



**DEPENDABLE**  
**INTERNET**  
OF THINGS

## Dependable Internet of Things

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Dependable Internet of Things in Adverse Environments

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## Internet of Things (IoT)


Computers embedded in things

- Connected to the Internet
- Sensing, actuation, processing, energy



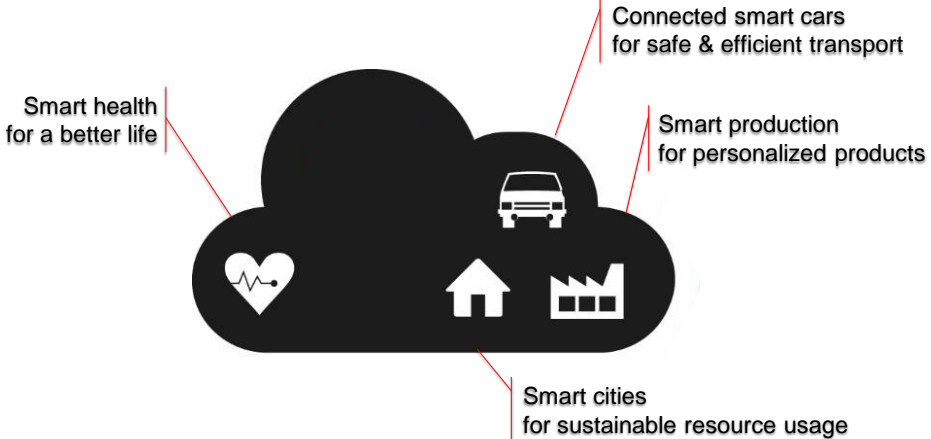

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## Critical Applications

- As ubiquitous as electrical appliances today
- Failures will have severe impact




Smart health for a better life


Connected smart cars for safe & efficient transport

Smart production for personalized products

Smart cities for sustainable resource usage


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## Dependability


Guaranteed and predictable performance

- Reliability – continued correct, accurate, timely service
- Availability – readiness for service
- Safety – no catastrophic consequences
- Security – no unauthorized disclosure and alteration




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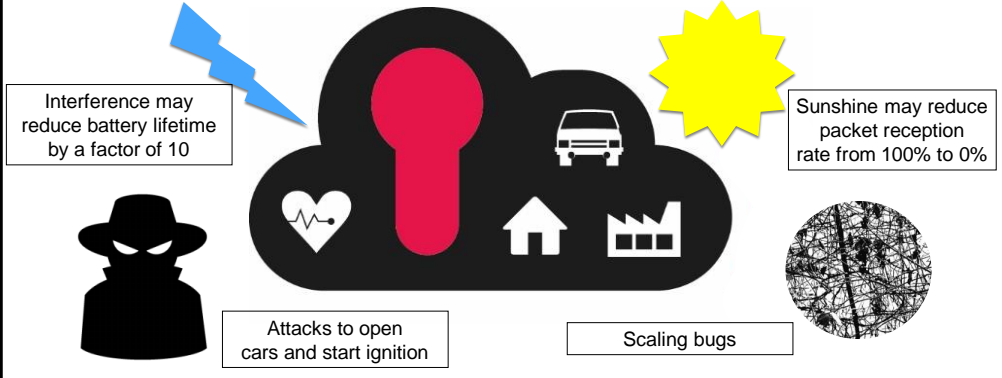
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# Adverse Environments

## Threats to dependability

T1: Harsh environments (interference, temperature, ...)  
 T2: Physical and remote attacks  
 T3: Complexity (scale, openness, constraints, ...)




