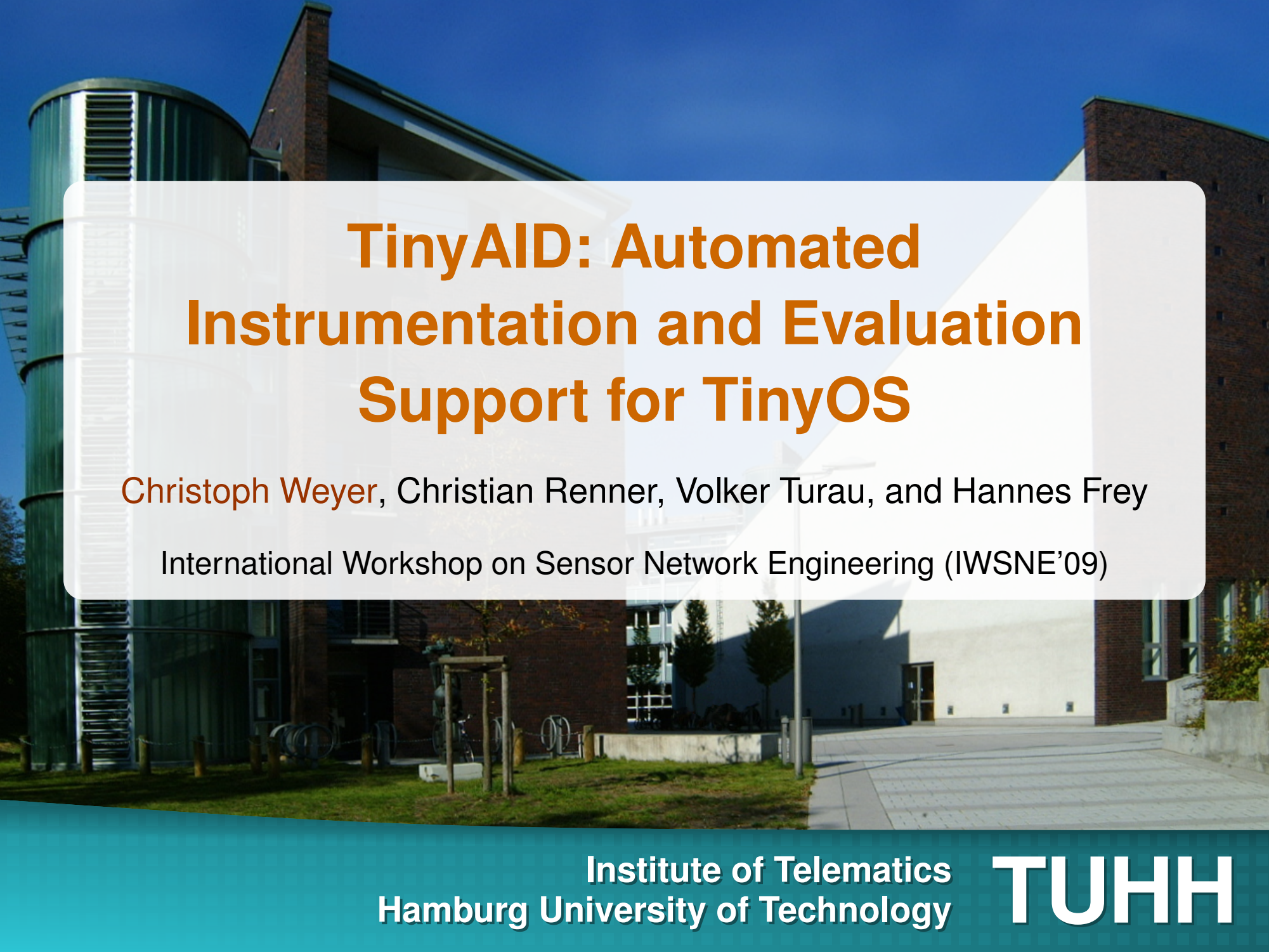

TinyAID: Automated Instrumentation and Evaluation Support for TinyOS

Christoph Weyer, Christian Renner, Volker Turau, and Hannes Frey

International Workshop on Sensor Network Engineering (IWSNE'09)

