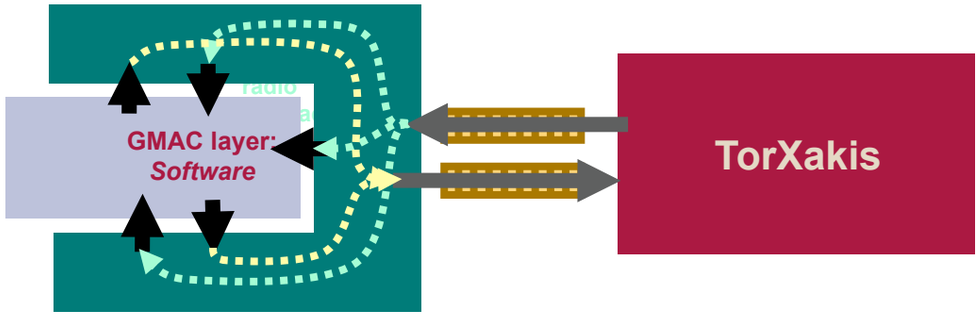




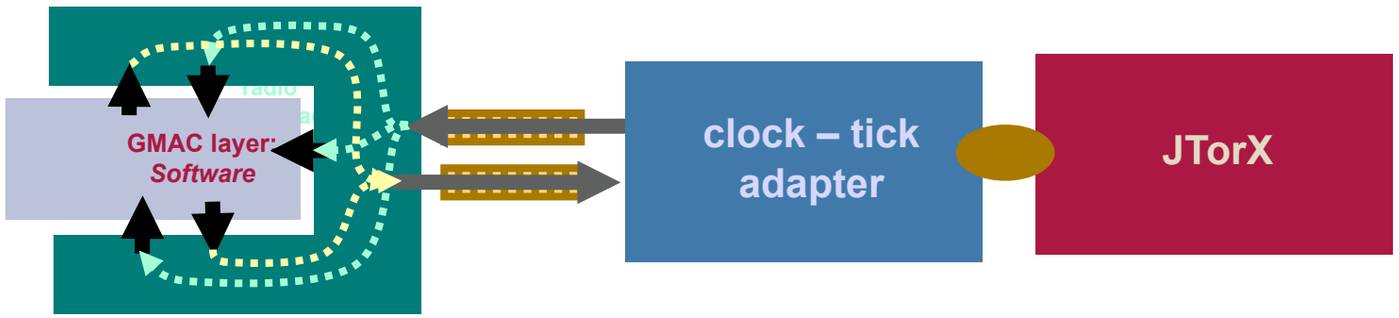
-similar
-complicated by 'new' use of simulated time

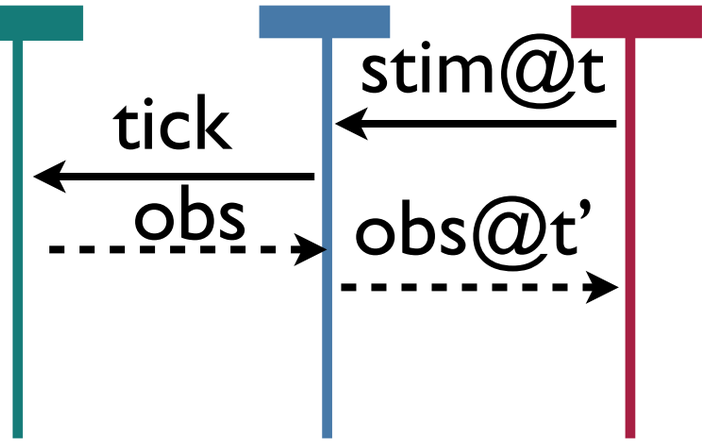
Testing a Wireless Sensor Network Node

How did we connect the testing tools to the SUT?