Interference may reduce battery lifetime by a factor of 10


Attacks to open cars and start ignition

Scaling bugs

Sunshine may reduce packet reception rate from 100% to 0%

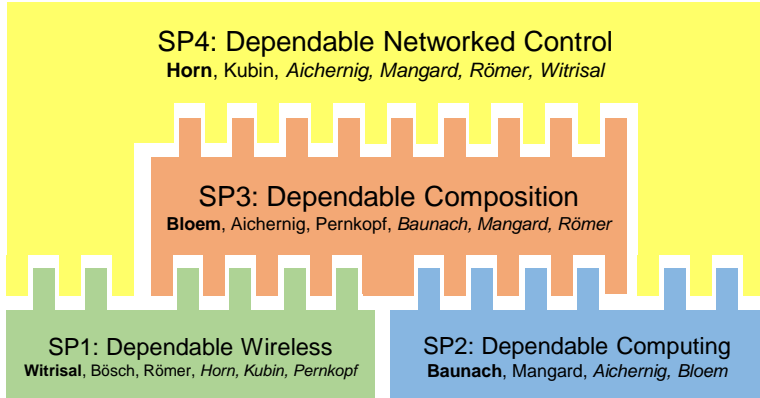

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# Research Program

## Dependability for key aspects of the IoT




**SP4: Dependable Networked Control**  
*Horn, Kubin, Aichernig, Mangard, Römer, Witrisal*


**SP3: Dependable Composition**  
*Bloem, Aichernig, Pernkopf, Baunach, Mangard, Römer*

**SP1: Dependable Wireless**  
*Witrisal, Bösch, Römer, Horn, Kubin, Pernkopf*











**SP2: Dependable Computing**  
*Baunach, Mangard, Aichernig, Bloem*


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## Multidisciplinary Team

*Klaus Witrissal	■ Wireless Signal Processing
Wolfgang Boesch	■ Microwave Engineering
Kay Römer	■ Embedded Networking
*Marcel Baunach	■ Real-Time Operating Systems
Stefan Mangard	■ Embedded Security
Roderick Bloem	■ Formal Verification
*Bernhard Aichernig	■ Model-Based Testing
*Franz Pernkopf	■ Machine Learning
Martin Horn	■ Control Theory
Gernot Kubin	■ Information Theory

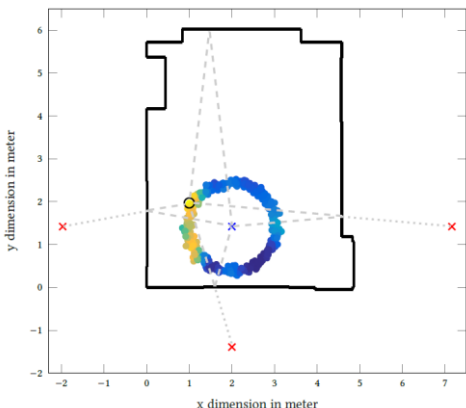

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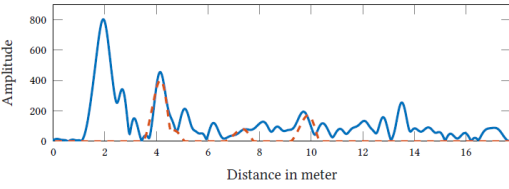
## Multi-Path Resolved UWB Positioning

- Anchor location + LOS distance -> possible positions on circle
- Draw sample locations on circle
- Compute hypothetical CIR from reflections using map
- Match against measured CIR to find best matching location



