TU/e Technische Universiteit Eindhoven University of Technology

CWT/e, October 2016

Wireless Electronic Systems: Trading off performance, reliability and energy efficiency

Twan Basten

Eindhoven University of Technology & TNO Embedded Systems Innovation

Joint work with Marc Geilen, Hailong Jiao, Majid Nabi, José Pineda, and many others

partners

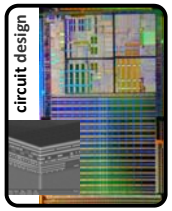
NXP imec DEVLAB dialog SEMICONDUCTOR

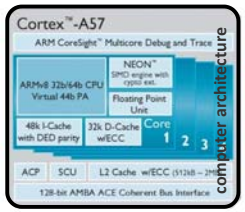
'Knowing is not understanding.'
Charles Kettering

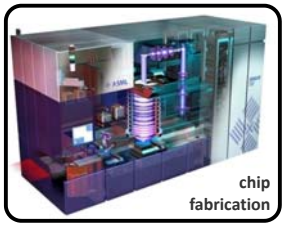
The Electronic Systems group

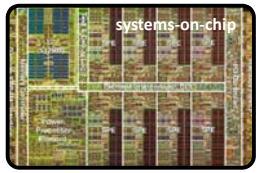
Mission

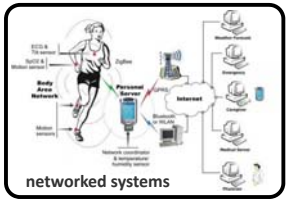
- Scientific basis for design trajectories
- From function to realization
- Constructive design



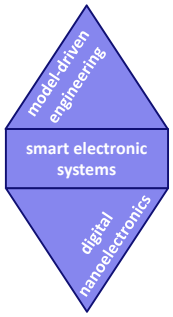


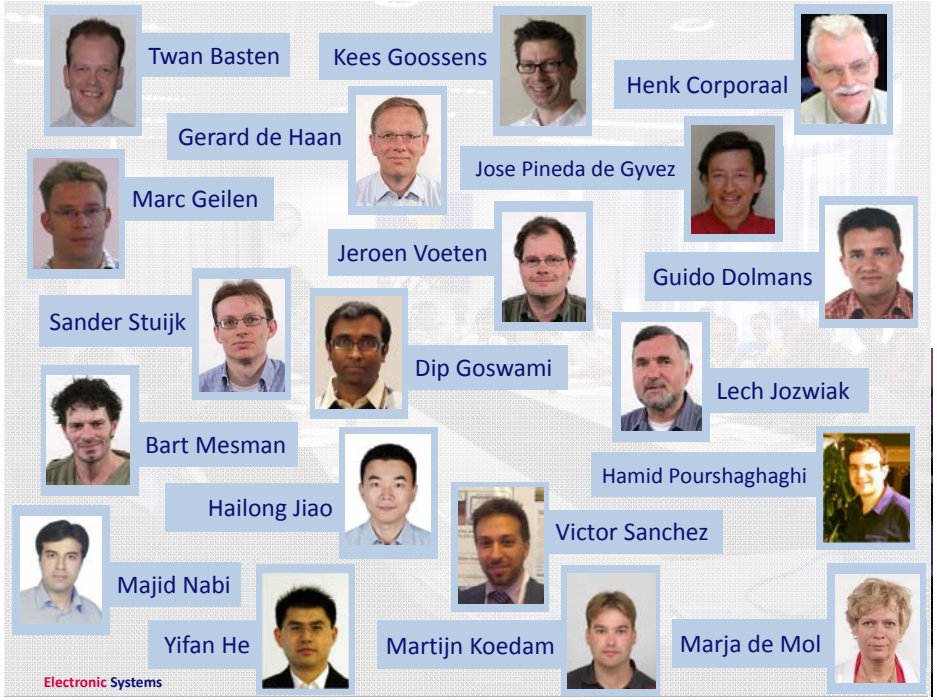






- SDF3: Model-driven synthesis of data-processing applications
- POOSL: Fast discrete-event simulation
- Embedded control and signal processing
- Health monitoring
- CompSOC: Predictable multiprocessor platforms
- GPUs and accelerators
- Brain-inspired computing
- Ultra-low power electronics