Institute of Telematics
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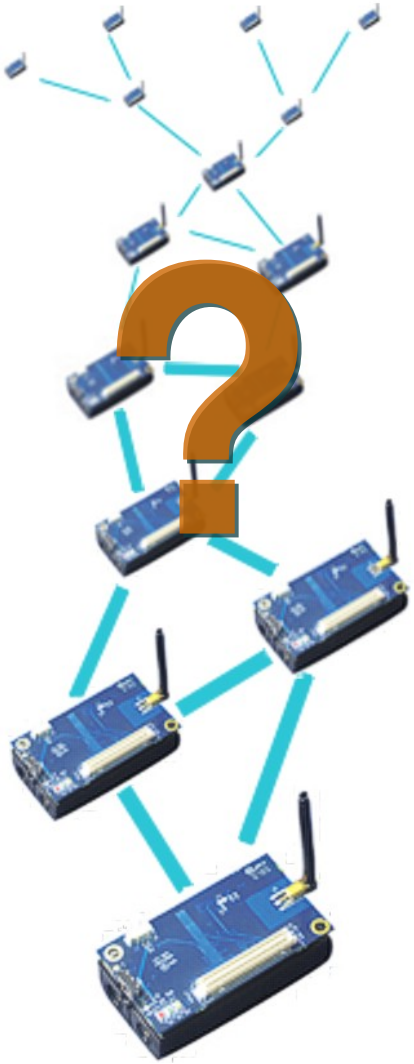
Development Support for WSNs



Problem:

- Debugging new implementations
  - → Logging of internal information
- Comparing existing implementations
  - → Extracting comparable metrics

Looking for: Development support tools

Solution: Automated approach

- Instrumentation
- Evaluation

Automated Development Support

Goals:

- Extract information without any manual interventions
- Gather essential information about network state
  - State of nodes
  - Packet flows within the network
- Small memory footprint and low runtime overhead

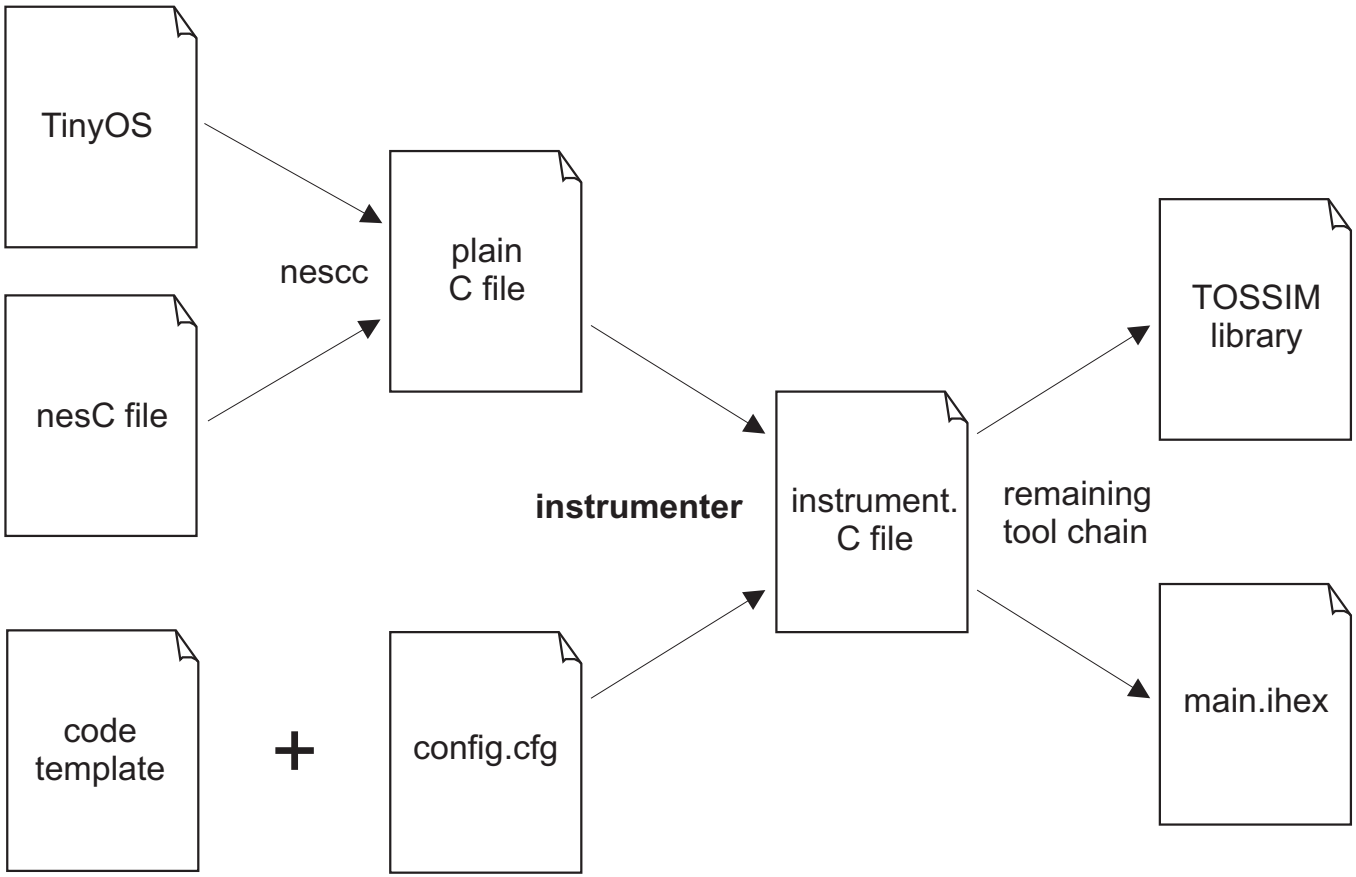
Preconditions:

- Coding conventions are required
- TinyOS provides some kind of conventions

Information gathered by TinyAID

- Call-chain logging
  - Occurrence of events reflects change of node state
    e.g., TinyOS events `Timer.fired`
  - Currently executed component
    Part of the C function name that is called
  - Monitoring what components are turned on/off
    Tracing specific events, e.g., `Radio.startDone`
- Packet logging
  - Sending and receiving a packet
  - Tracking of packets over multiple hops
- Adding timestamps to logged data

Instrumentation



Configuration of Call Chain Logging

```
-d /opt/tinyos-2.x/.*   # exclude everything in /opt/tinyos-2.x
+f Test.nc              # include everything in file Test.nc
+h fired                # include all fired event handler
+h booted               # include all booted event handler
```

- Instrumentation code is inserted based on configuration
- Configuration includes (+) or exclude (-)
  - Directories (d)
  - Files (f)
  - Commands or Events (h)
- First match decides action
- If no match is found no instrumentation is inserted

Call Chain Logging

Node ID	Time [ms]	Direction	Handler ID
5	1320	>	42
5	1322	>	36
5	1323	>	12
5	1324	<	12
5	1328	<	36
5	1333	<	42
3	1648	>	20
3	1649	<	20
7	1930	>	42
7	1931	<	42
...	...	...	...

Call Chain Logging

Node ID	Time [ms]	Direction	Handler ID
5	1320	>	42
5	1322	>	36
5	1323	>	12
5	1324	<	12
5	1328	<	36
5	1333	<	42
3	1648	>	20
3	1649	<	20
7	1930	>	42
7	1931	<	42
...	...	...	...

Message Logging

- Adding additional fields to each packet
  - Originating node
  - Unique sequence number for each node
- Information is inserted by calling `Packet.clear()`
- Trace: creating, sending, and receiving of packets

node	time [ms]	action	type	src	dest	origin	seqno
3	3520	c				3	42
3	3521	s	17	3	12	3	42
5	3524	c				5	14
5	3525	s	34	5	65535	5	14
12	3535	r	17	3	12	3	42
3	3520	c				3	43
...	...	...	...	...	...	...	...

Message Logging

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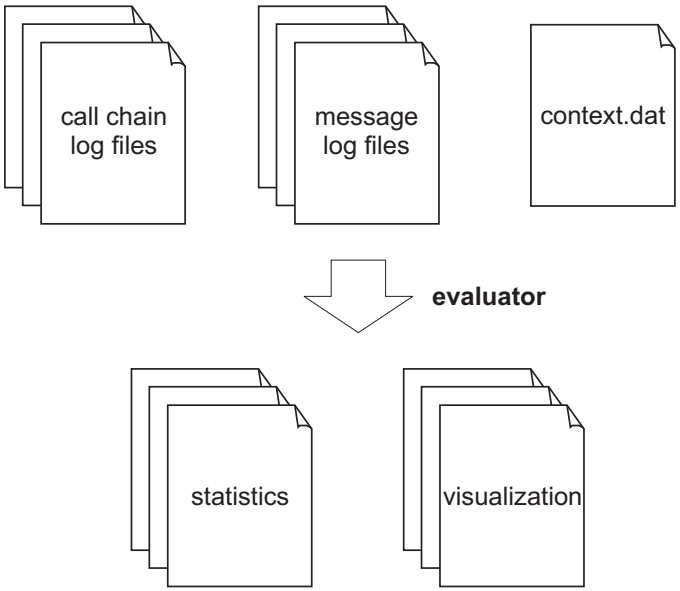
12	3535	r	17	3	12	3	42
3	3520	c				3	43
...	...	...	...	...	...	...	...