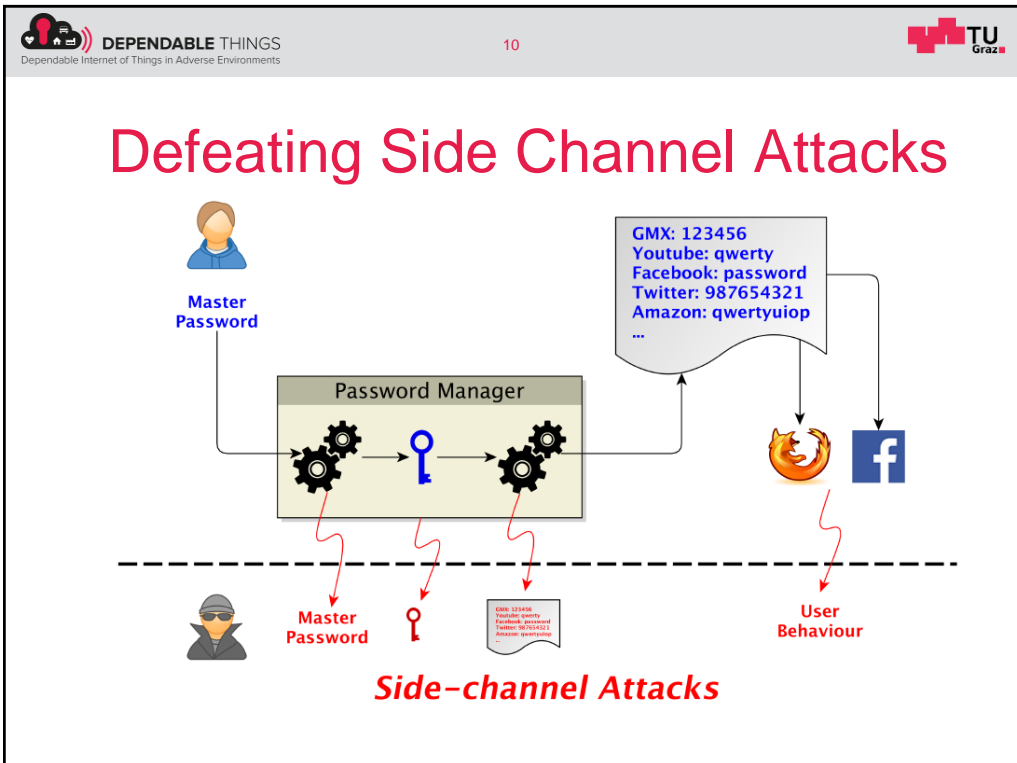
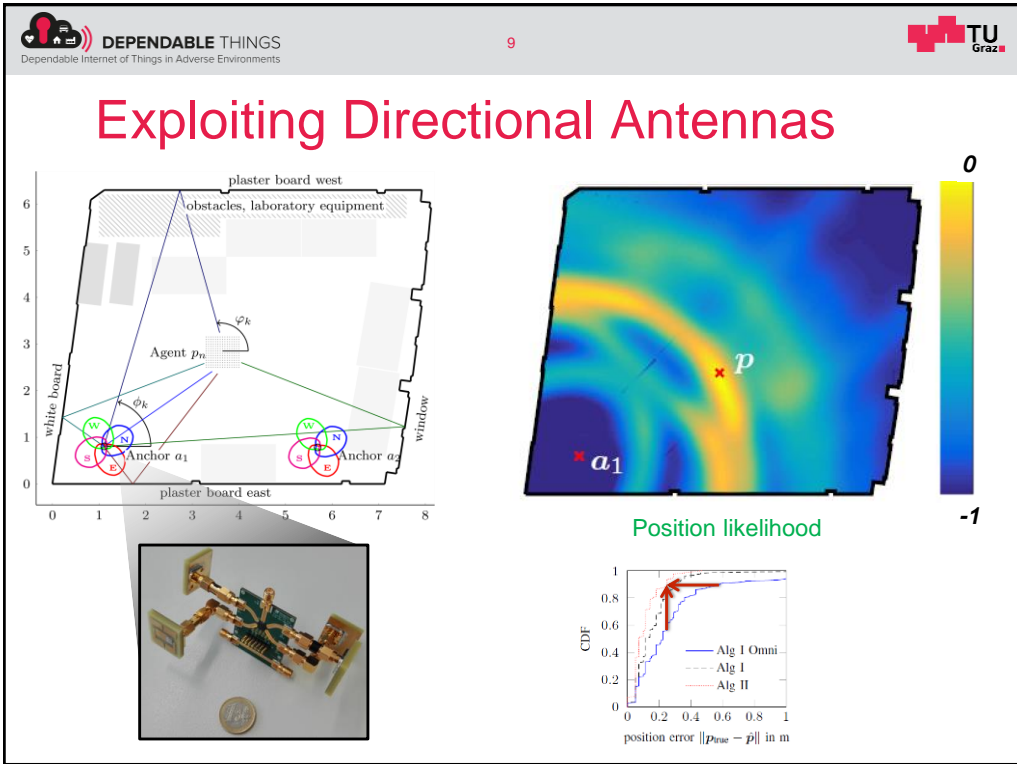
y dimension in meter