Wireless Electronic Systems

7 Trade offs

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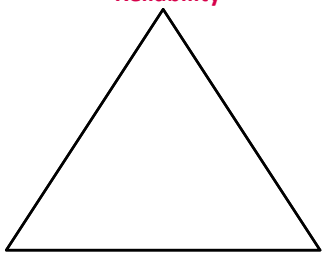
- Cross-technology interference
- Device density
- Limited transmit power
- Wireless channel behavior

Reliability



Performance

- Latency and throughput requirements
- Safety-critical real-time applications

Energy Efficiency

- Communication
- Processing

and of course **cost** …

8 An integral approach

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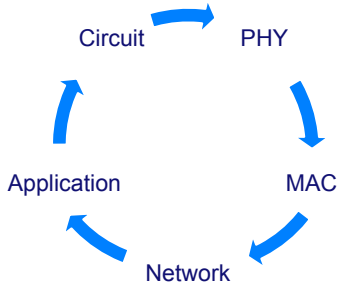

- Co-design
- Model-driven development
- Experimental validation

CC2530 ZigBee Development kit

150 NXP JN5168 dongles

130 TI CC2650 SensorTags

100 MyriaNed nodes

Circuits

10 Approximate computing

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Can you see the difference between the two figures?

$$\begin{array}{r} 10 \\ \times\ 10 \\ \hline = 100 \end{array} \qquad \begin{array}{r} 10 \\ \times\ 10 \\ \hline \approx\ 99 \end{array}$$

100% accuracy is not always necessary

11 Trade off between power, performance, area and accuracy

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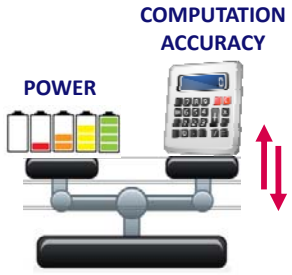

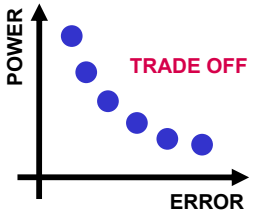

Approximate data
- Simplified logic
- Bit-width representation

Approximate timing
- Clock frequency
- Supply & threshold voltage

12 Better-Than-Worst-Case Design – Approximate timing

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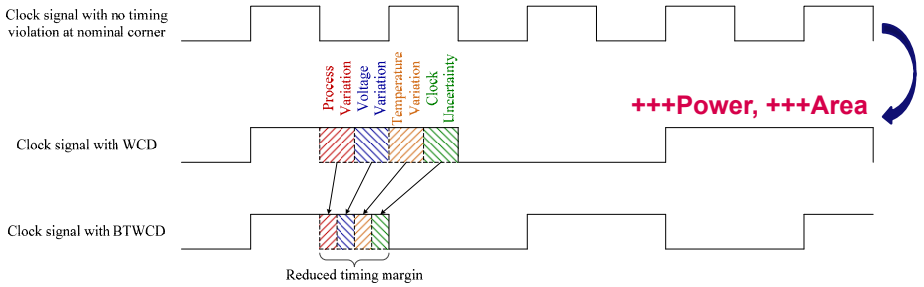

- Enhanced performance
- Lower power consumption
- Smaller silicon area

at the cost of

- Reduced reliability

13 Wireless baseband processing in the Internet of Things

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- Targeting IEEE 802.15.4 / WiFi standards
- Requires protocol / circuit co-design

802.15.4 wireless + Wi Fi™

QoS-AB project, with NXP

14 Potential approximate modules

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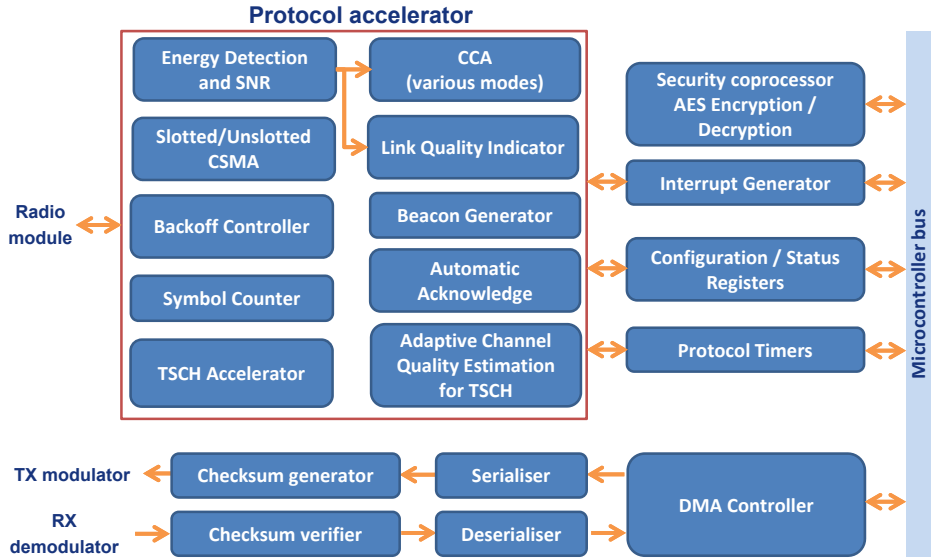