-sends 'tick' directly from model
-wait a bit for response

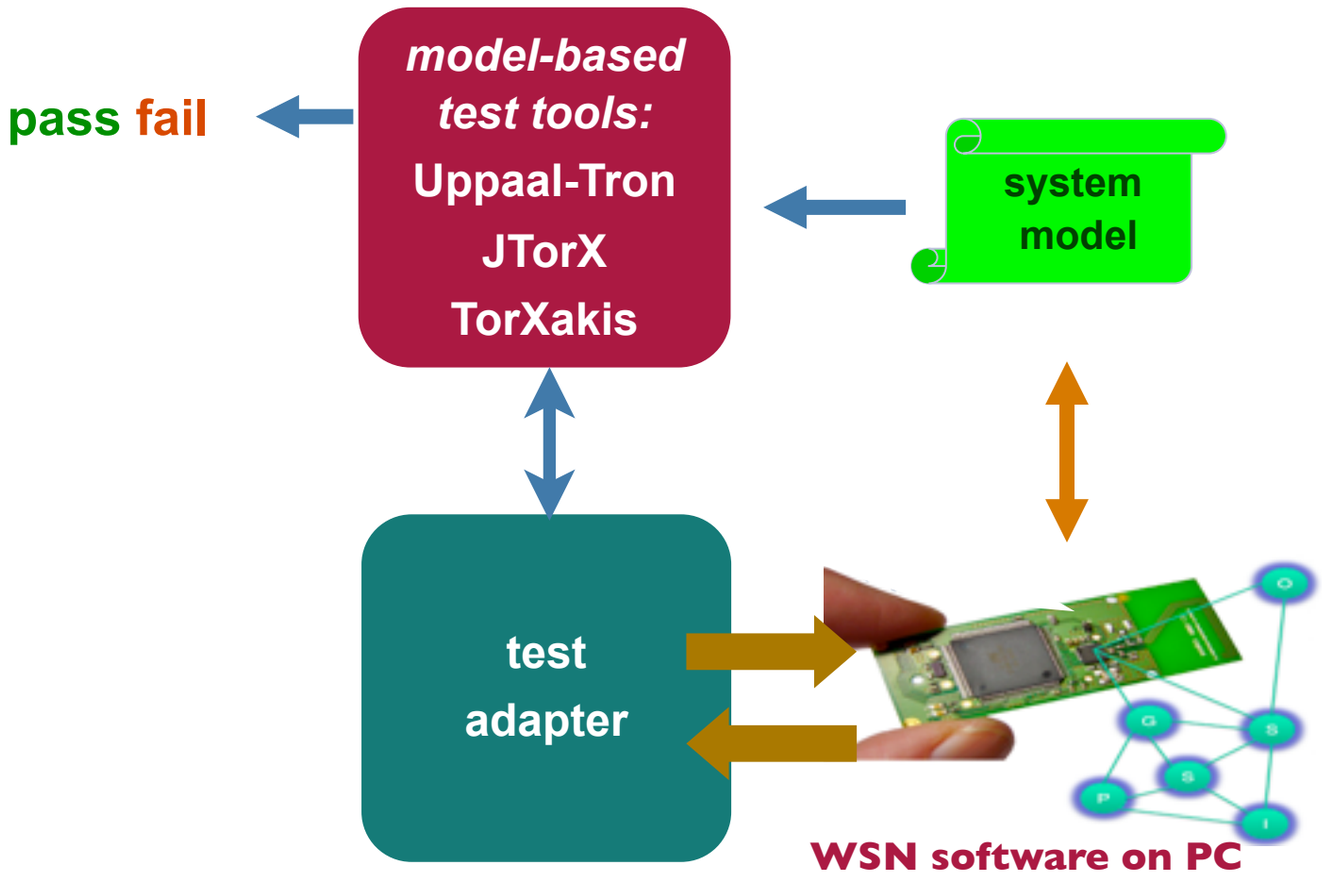




-similar
-complicated by 'new' use of simulated time

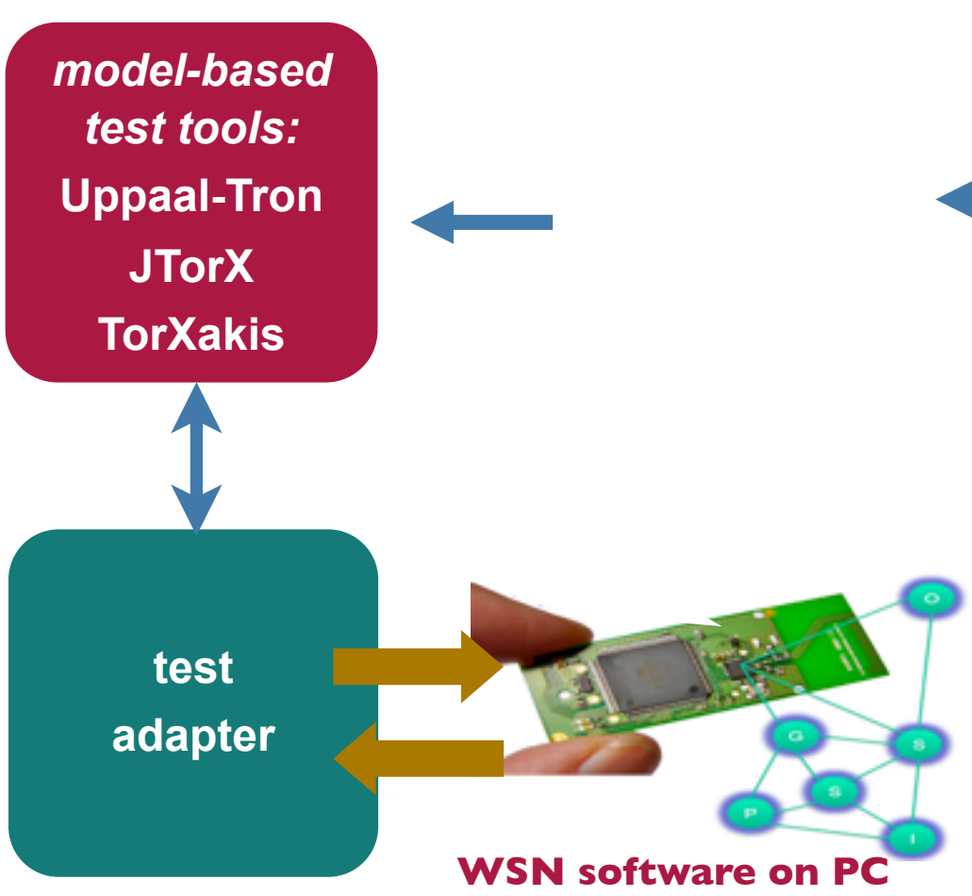
Testing a Wireless Sensor Network Node

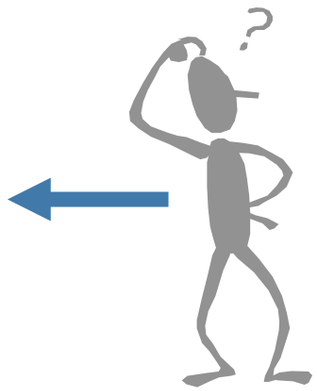
Now we have all MBT ingredients, except model...



Testing a Wireless Sensor Network Node

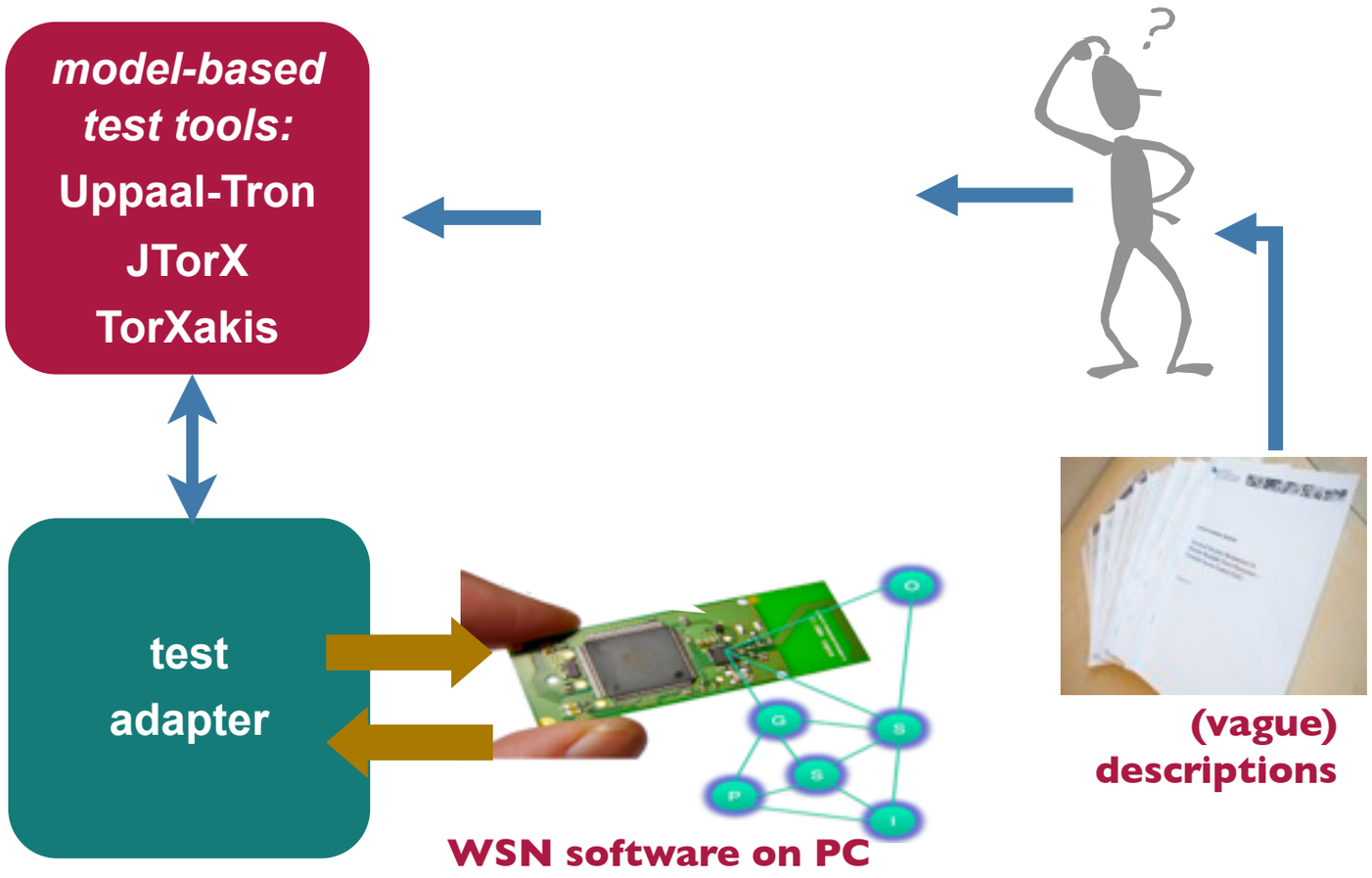
Now we have all MBT ingredients, except model...





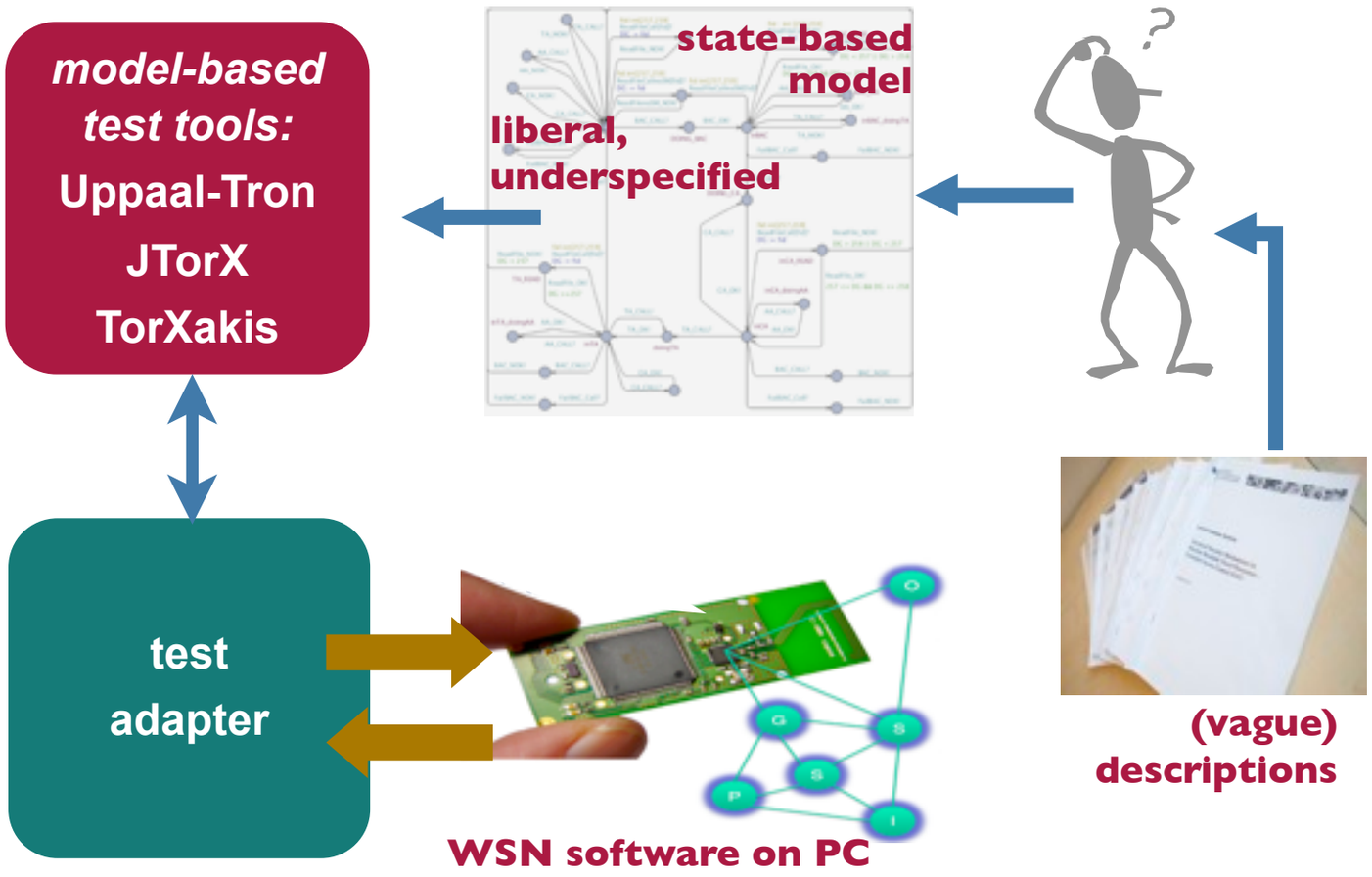
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