Limitations

- Monitoring generally influences system
  - Influence depends on precision
  - System behavior should not be changed
- Not all information can be extracted by an automated process
  - Call-chain not always reflects node state
  - Expressiveness of message reception
- Meta or semantical information is needed

Evaluation

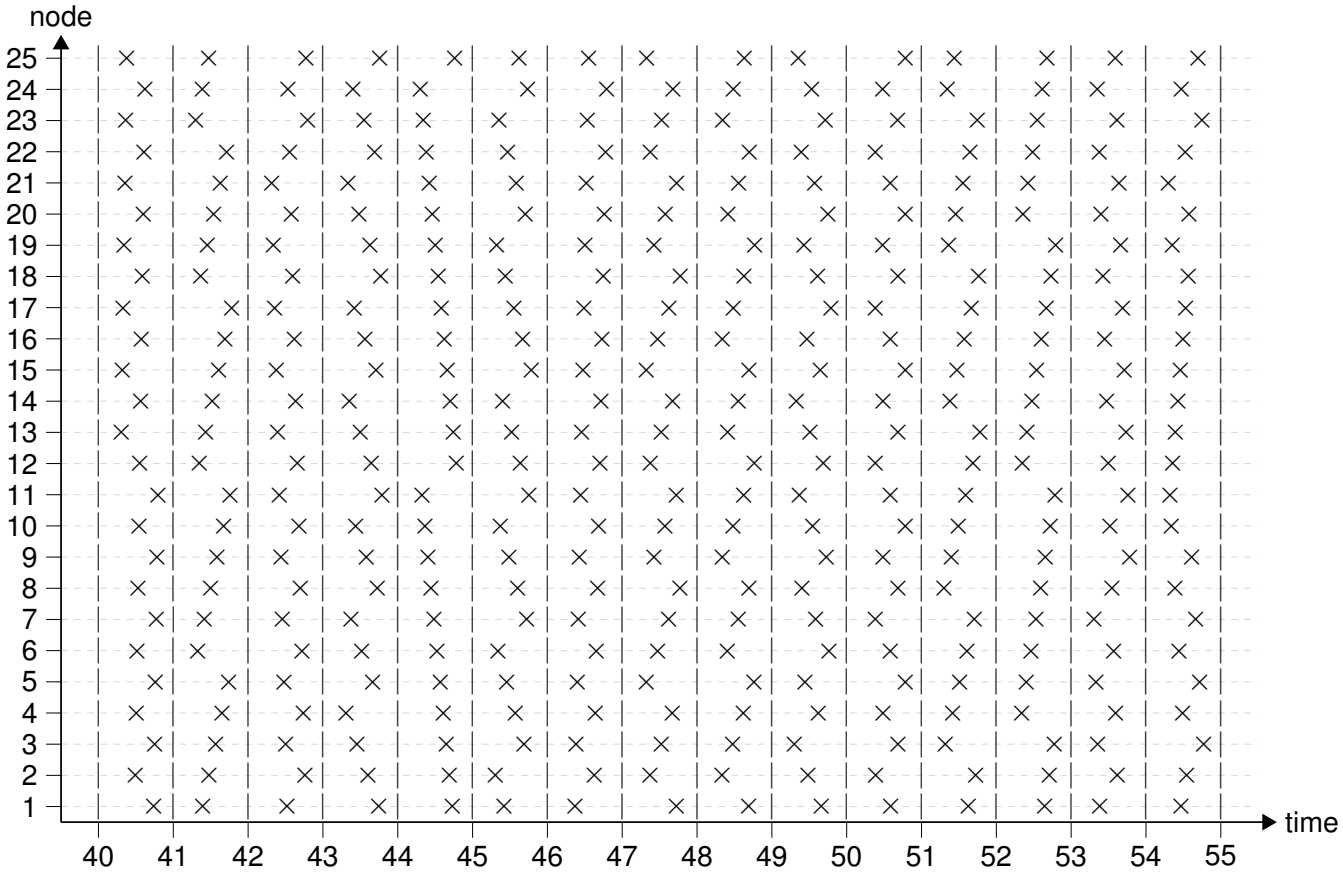


- Runs after instrumentation
- Used input
  - Call-chain logs
  - Message logs
  - Additional semantic information
- Visualization of large amount of data
- Leverages the human visual capabilities