QoS-AB project, with NXP

15 Approximate multiplier – Approximate data

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A low power accuracy-controllable iterative-approximate multiplier

- Basic idea: piece-wise linear approximation, shift operations
- Low error rate (0.13% NMED, normalized mean error distance)

	Area savings	Power savings
32-bit Approximate Multiplier Based 5th Order FIR Filter	-26 %	-49 %

Protocol Stacks

Protocol Stacks WBAN

18 Wireless Body-Area Network (WBAN) communication

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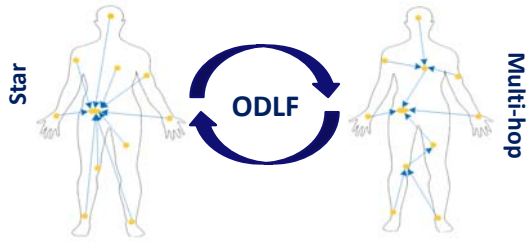

ODLF: On-Demand Listening and Forwarding

WBAN

- One gateway
- Number of nodes known
- Highly dynamic link quality

ODLF

- Hybrid star and gossiping protocol
- Gateway dynamically requests transmission support
- Efficient implementation with a support bitmap

19 Wireless Body-Area Network (WBAN) communication

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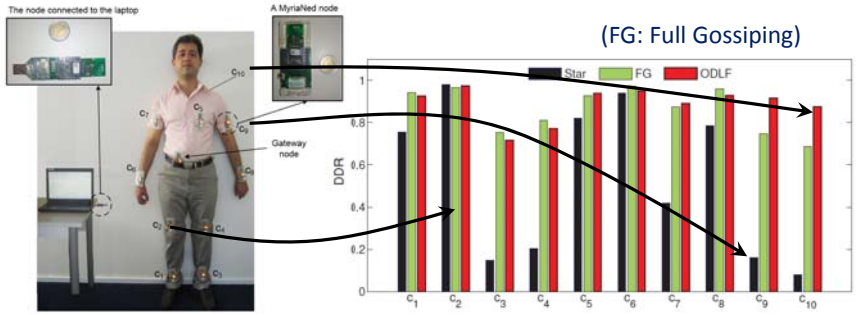

(FG: Full Gossiping)