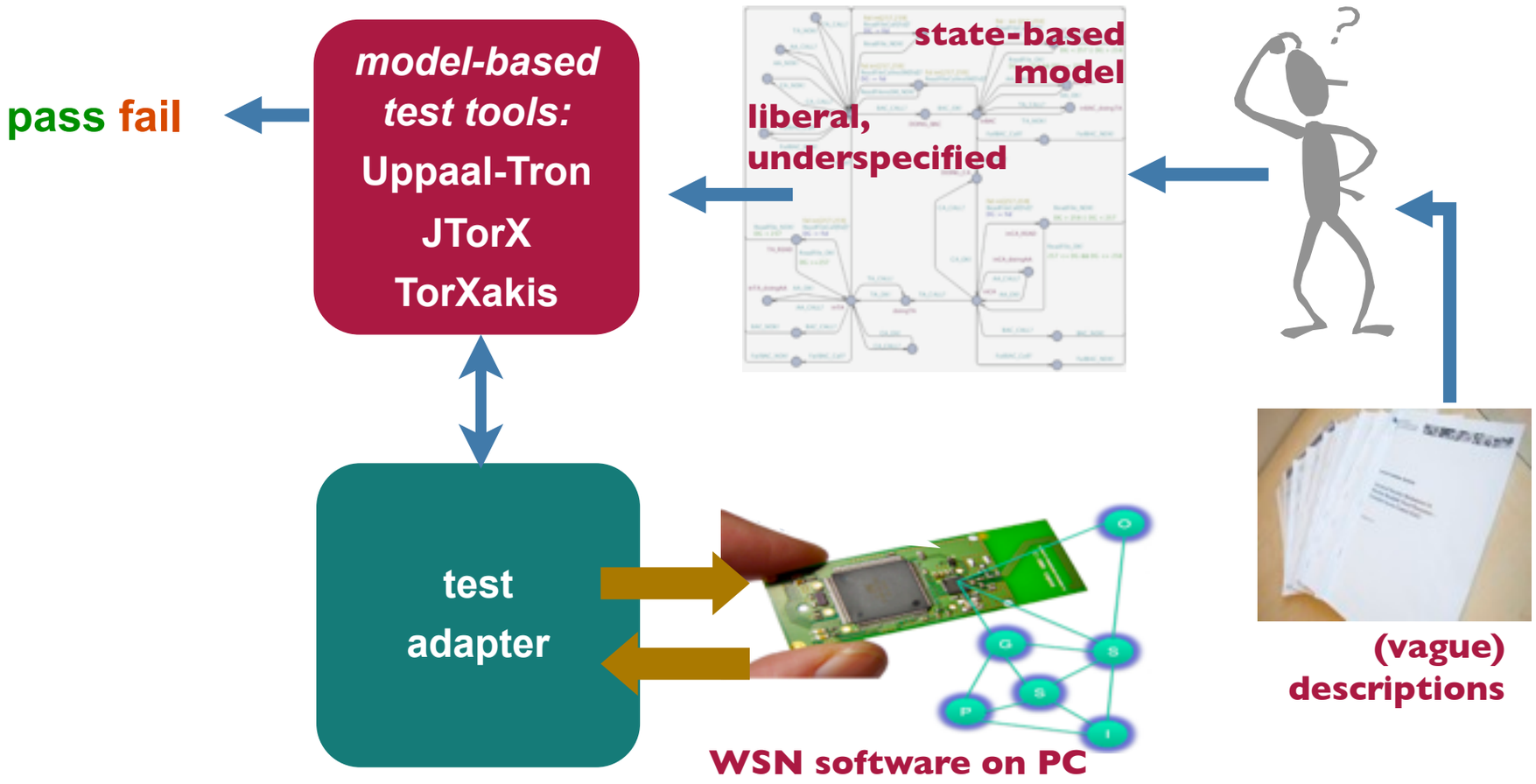
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



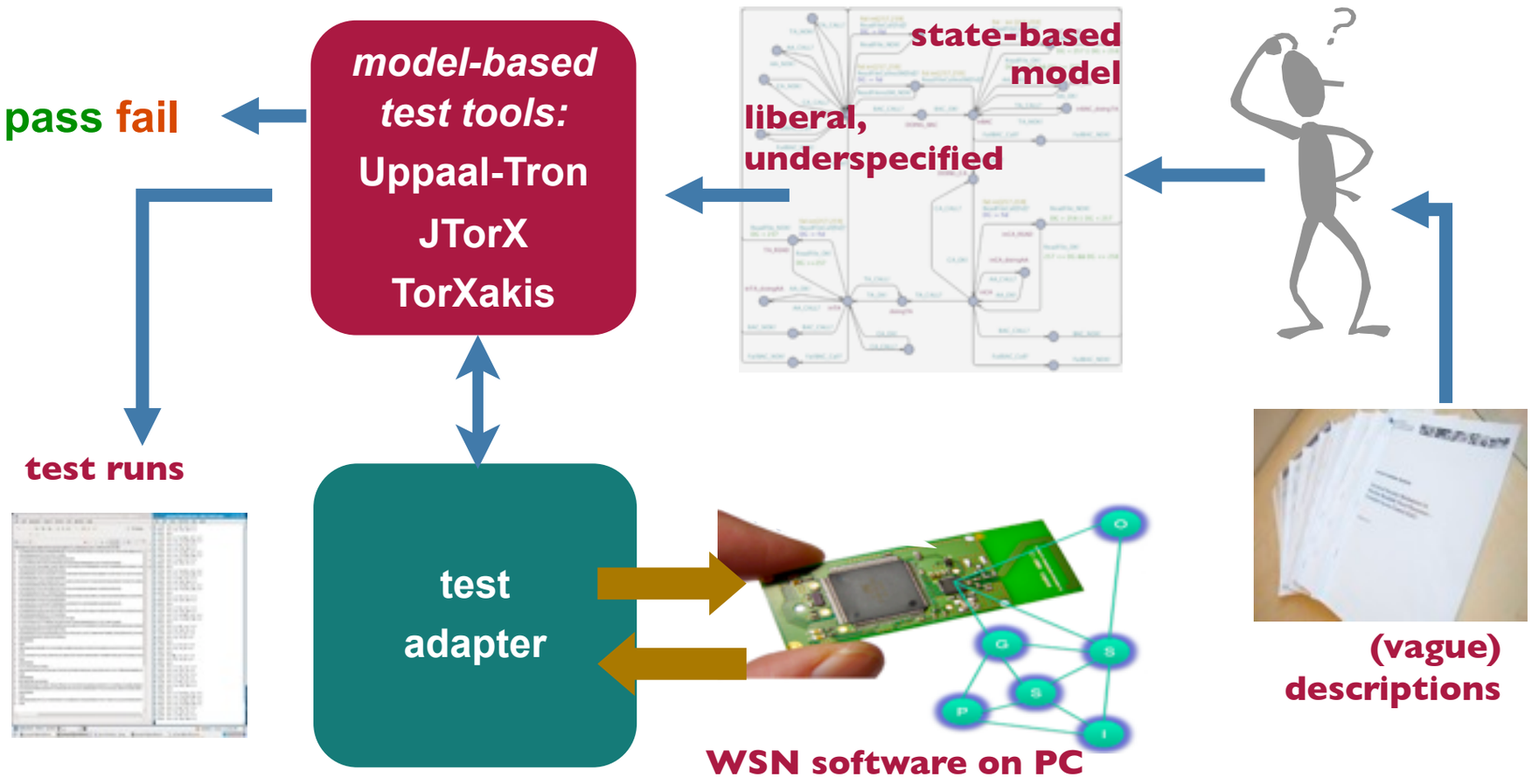
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



