

Event Detection in Wireless Sensor Networks - Can Fuzzy Values Be Accurate?

Krasimira Kapitanova, Sang H. Son, and Kyoung-Don Kang

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“Each year, there are an estimated **405,000 fires** in residential structures, which cause nearly

3,600 fatalities, 18,600 injuries, and \$4.7 billion in property loss.” U.S. Fire Administration



- 38% of the homes had fire alarms in perfect condition
- Major cause for smoke alarm failure: disconnected battery (54%)
 - Leading reason : unwanted activation

Problem statement

- Event detection in sensor networks is not accurate
 - Determining the exact event thresholds is a hard task
 - The lack of precision of sensor readings increases the complexity of event detection

Current approaches

- Calculating the average of multiple readings
 - A precise threshold is still required
 - More sensors -> higher cost
- Probabilistic methods
 - Markov models
 - Bayesian networks
 - Complex
- **Fuzzy Logic**

Hypothesis

Fuzzy logic can be used to improve the accuracy of event detection in sensor networks

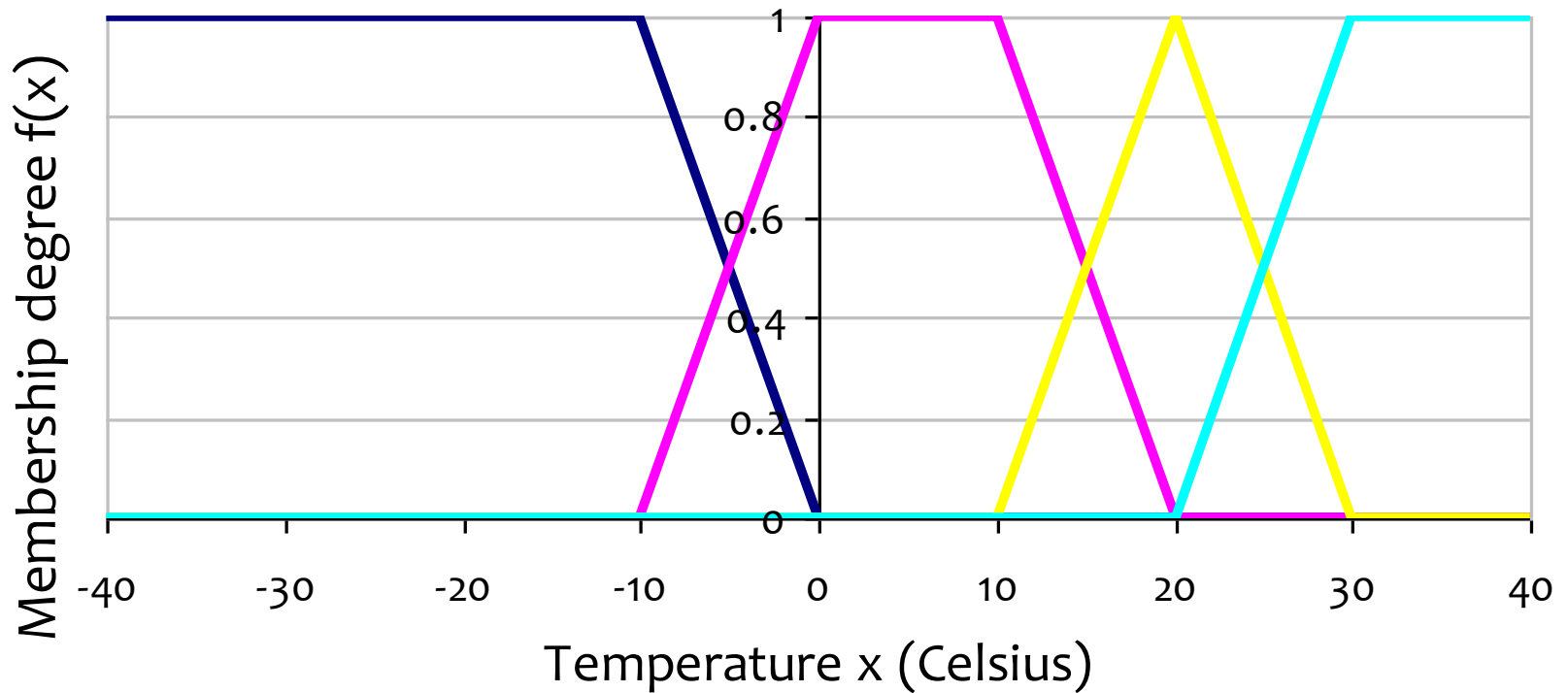
Additional goals:

- Does not increase detection delay
- Does not consume a lot of additional resources

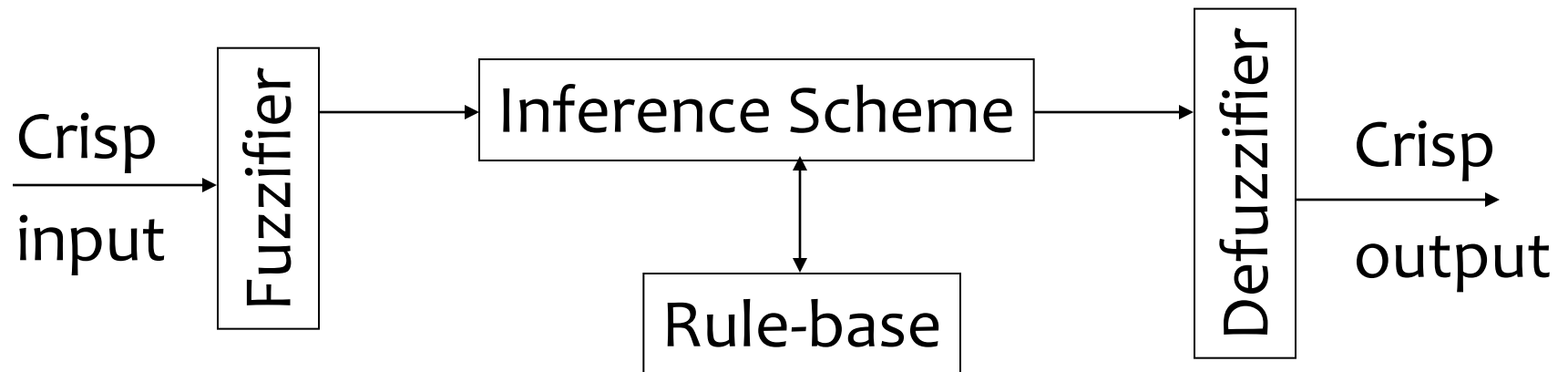
What is fuzzy logic?

- Uses reasoning that is approximate rather than precise
 - Suitable for expressing sensor values which are often within some range
- Example: temperature
 - **Crisp values:** -5°C , 0°C , 67°C ...
 - **Fuzzy logic:** uses linguistic variables – **Cold, Warm, Hot**

Temperature membership function



A fuzzy logic system



If-Then rules:

IF temperature is High AND smoke is High
THEN Fire confidence is High

Increasing the detection accuracy

- Use fuzzy values instead of crisp ones
- Further steps:
 - Incorporate readings from multiple sensors (*spatial semantics*)
 - Incorporate readings over a period of time (*temporal semantics*)

Instrument the event detection logic with temporal and spatial variables.

Event semantics

IF TEMP1 is High AND SMOKE1 is High AND DISTANCE is High AND TEMP2 is High AND
AND SMOKE2 is High
AND DISTANCE is Low
AND TIME is Short
THEN FIRE is High
THEN FIRE is High

- Spatial semantics
 - Considers the distance between sensors
- Temporal semantics
 - Considers the generation times of readings
- Incorporate readings from multiple nodes

However...