Evaluation of TinyAID

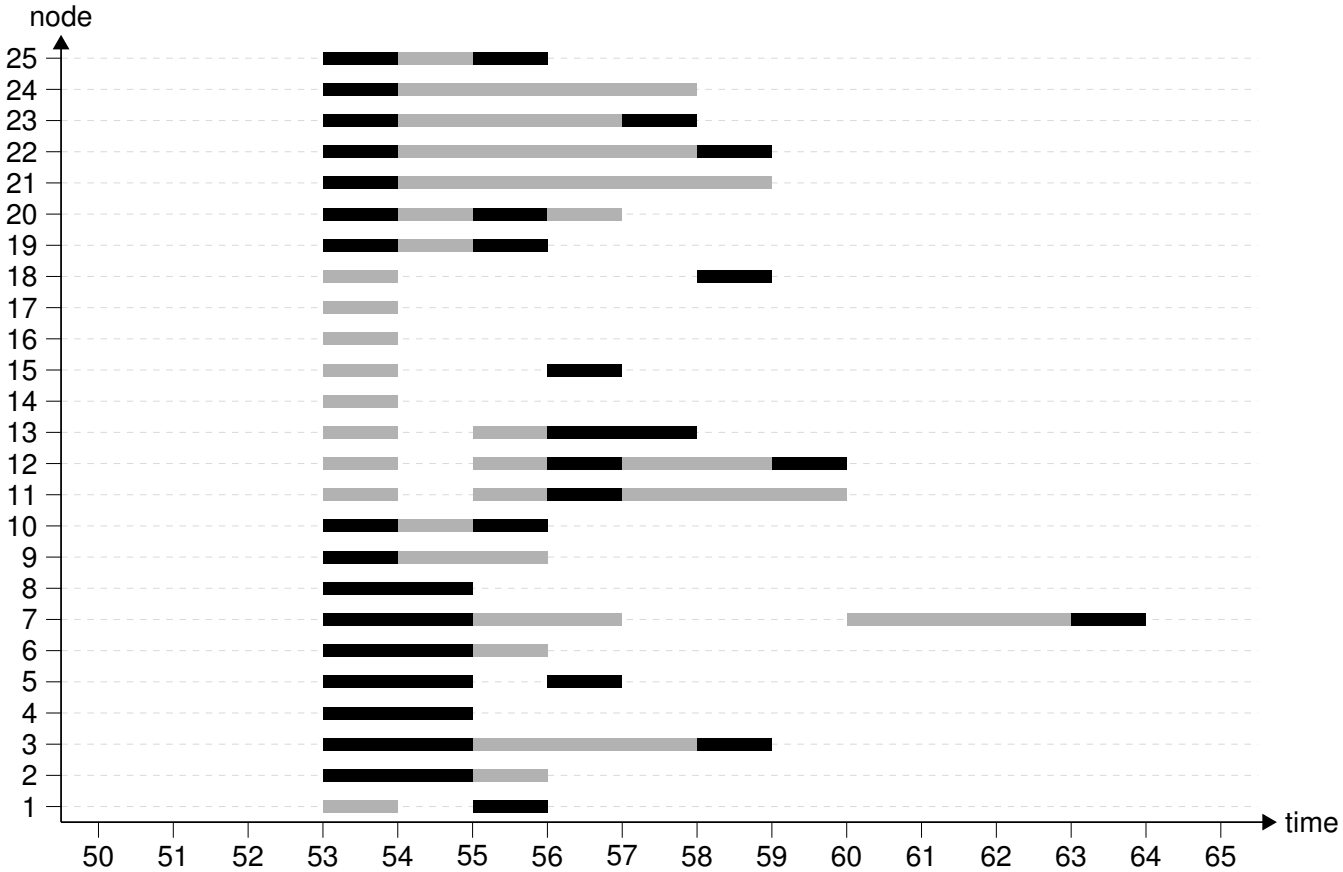
- In real deployments serial interface is the limiting factor
- Overhead due to packet oriented communication
- Presented evaluation is based on TOSSIM only
  - Debugging own implementations
  - Performance comparison of routing algorithms
    - TYMO (part of TinyOS 2.x)
    - Dynamic source routing protocol (DSR)
    - Greedy geographic routing