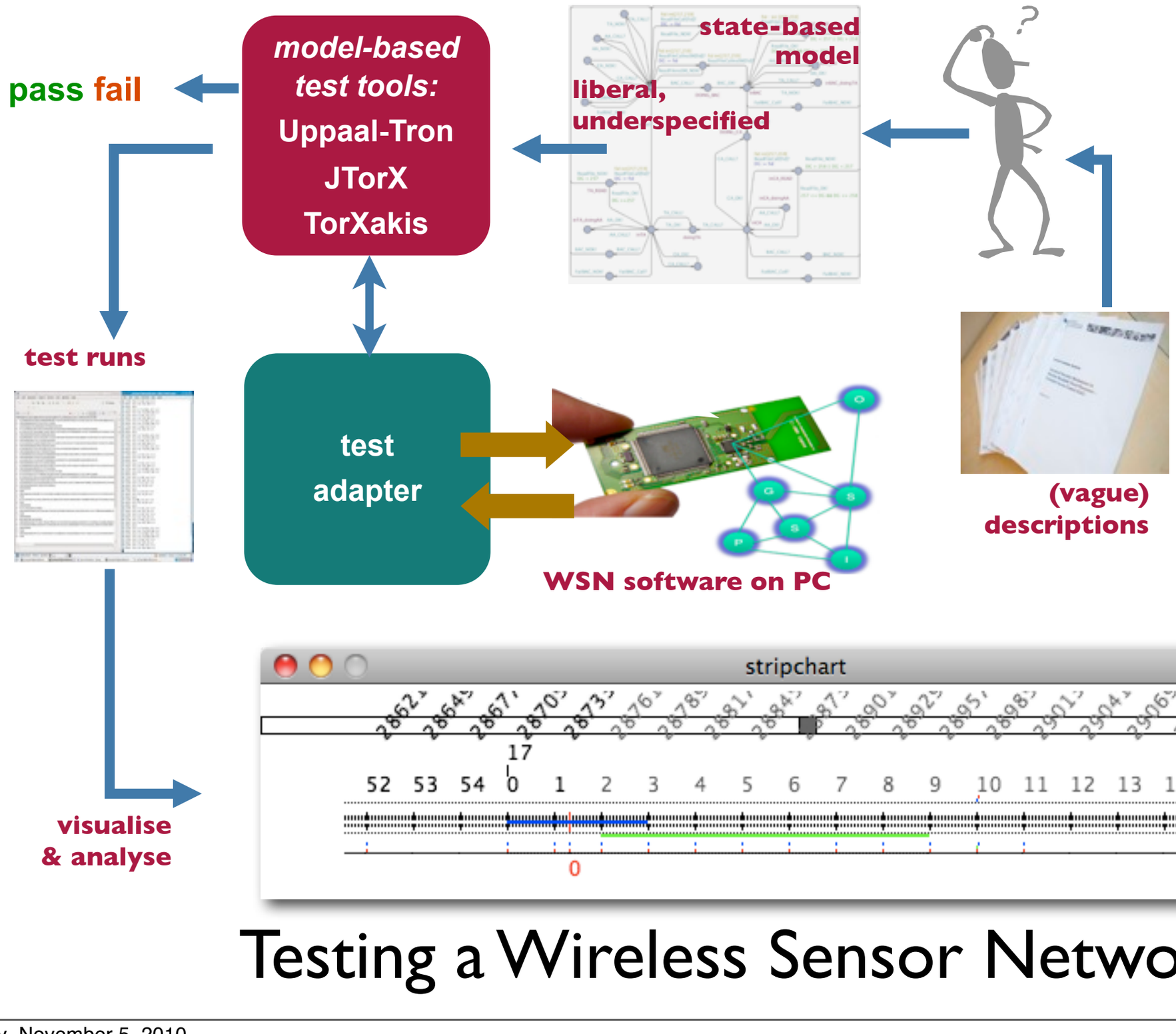
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



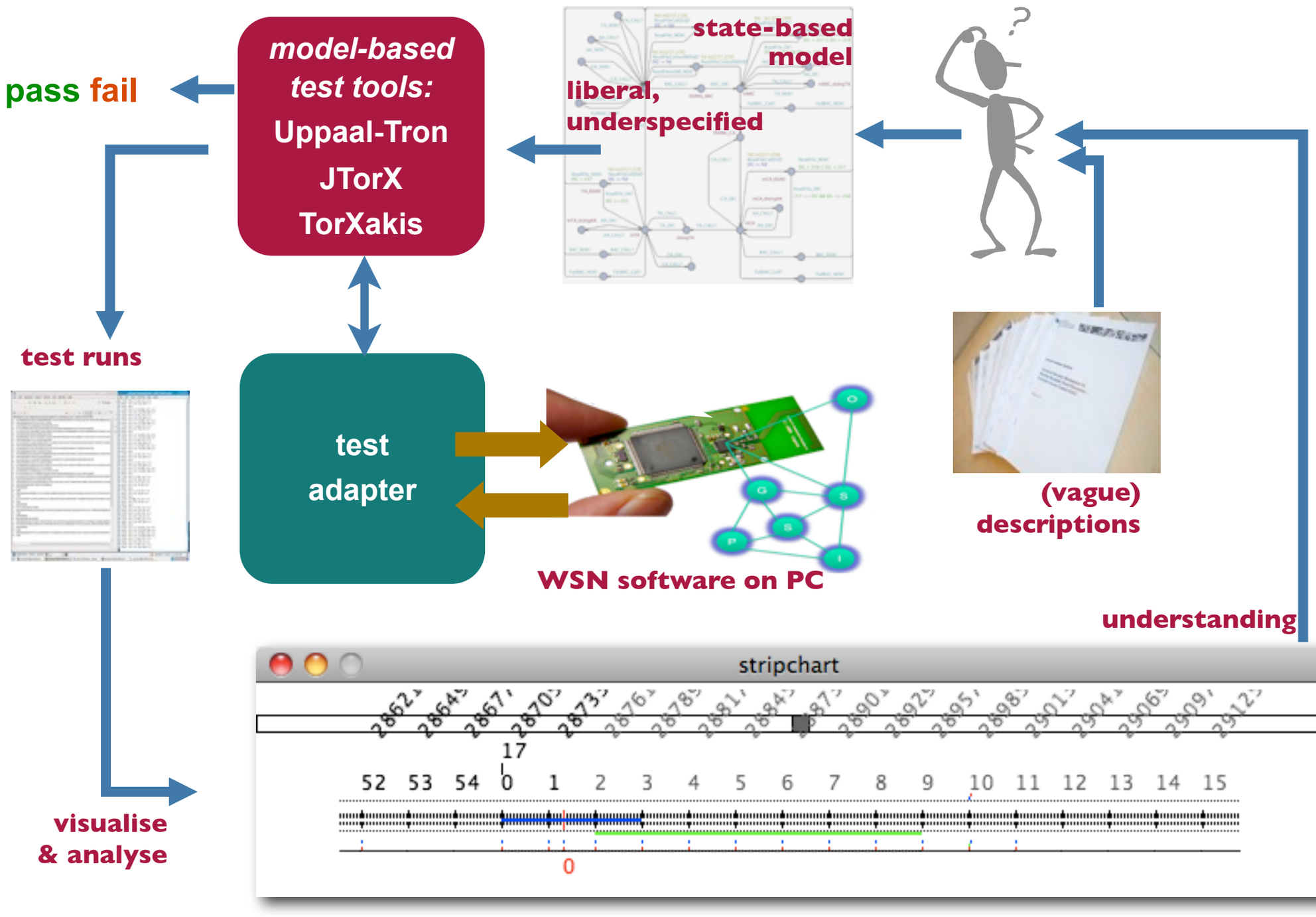
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