- The number of rules grows exponentially to the number of linguistic variables

- Beginning:

- 2 variables (T and S)
- Low, Medium, High

$$3^2 \rightarrow 9$$

- End:

- 6 variables (T1, T2, S1, S2, Distance, Time)
- Low, Medium, High

$$3^6 \rightarrow 729$$

Rule-base reduction techniques

Rule#	T1	S1	T2	S2	D	Time	Confidence
1	L	L	L	L	L	L	L
2	L	L	L	L	L	M	L
3	L	L	L	L	L	H	L
4	L	L	L	L	M	L	L
...
728	H	H	H	H	H	M	H
729	H	H	H	H	H	H	H

1. Separate the rule-base
2. Combine rules with similar outcomes

Rule-base reduction techniques

Rule#	T1	S1	T2	S2	D	Time	Confidence
1	L	L	L	L	L	L	L
2	L	L	L	L	L	M	L
3	L	L	L	L	L	H	L
4	L	L	L	L	M	L	L
...
728	H	H	H	H	H	M	H
729	H	H	H	H	H	H	H

1. Separate the rule-base
2. Combine rules with similar outcomes

Rule-base reduction techniques

Rule#	T1	S1	T2	S2	D	Time	Confidence
1	L	L	L	L	L	<=H	L
4	L	L	L	L	M	L	L
...
728	H	H	H	H	H	M	H
729	H	H	H	H	H	H	H