Trading off **performance** and **energy**

Energy dissipation increases with lower-quality links

Support set Ψ grows with lower-quality links

20 Link Quality Estimation (LQE)

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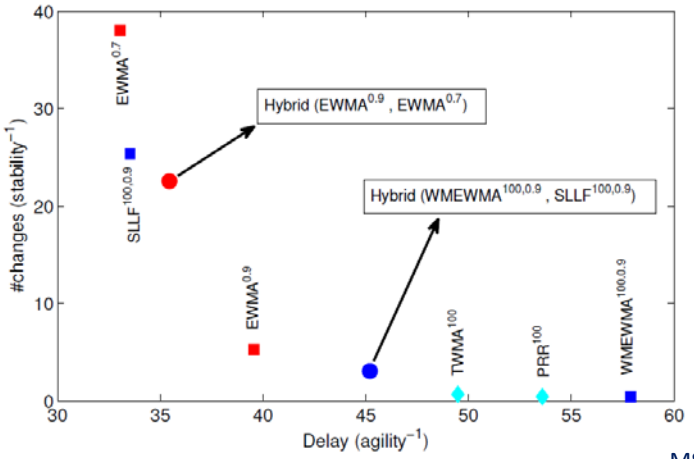
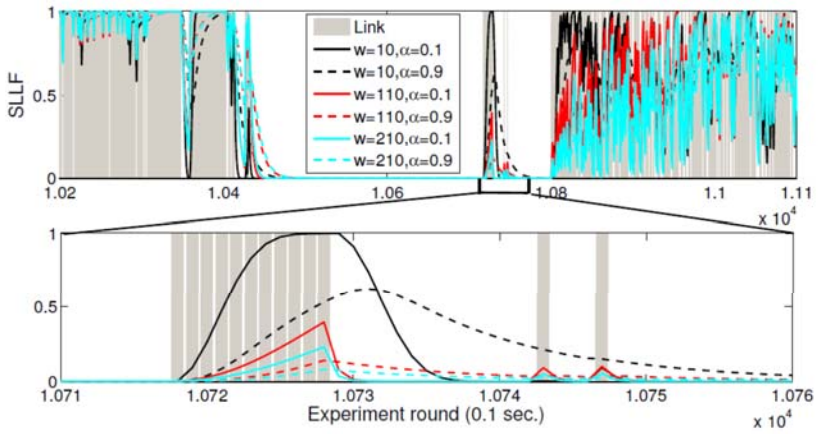
- Prerequisite for many adaptive mechanisms, many variants
- Typical parameters: window size w and coefficient α
- Agility and stability trade offs



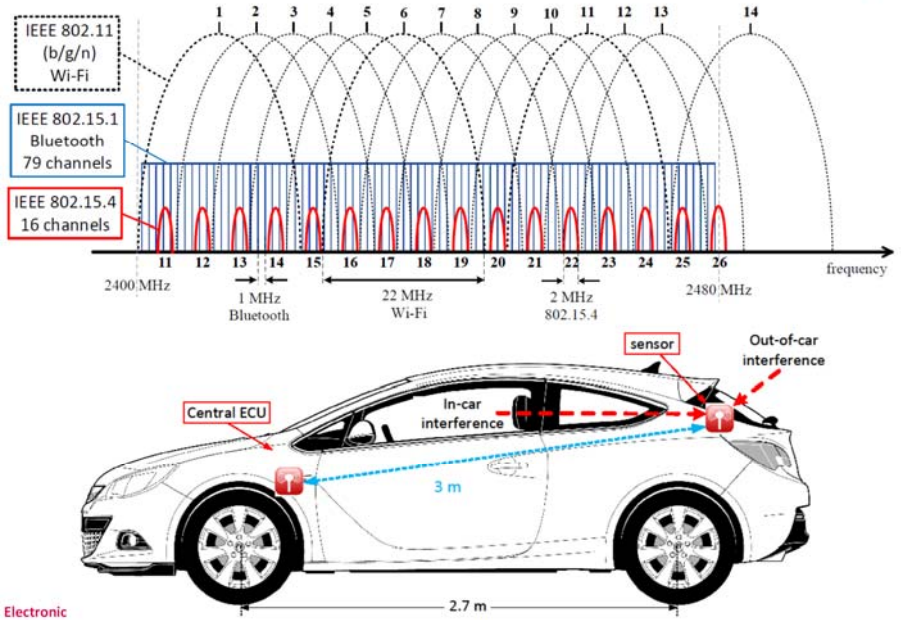
21 WBAN LQE: Smoothed Link Likelihood Factor (SLLF)

- Prerequisite for many adaptive mechanisms, many variants
- Typical parameters: window size w and coefficient α
- Agility and stability trade offs

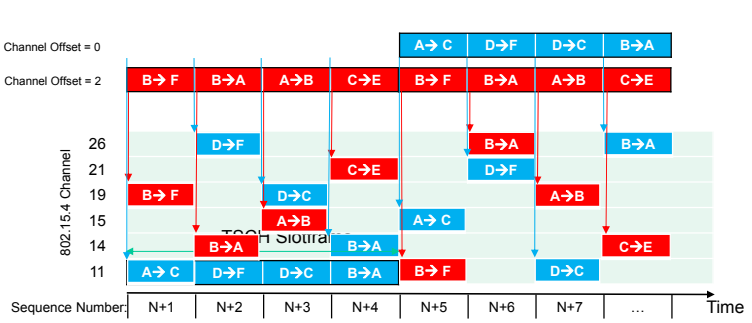


Protocol Stacks IVN

23 Cross-technology interference – in-vehicle networking



24 802.15.4 - Time-Slotted Channel Hopping (TSCH)