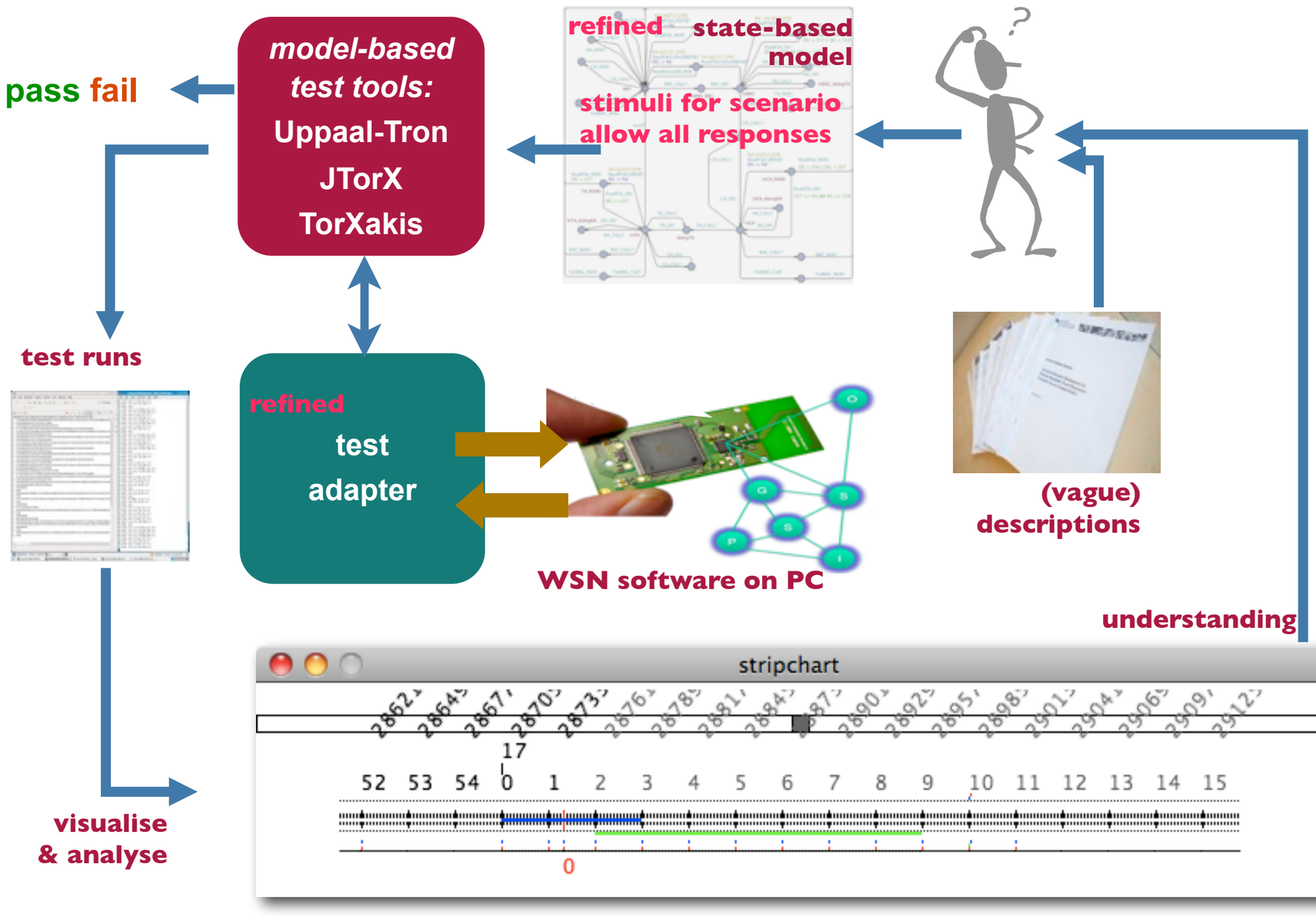
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



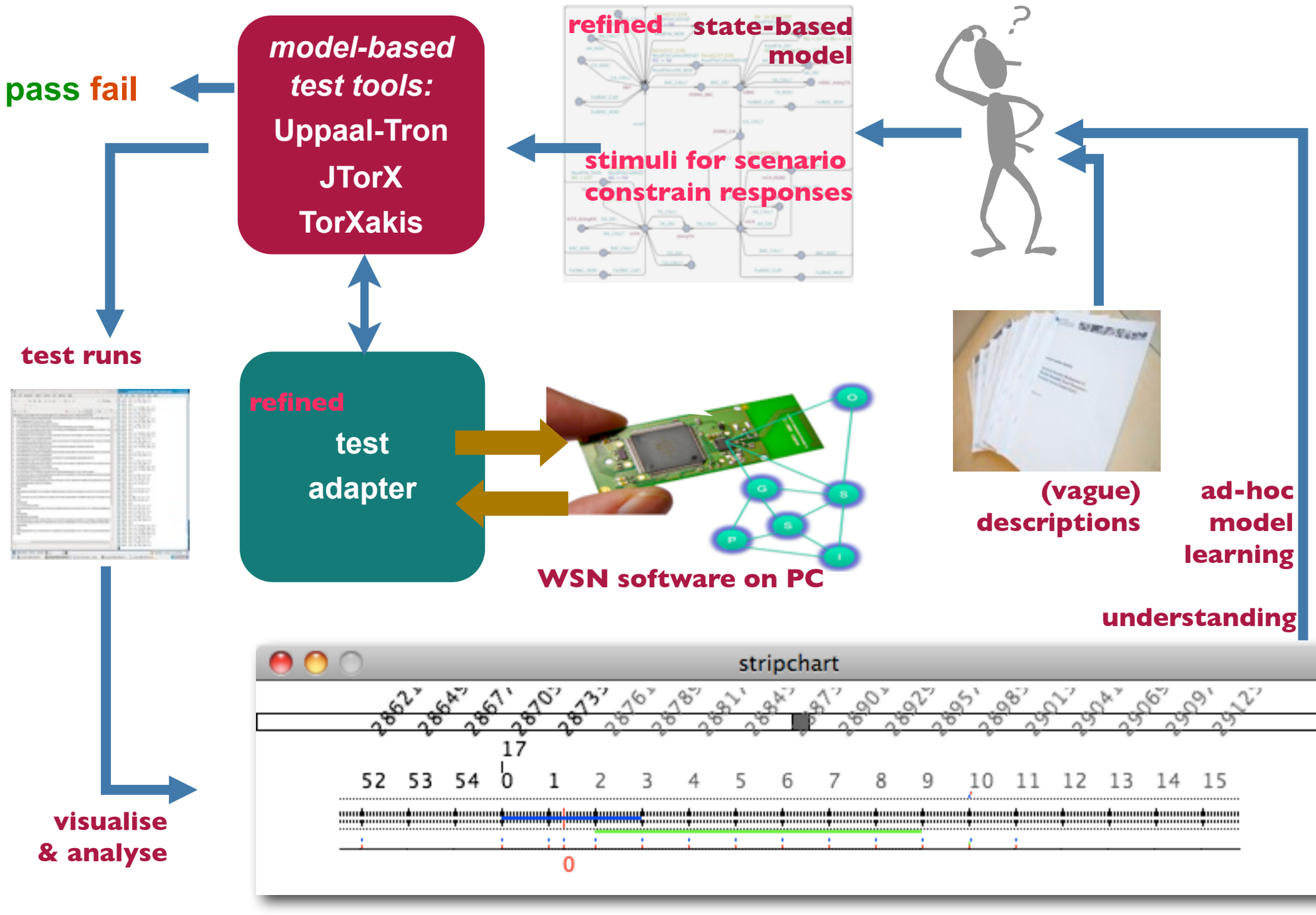
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



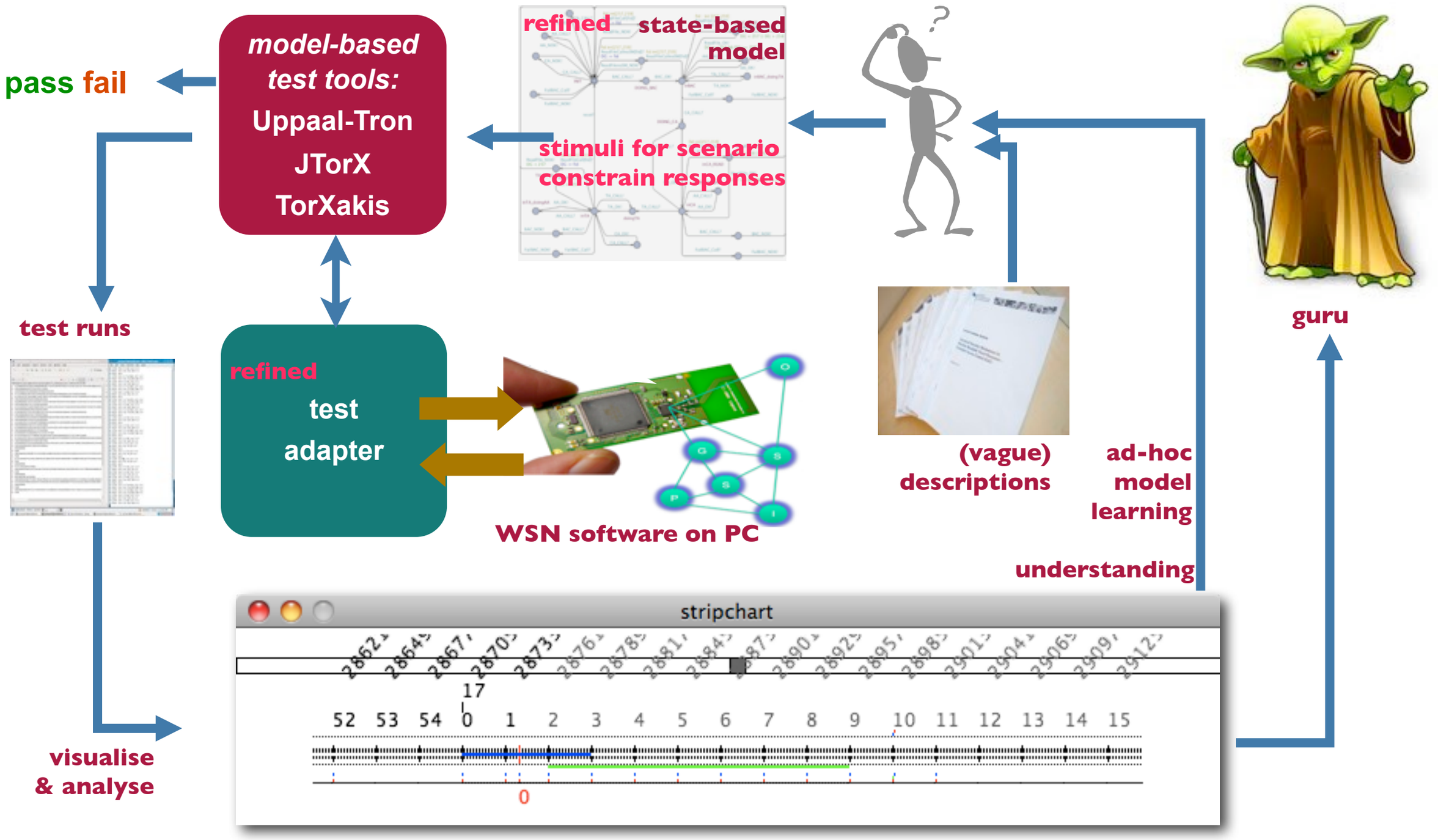
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