1. Separate the rule-base
2. Combine rules with similar outcomes
3. Incomplete rule-base

Experimental results

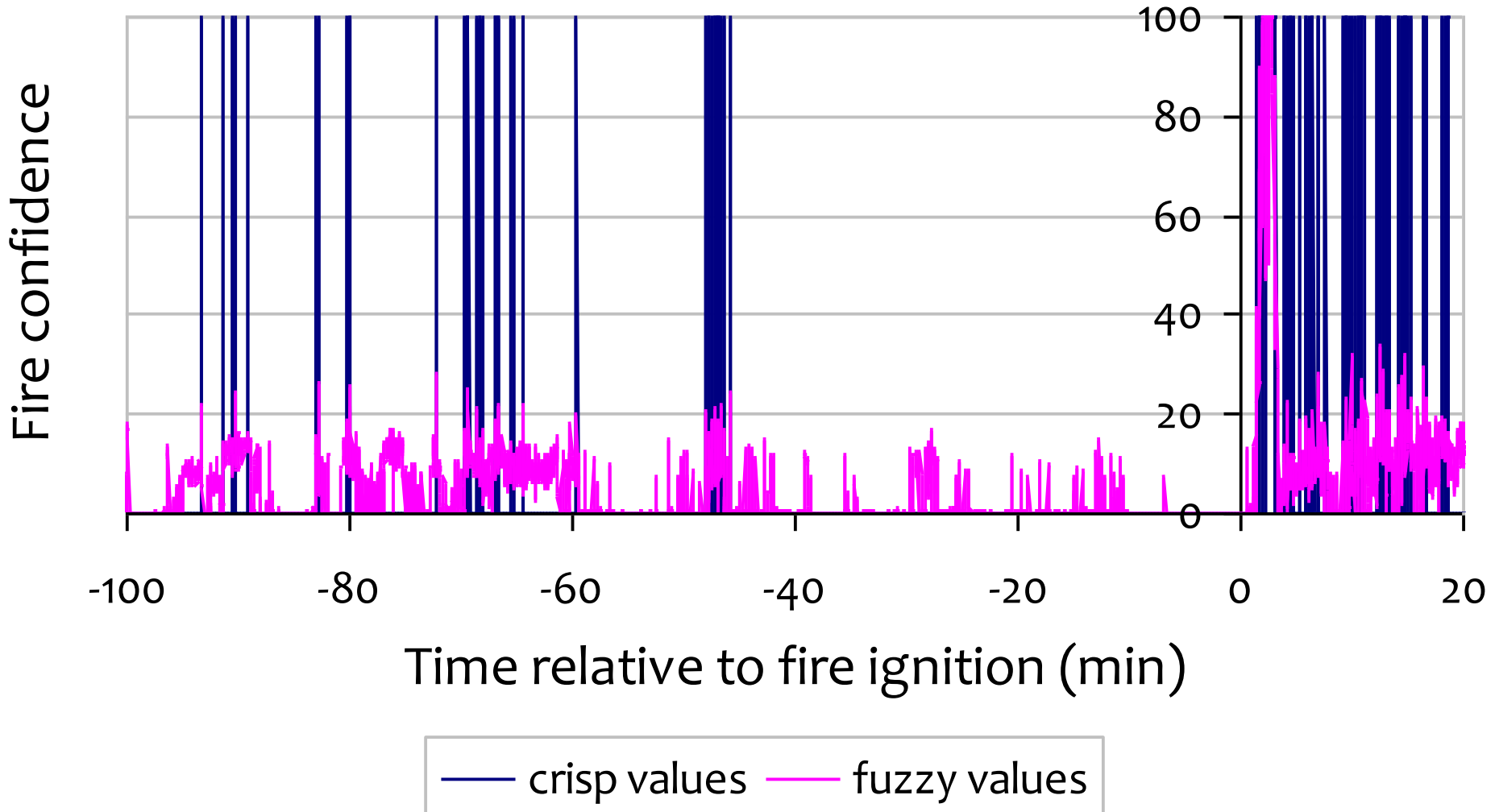
Evaluation

- Compare the detection accuracy of crisp and fuzzy logic
- Evaluate how spatial and temporal semantics affect the detection accuracy