Concept Evaluation: Event Tracing



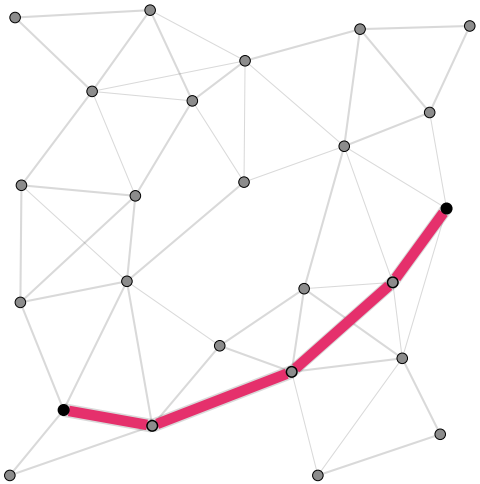
Shortcomings of the random number generator in TOSSIM

Concept Evaluation: State Tracing

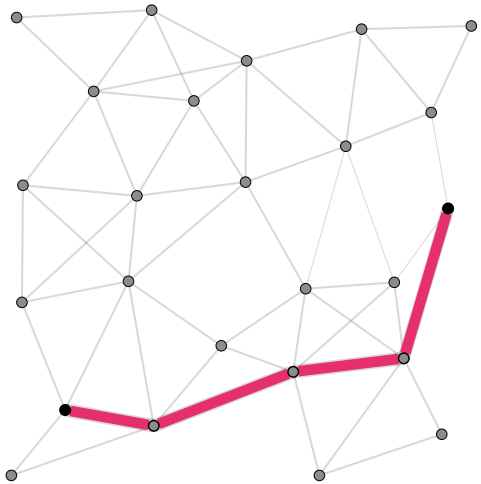


Visualization of program states over time

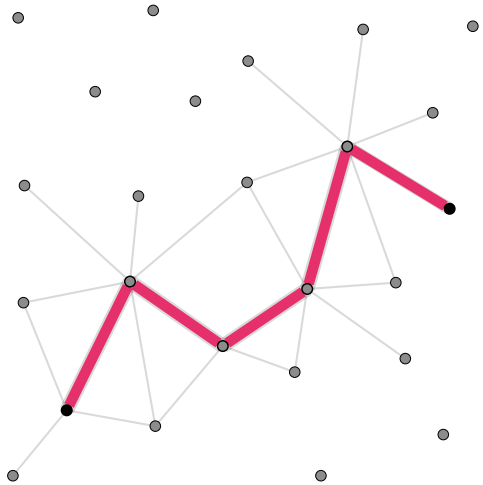
Concept Evaluation: Packet Flow



TYMO



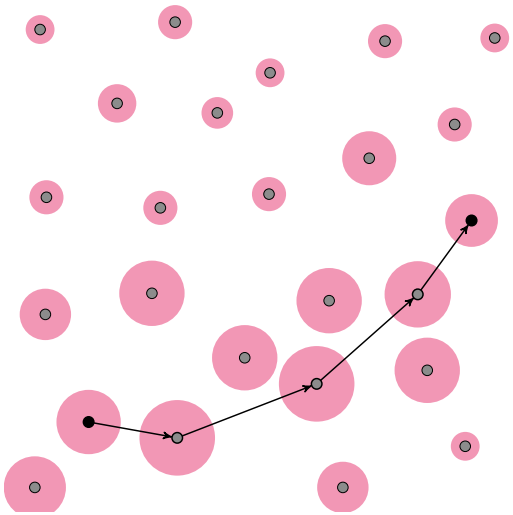
DSR



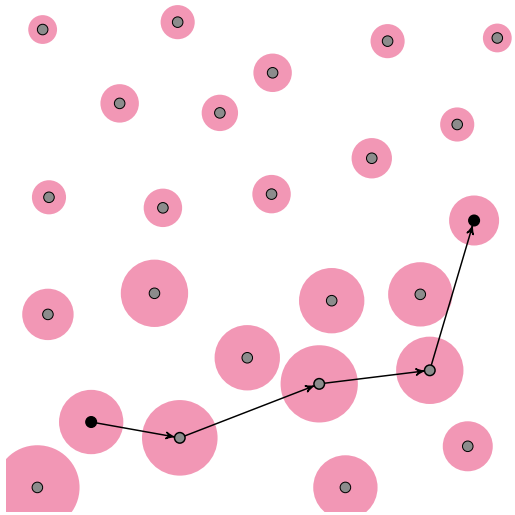
Greedy

- Visualization of number of sent packets over a link
- Identifying routing path decisions