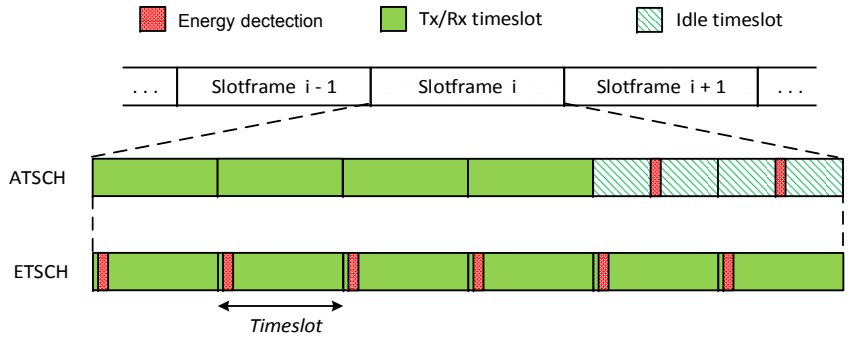


Hopping Sequence List

index	Ch #
0	11
1	26
2	19
3	14
4	15
5	21

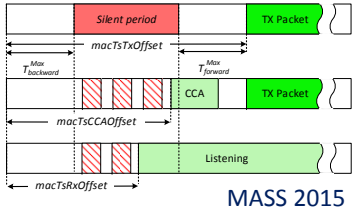
- Provides guaranteed access to the medium
- Prevents persistent multi-path fading
- Eliminates blocking of wireless links

25 Enhanced TSCH (ETSCH)

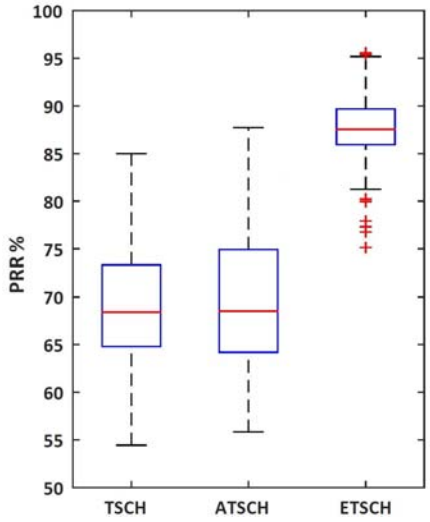


- ATSCH = energy detections in payload slots + whitelisting
- ETSCH = NICE + smart whitelisting

NICE, Non-Intrusive Channel-quality Estimation, uses
- silent period in coordinator time slots
- energy detections to asses channel quality



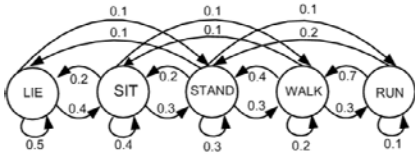
26 Enhanced TSCH

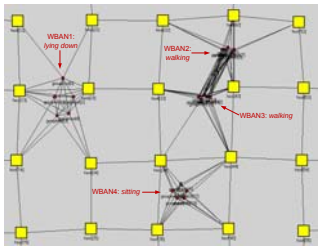


Intermezzo: the Environment

28 MoBAN: mobility model for WBANs

- Reference point group mobility (RPGM)
- Markov chain for posture selection
- Spatial and temporal correlations
- Based on extensive measurements
- Intra-WBAN and ambient network simulation
- Implemented in MiXiM





29 Cross-technology interference in vehicles

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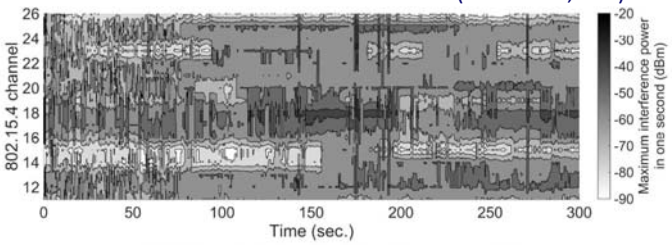
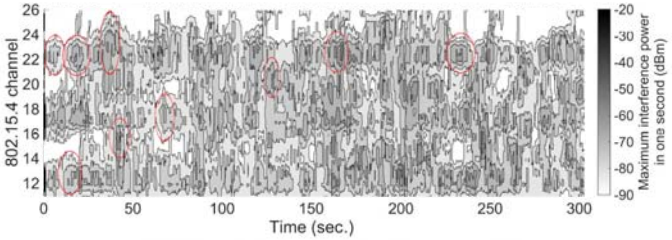
- Interference measurements inside a car (bluetooth, wifi)