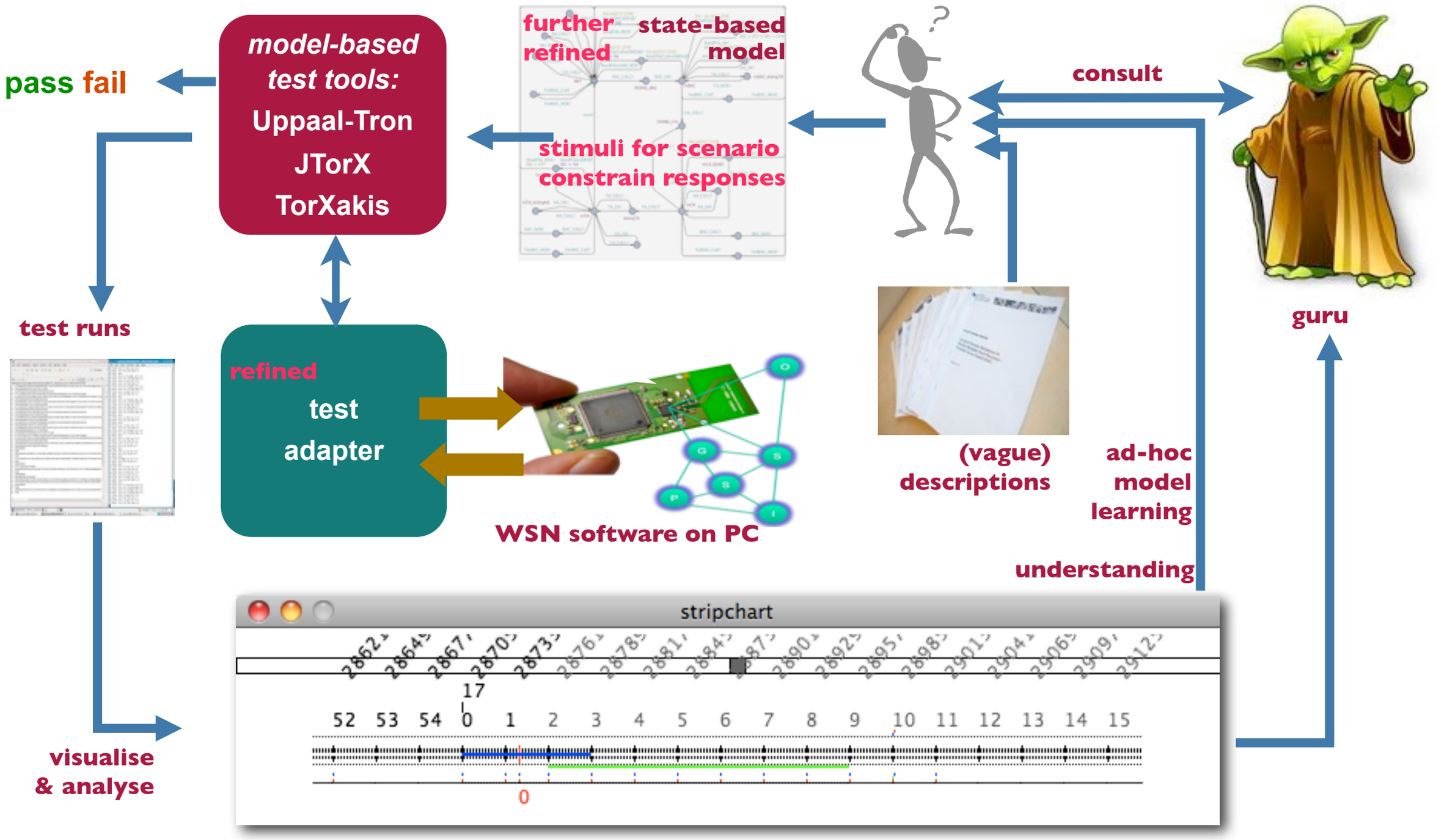
Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...



Testing a Wireless Sensor Network Node

Now we have all MBT ingredients, except model...

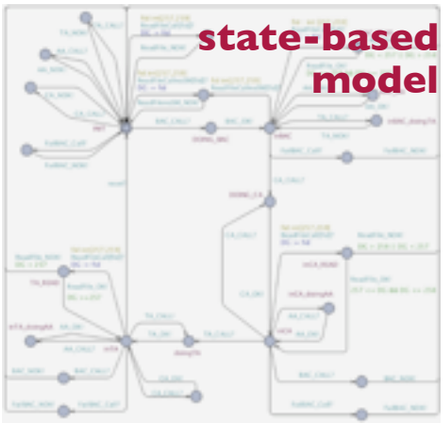


Testing a Wireless Sensor Network Node

What...

results did we obtain?

- more insight in SUT
- more insight in MBT
- model of SUT
- anomalies detected
- test harness to ‘zoom in’ on details (time-wise)
- first use of simulated time with uppaal-tron

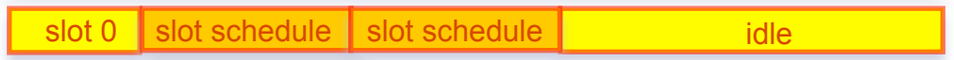


Demo...