- Evaluate how using a decreased rule-base affects the quality of event detection
- Evaluate the detection delay when fuzzy logic is used

Experimental setup

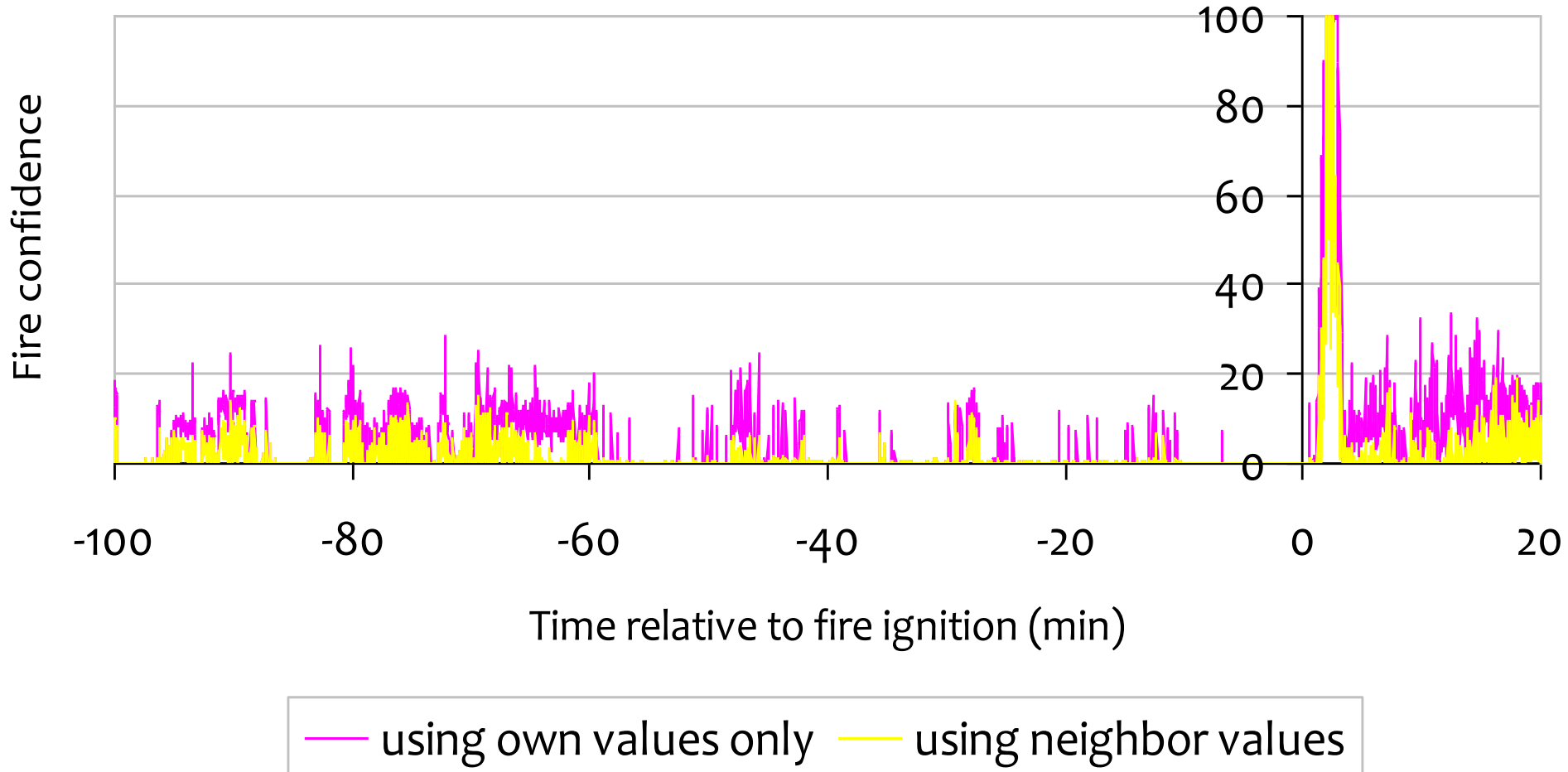
- Commercial fire alarms thresholds
 - Temperature: 55°C
 - Smoke obscuration: 0.15 m⁻¹
- Simulation based on fire data available from NIST
 - Burning mattress
 - Burning chair