- Interference from outside (mostly wifi)



- Usable to drive simulations

Networks

31 QoS provisioning in static trees

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Wireless sensor network

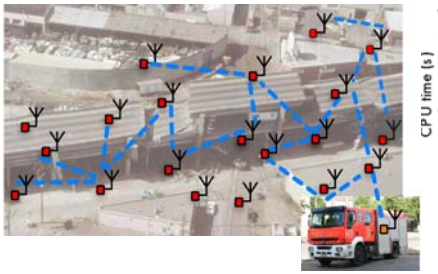
- 900 nodes
- 27 configurations per node
- 4 quality metrics
- Routing tree to data sink

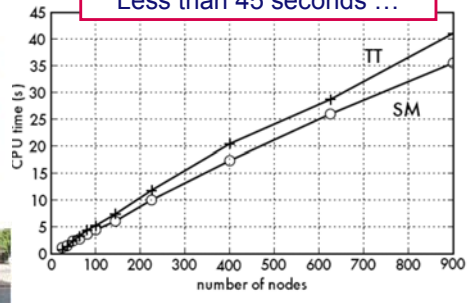
27^{900} configurations in 4D space

Problem
How to configure the network ?

Approach
Compositional computation following the routing-tree structure

Less than 45 seconds …





32 Pareto algebra

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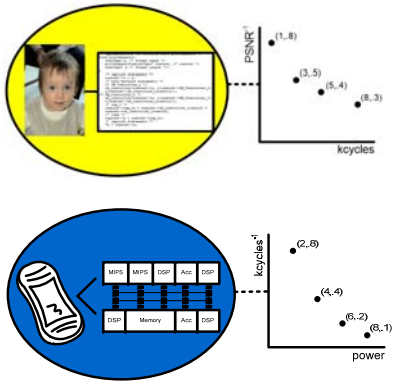
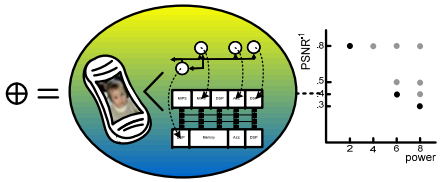
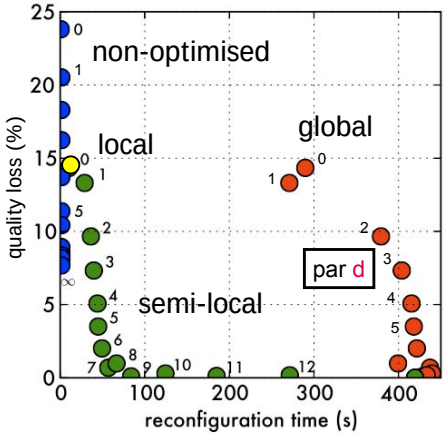
Goal: Compositional computation of trade-offs



producer-consumer operation



33 QoS provisioning in dynamic trees

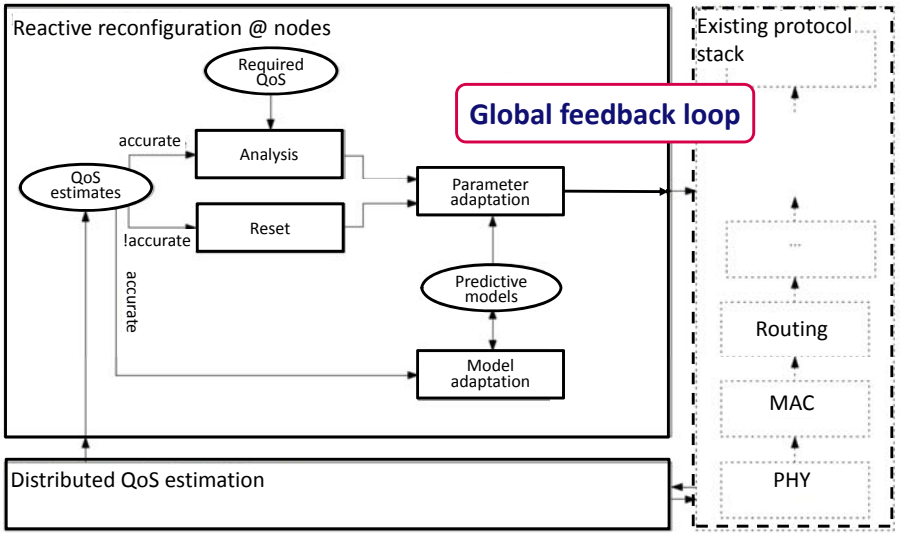


900 node network
Simulated in the OMNET++ simulator
Calibrated for TelosB sensor nodes
8 Mhz processor
250 kbps tranceiver bit rate