(1) WSN frame structure

Time Frames

A Frame



58 slots
= 1624 ticks

Slot schedule

8 slots
= 224 ticks

Slot

28 ticks

Message

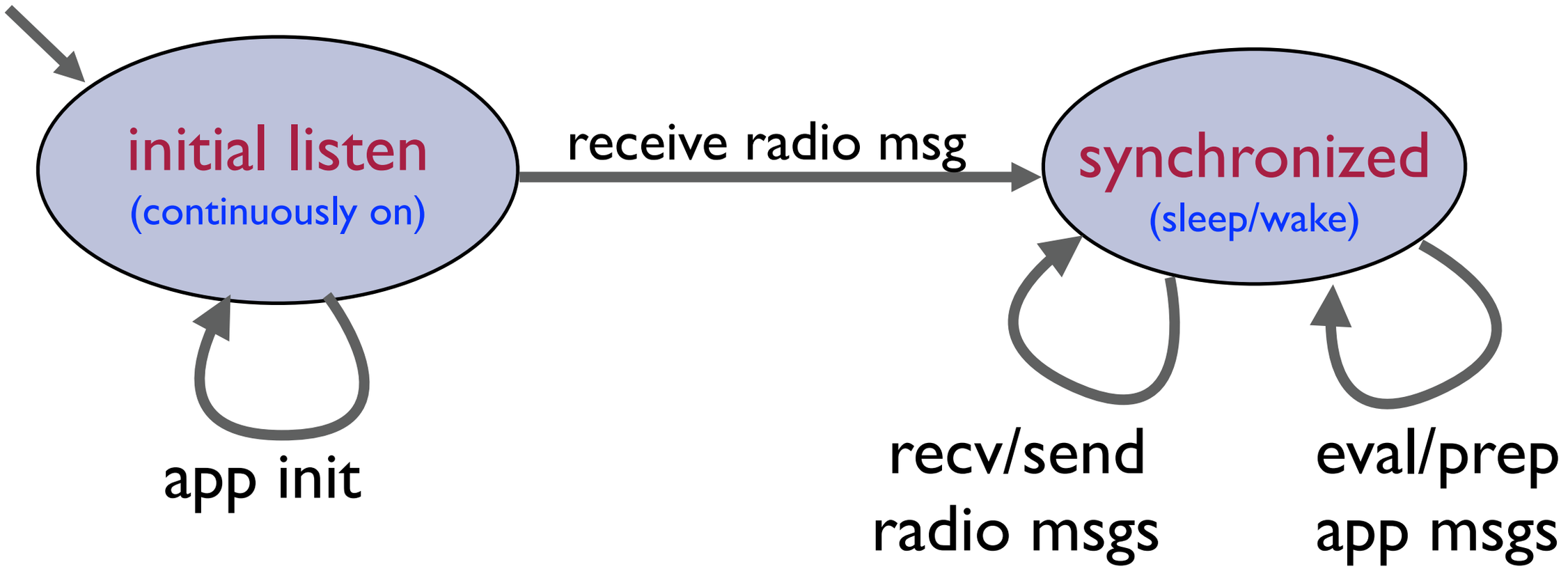
2 bytes
slot nr

total 32 bytes

Testing a Wireless Sensor Network Node

Demo...

(2) WSN state machine

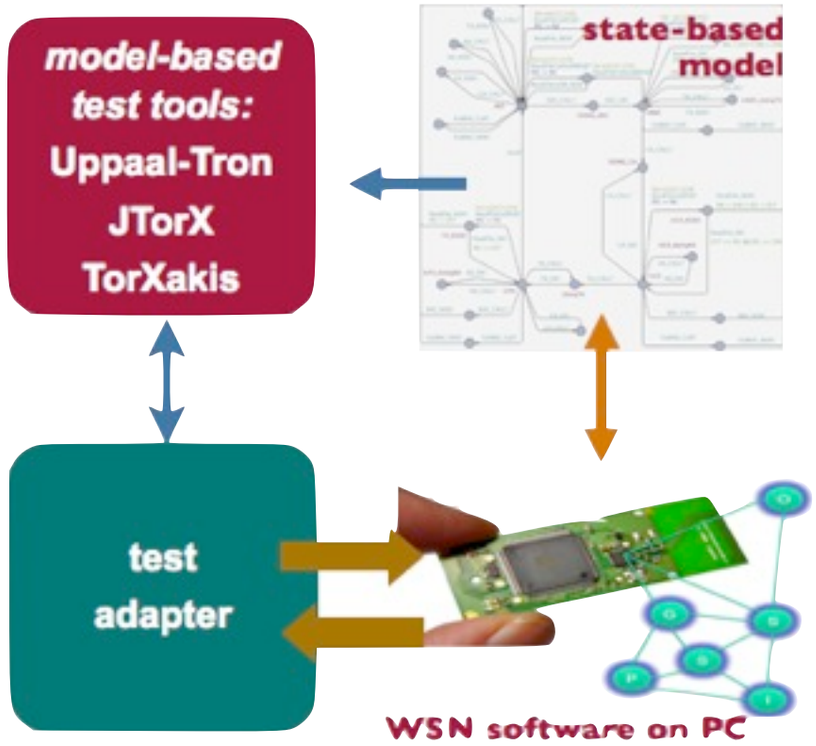


What...

lessons did we learn? (1)

MBT set-up:

- first make MBT setup work,
  only then start refining
  - any MBT 'ingredient' may be wrong
  - adapter may contain errors too:
    treat as part of SUT
- use general interfaces
- *software* test harness beneficial,
  but has its limitations



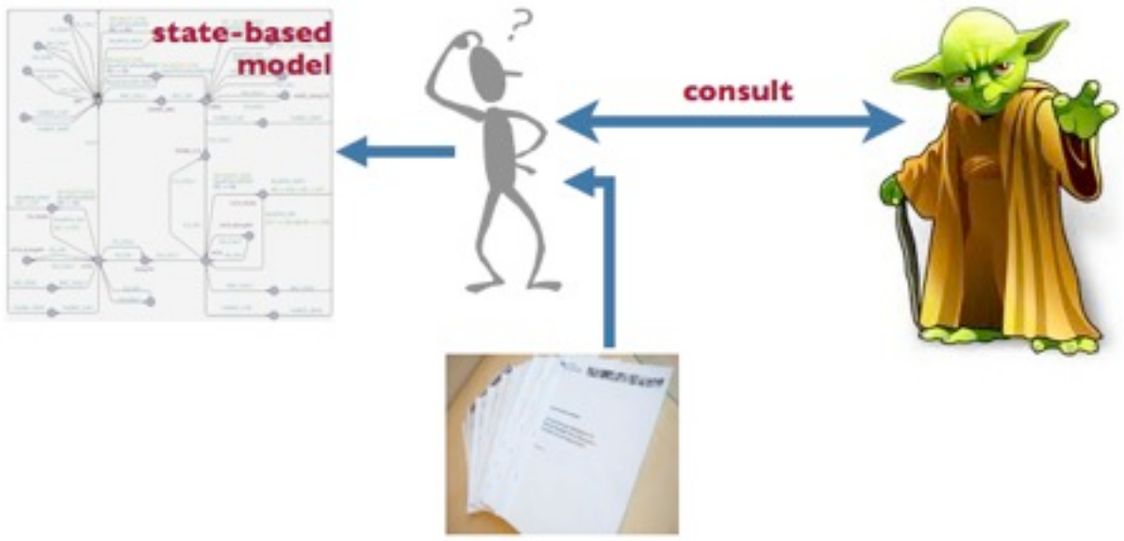
Testing a Wireless Sensor Network Node

What...

lessons did we learn? (2)

Modeling:

- start with liberal model,
  add detail as insight grows
- non-determinism
  & things unknown
  ➛ use underspecification
- documentation likely to be
  insufficient for modeling

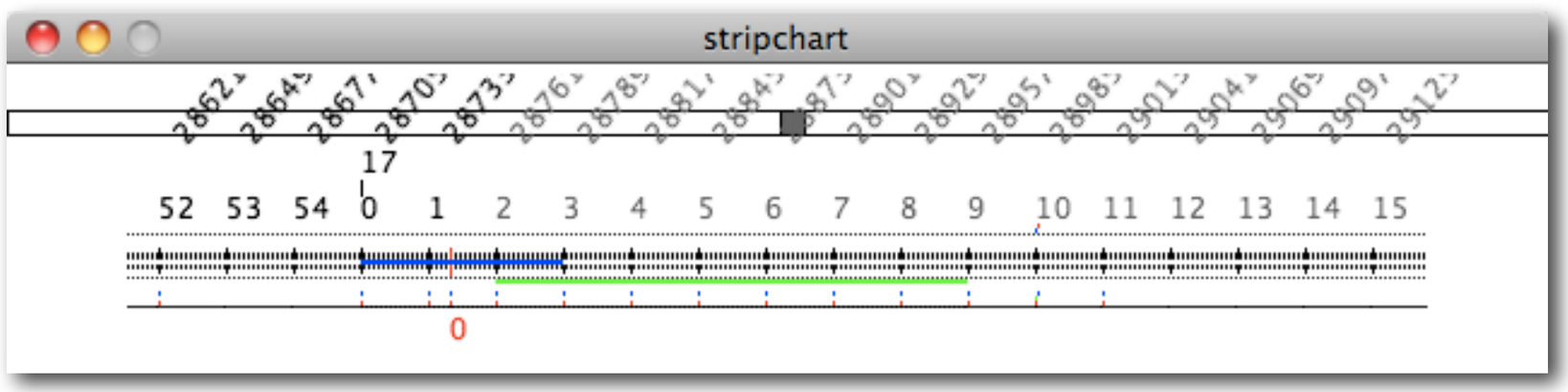


What...

lessons did we learn? (3)

Process:

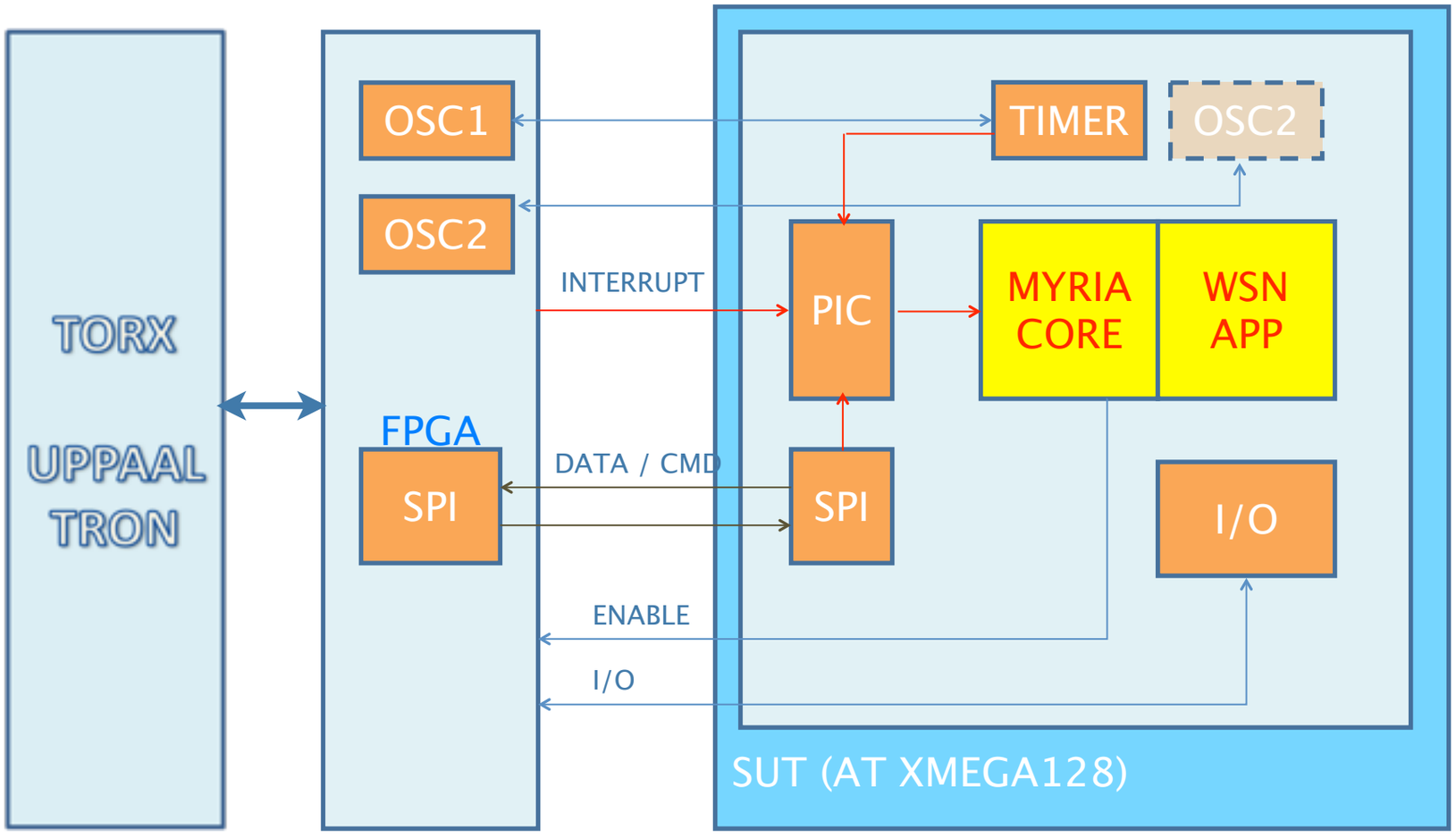
- chief designer != modeler
- be prepared to deal with moving target
- underspecified things unknown:
  manual analysis
- analysis tools



Testing a Wireless Sensor Network Node

What...

do we have in store for the future?



work-in-progress ability to test on real hardware

Testing a Wireless Sensor Network Node

What...

about security testing?

- ‘our’ MBT typically is conformance testing
- can show whether SUT behaves according to specification, for those input scenarios tested
- typically this implies testing ‘good-weather’ scenarios, and
- maybe even some ‘bad-weather’ ones, but (in the way we use MBT) only those that we can think of
- *must* be complemented by other techniques (e.g. whitebox fuzzing?)

Conclusions

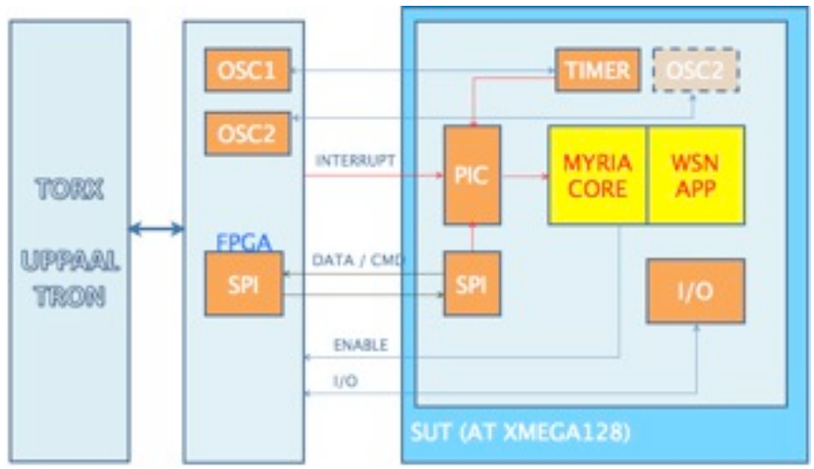
- we are applying MBT to the system software of a WSN node, using a software test harness with simulated time

- this resulted in

  ➡ insight (MBT, WSN),

  ➡ anomalies found,

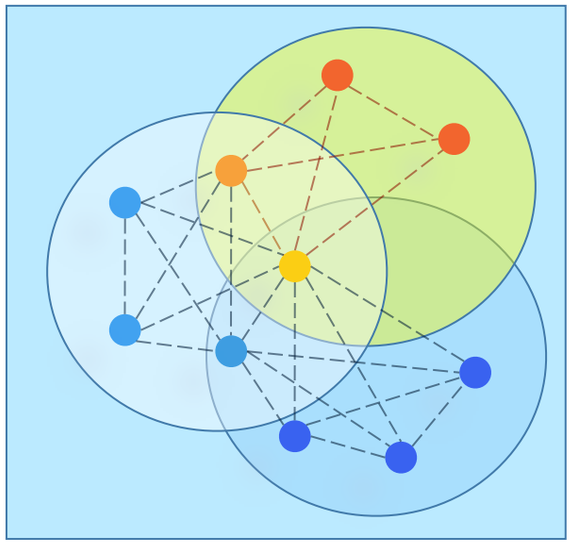
  ➡ and a reusable technique to apply uppaal-tron with simulated time (MSc thesis Feng Zhu)

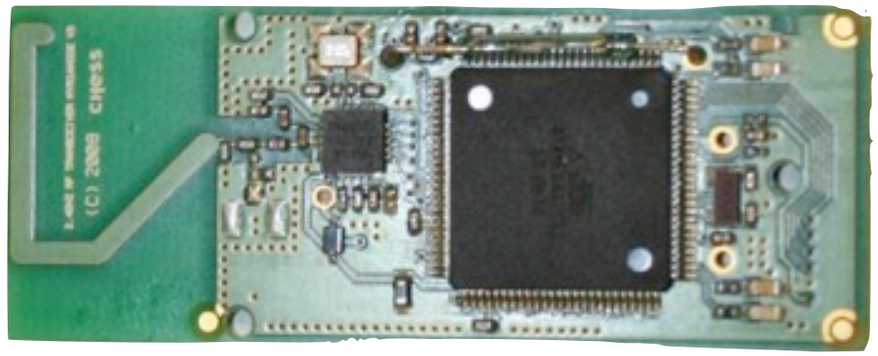


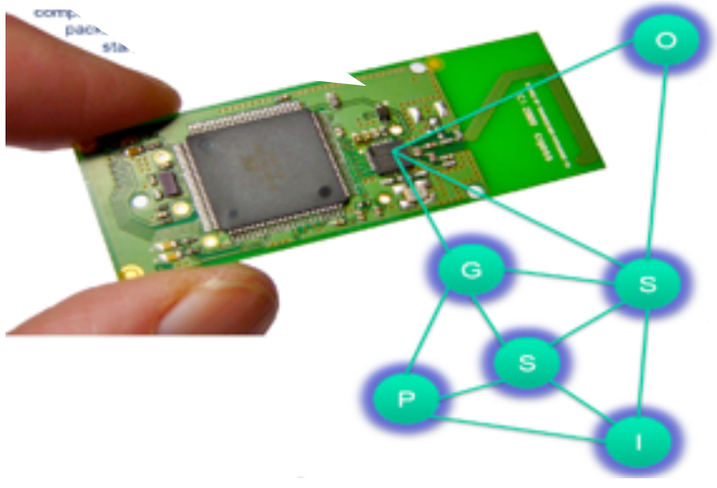
- we are working on carrying this forward to a hardware test harness, also with simulated time

Questions?

thank you for your attention!







Testing a Wireless Sensor Network Node