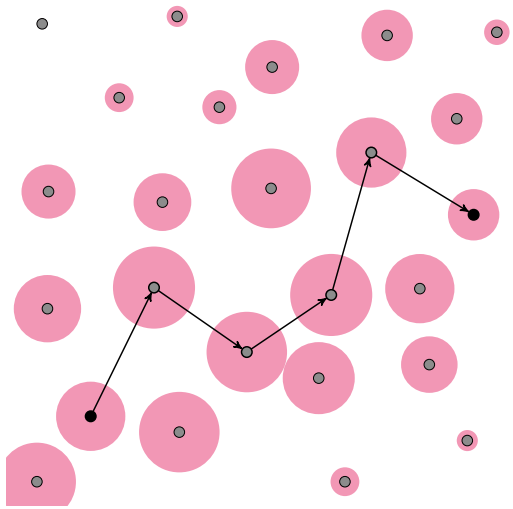
Concept Evaluation: Energy Consumption



TYMO



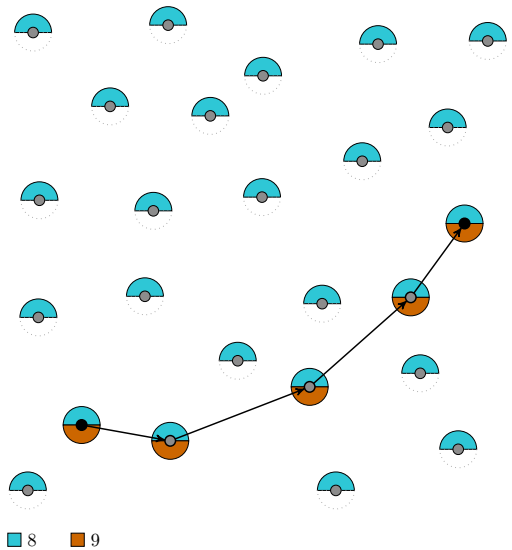
DSR



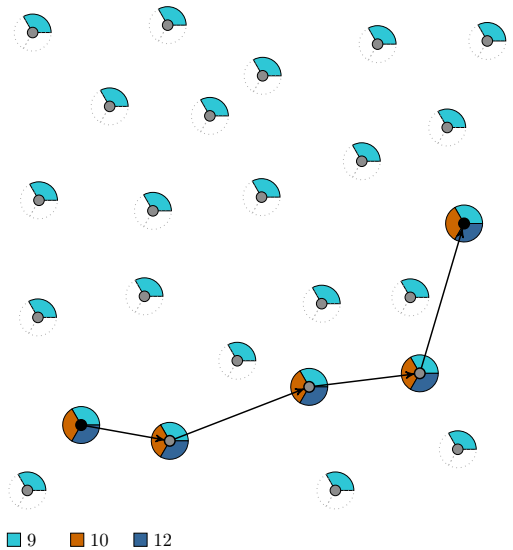
Greedy

- Energy consumption based on communication efforts
- Identification of hot-spots

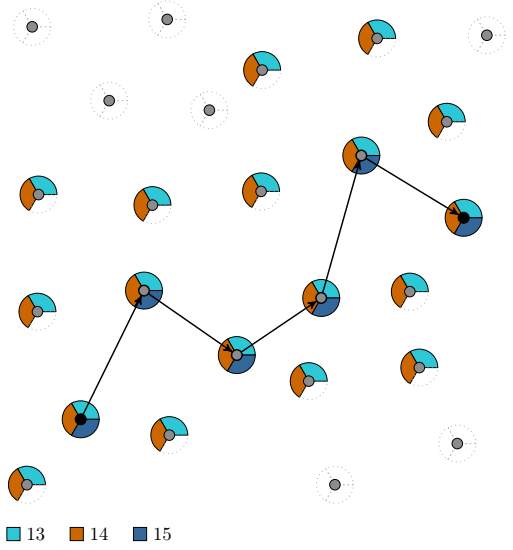
Concept Evaluation: Packet Types



TYMO



DSR



Greedy

- Visualization of activities in the network based on packet types
- Identification of protocol execution

Concept Evaluation: Packet Statistics

	TYMO	DSR	Greedy
Number of Packets			
Created Data Packets	10	10	10
Sent Total	68	68	78
Sent Broadcast	24	24	5
Sent Unicast	44	44	83
Involved Nodes			
Sending	100%	100%	72%
Receiving	100%	100%	72%
Overhearing	56%	56%	96%
Data Packet Latency [ms]			
Minimum	17	24	29
Lower Quartile	23	27	32
Median	26	31	37
Upper Quartile	35	38	45
Maximum	123	144	527