Fuzzy value experiments

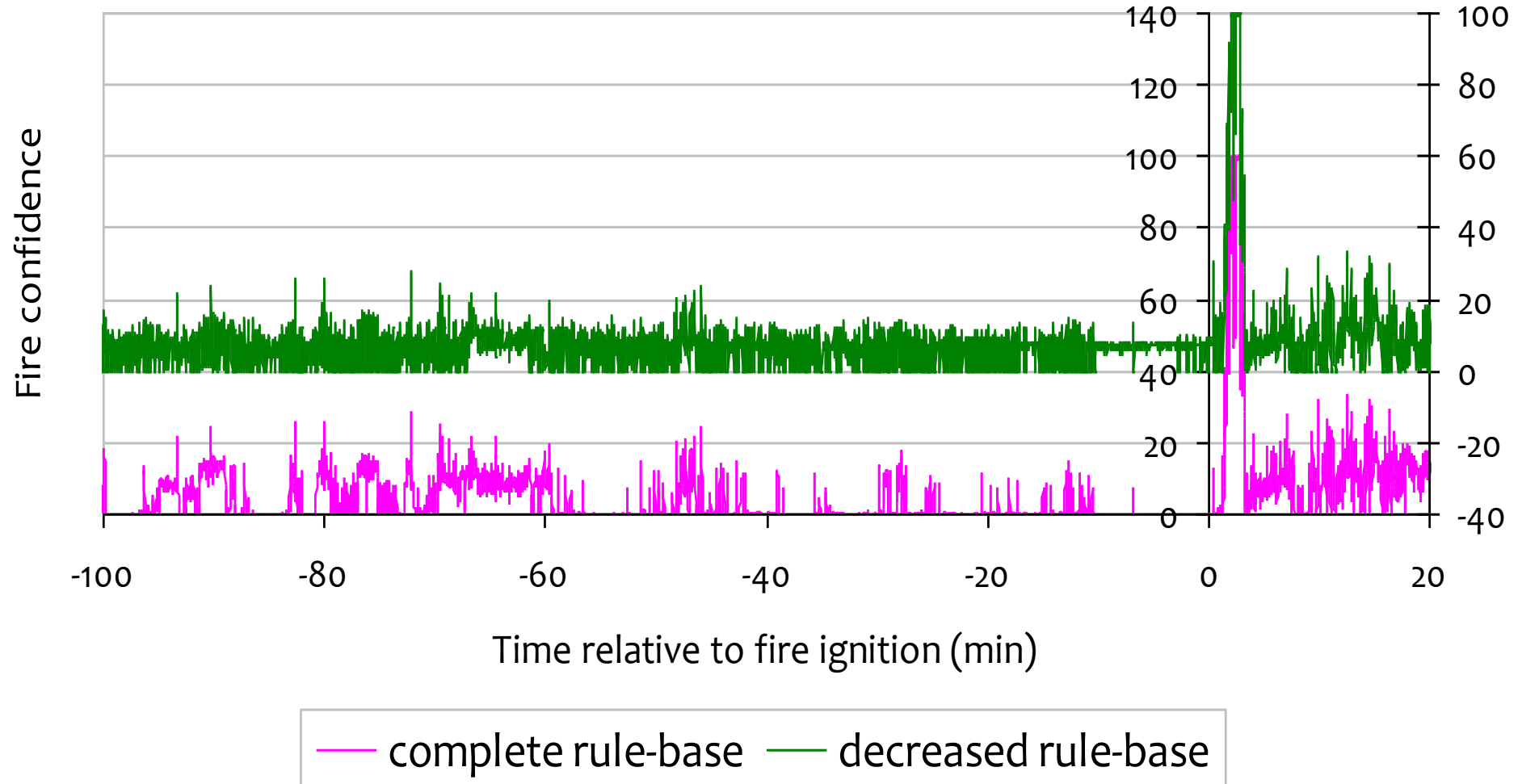


40 false alarms (1.4% of the readings)

Including readings from neighbor nodes



Using a reduced rule-base



We achieve 70% decrease in the number of rules.

Detection delay

Scenario	Crisp values	Fuzzy values	Neighbour readings	Reduced rule-base
Burning chair	236	236	248	236
Burning mattress	103	97	117	97

Delay in seconds

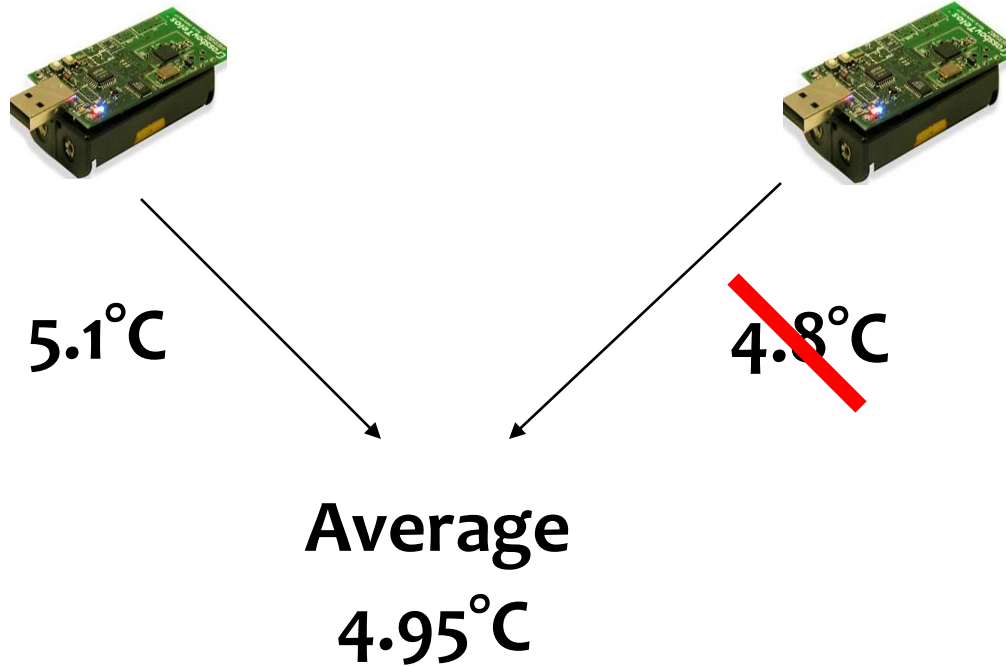
Conclusions

- Using fuzzy logic is suitable for event detection in WSNs
- Including spatial and temporal semantics improves the accuracy of event detection
- Our reduction techniques decrease the size of the rule-base by more than 70%

Thank you!

Example

Cooling is turned on if the temperature $> 5^{\circ}\text{C}$



1. Extremely close to the threshold
2. What if ...

Detection accuracy

- Comparing fuzzy logic to:
 - Naïve Bayes classifier
 - Decision tree

Number of incorrect classifications

	Naïve Bayes		Decision tree		Fuzzy logic	
	number	%	number	%	number	%
Burning chair	105	1.56%	7	0.13%	0	0
Burning mattress	89	2.35%	5	0.13%	0	0