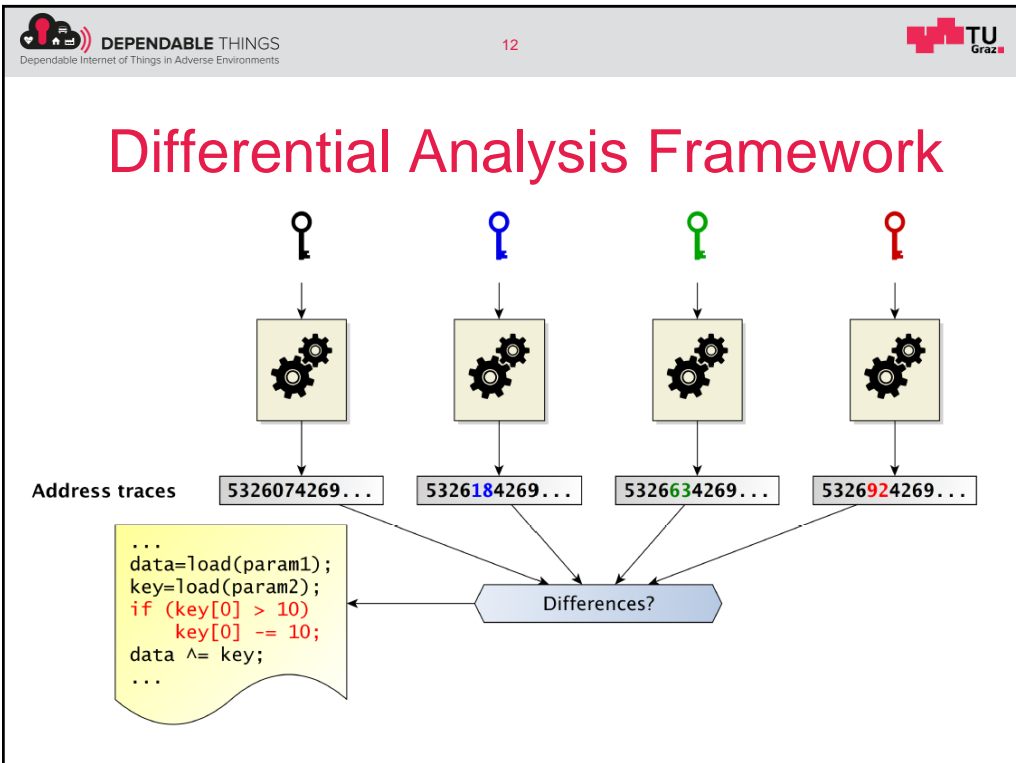
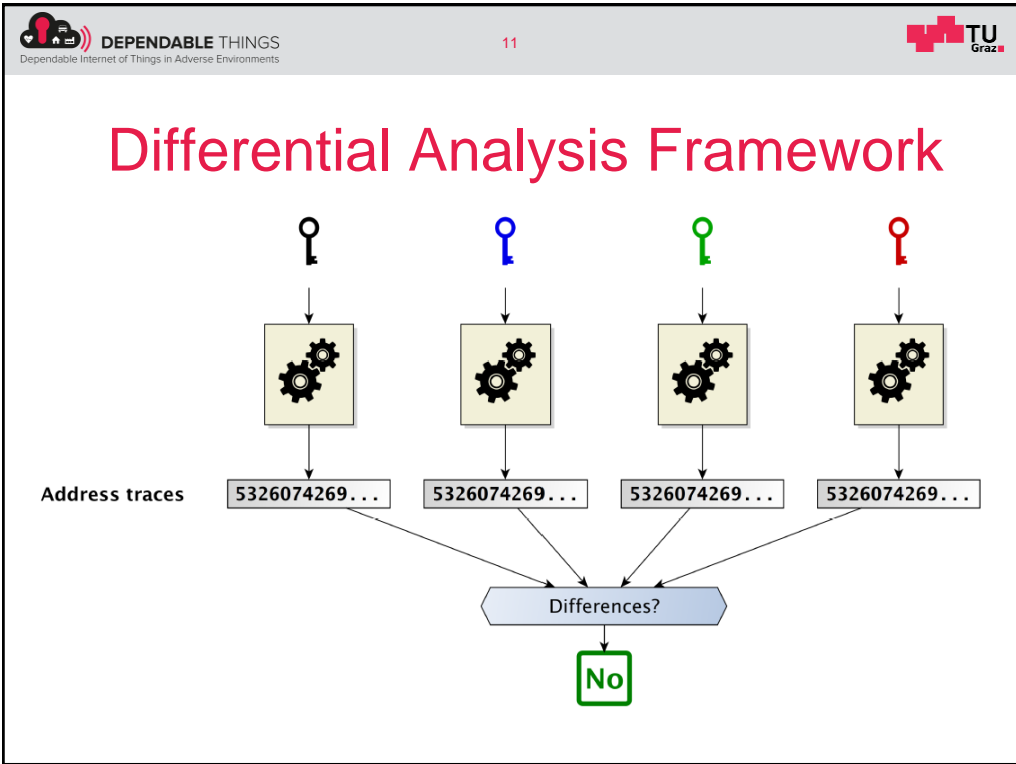
x dimension in meter