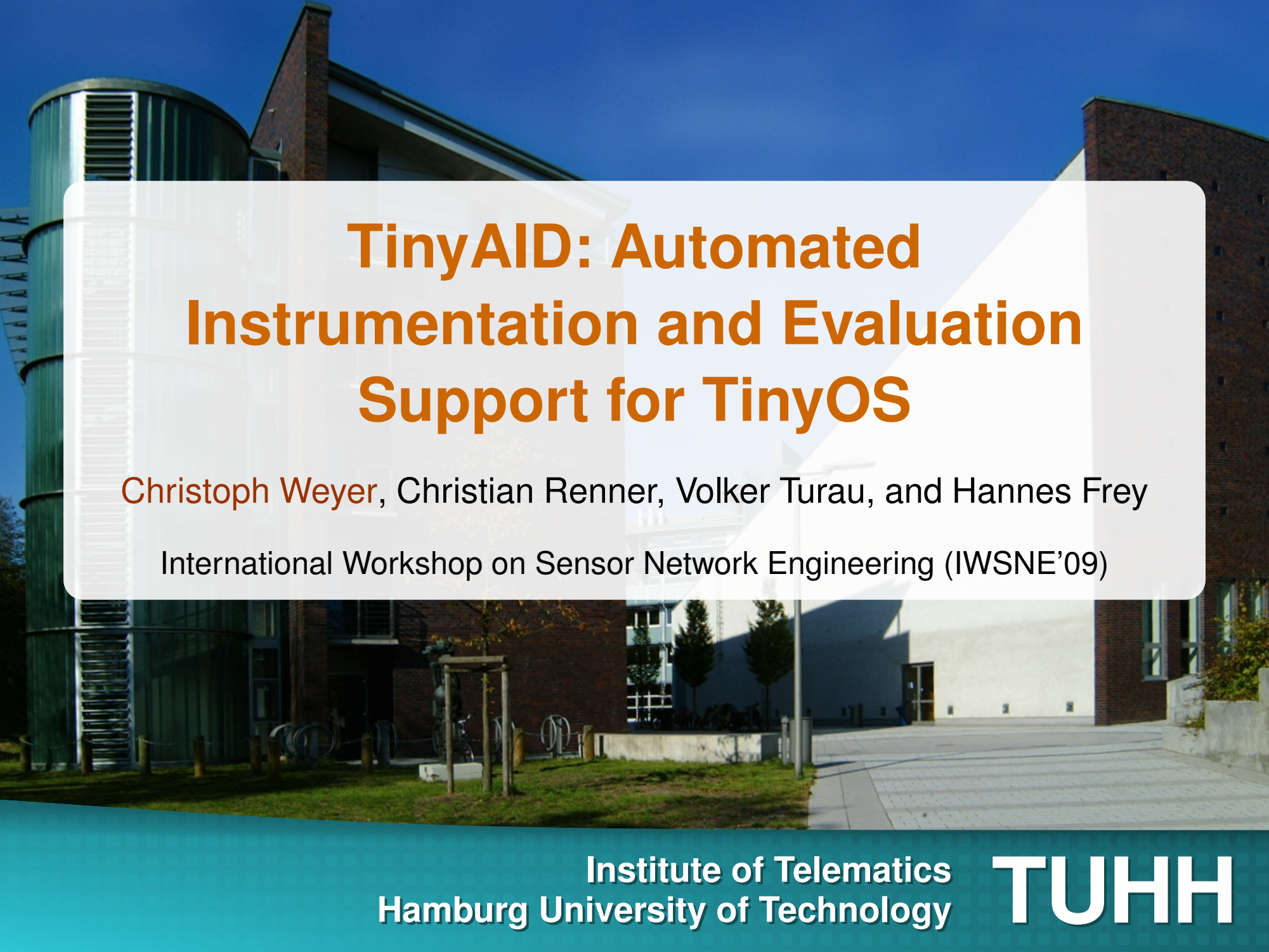
- TinyAID used for performance comparison
- No additional code needed
- Extract statistics from logged data
  - Number of packets
  - Involved Nodes
  - Latency
- Extract reception rate only by
  - Additional information
  - Manual instrumentation

Conclusion

- TinyAID valuable support for TinyOS-based programming
- Simple practicability on legacy source code
- Instant information about internal sequences
- Automated packet tracing

Next steps:

- Apply TinyAID to real hardware
  $\longrightarrow$ hardware interface needed
- Language for specifying instrumentation procedure
  $\longrightarrow$ based on TraceSQL



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