Good quality reconfiguration within one minute

EWSN 2009

34 Distributed QoS provisioning in dynamic networks



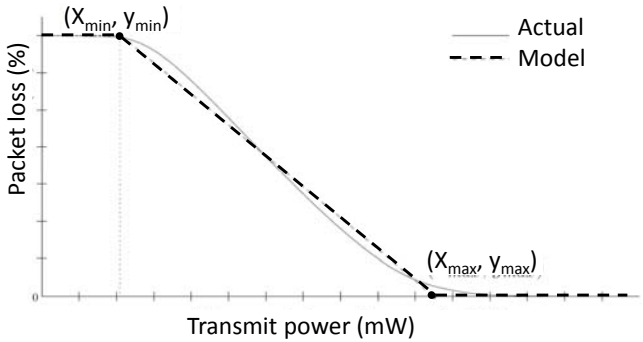
Global feedback loop

Challenge: distribute contributions to QoS changes

TOSN 2015

35 Distributed QoS provisioning in dynamic networks

- Relations network & node parameters – QoS properties

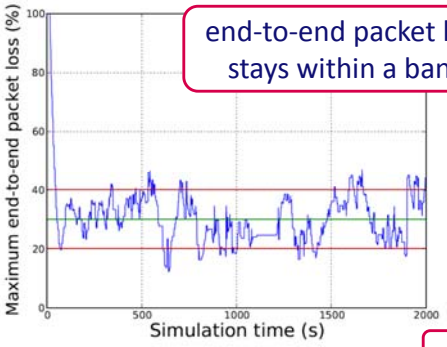


- Model-driven approach
- Impact models with 4 parameters

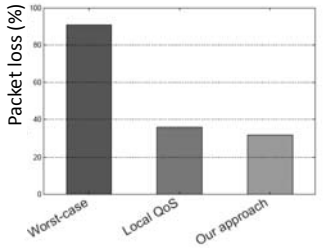
TOSN 2015

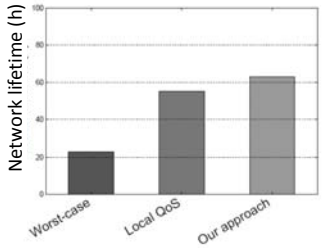
36 Distributed QoS provisioning in dynamic networks

end-to-end packet loss stays within a band



and outperforms other approaches





Wrapping up

38 Conclusions – wireless electronic systems

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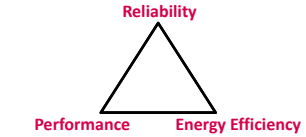
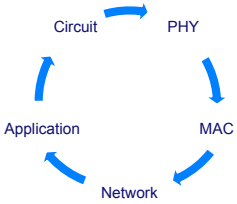
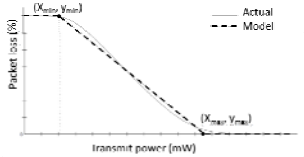
- is all about trade offs



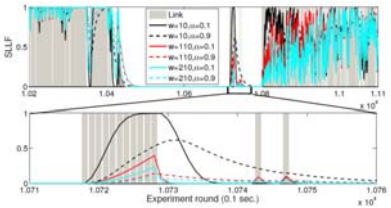
- requires co-design of circuit, protocols and application



- model-driven



- with experimental validation



39 Funding acknowledgement

TU/e

- WASP – EC FP6 project IST-034963
- ALwEN – Dutch innovation program Point-One, grant PNE07007
- DEWI – ARTEMIS grant 621353.
- RESIST – CATRENE grant CT217
- QoS-AB – SRC grant 2016-IT-2681

40 Thank you !

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Questions ?

More info: www.es.ele.tue.nl/~tbasten/

www.es.ele.tue.nl/nes/

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