Amplitude

Distance in meter








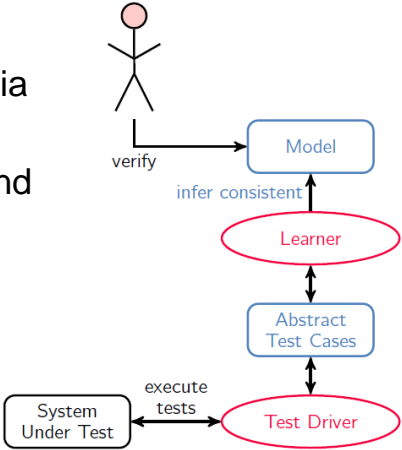
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## Learning-Based Protocol Testing

- Protocol mess, lack of formal specifications
- Infer state-machine model via active learning
- Use model for verification and testing
  - Model checking
  - Differential testing




The flowchart shows a cycle: **System Under Test** → **Test Driver** → **Abstract Test Cases** → **Learner** → **Model** → **verify** → **System Under Test**. The **Learner** and **Test Driver** components are circled in red.

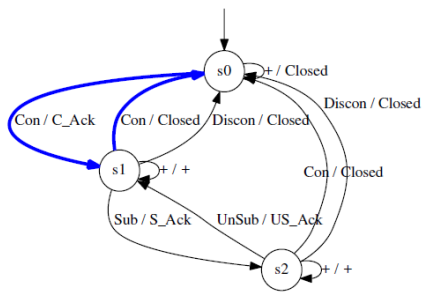


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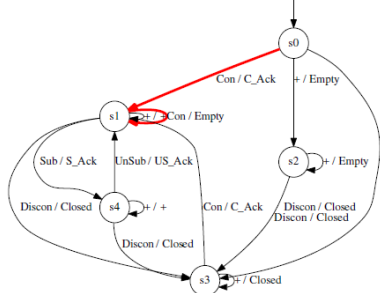
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## A Simple Bug in MQTT



**Mosquitto**



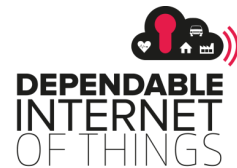
**HBMQTT**

Counterexample showing Mosquitto  $\not\equiv$  HBMQTT

Input	Output(Mosquitto)	Output(HBMQTT)
Connect	ConnAck	ConnAck
Connect	ConnectionClosed	Empty

## Conclusions

- Critical IoT applications will be ubiquitous
  - People may be hurt
  - Business models may fail
- Adverse environments impact IoT performance
  - Harsh environment (temperature, interference)
  - Attacks
  - Complexity
- Need for guaranteed performance
  - Whole-system perspective



<http://dependablethings.tugraz.at>