

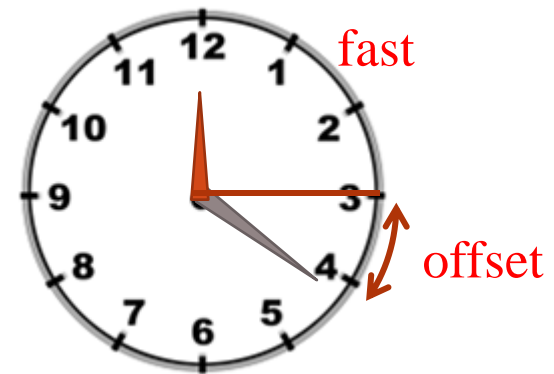
Exploiting FM Radio Data System for Adaptive Clock Calibration in Sensor Networks

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Time Synchronization

- Important for various applications
 - Event ordering, Coordination, etc
- Two issues in time synchronization
 - Initial time offset
 - Different time scale (/rate/speed)

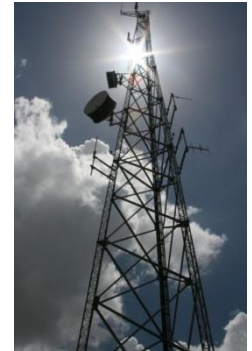


State of Art

- Time synchronization based on **message passing**
 - RBS[OSDI'02], TPSN[SenSys'03], and FTSP[SenSys'04]
 - Pros: no special hardware
 - Cons: high communication overhead
- Time synchronization based on **external signals**
 - GPS, WWVB[SECON'06], and Power Line[SenSys'09]
 - Pros: low communication overhead
 - Cons: special hardware receiver, limited coverage

Key Idea

- Exploiting FM Radio Data System (RDS) for clock calibration
 - A **fixed** data rate of 1187.5 bps modulated by pilot-tone
 - Excellent coverage(**160** km, in/outdoor)
 - Widely available all over the world



An FM station

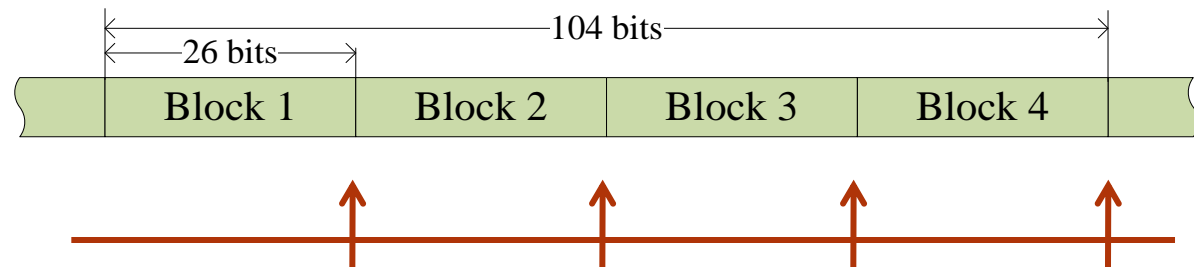
Frequency	Name	Frequency	Name
90.5	WKAR.org	88.1	Smile.FM
106.1	Q106	88.9	WDBM-FM
94.6	WMMQ	94.9	Lansings
92.9	WJZL	94.1	Ear

- Periodic clock from RDS

RDS bit stream



Periodic clock

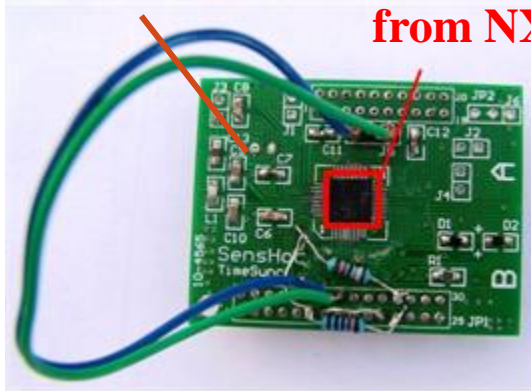


Our contributions

- An FM hardware receiver integrated with sensor network platforms
- Extensive measurements on RDS signal
- An adaptive RDS based clock calibration method

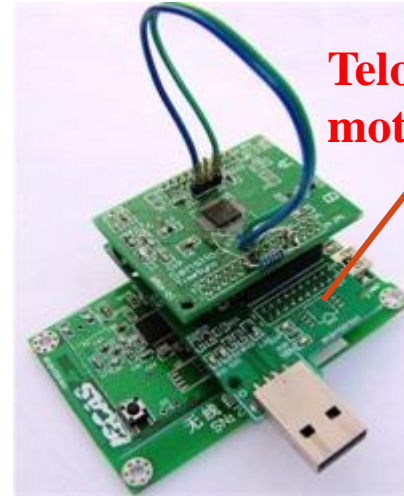
FM Hardware Receiver

FM receiver board

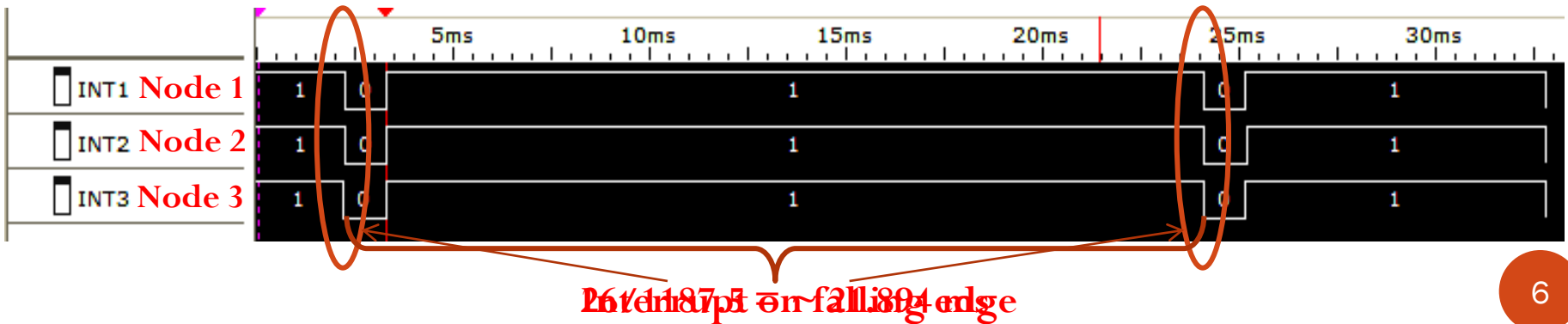


from NXP ~40 mW

TelosB-compatible mote

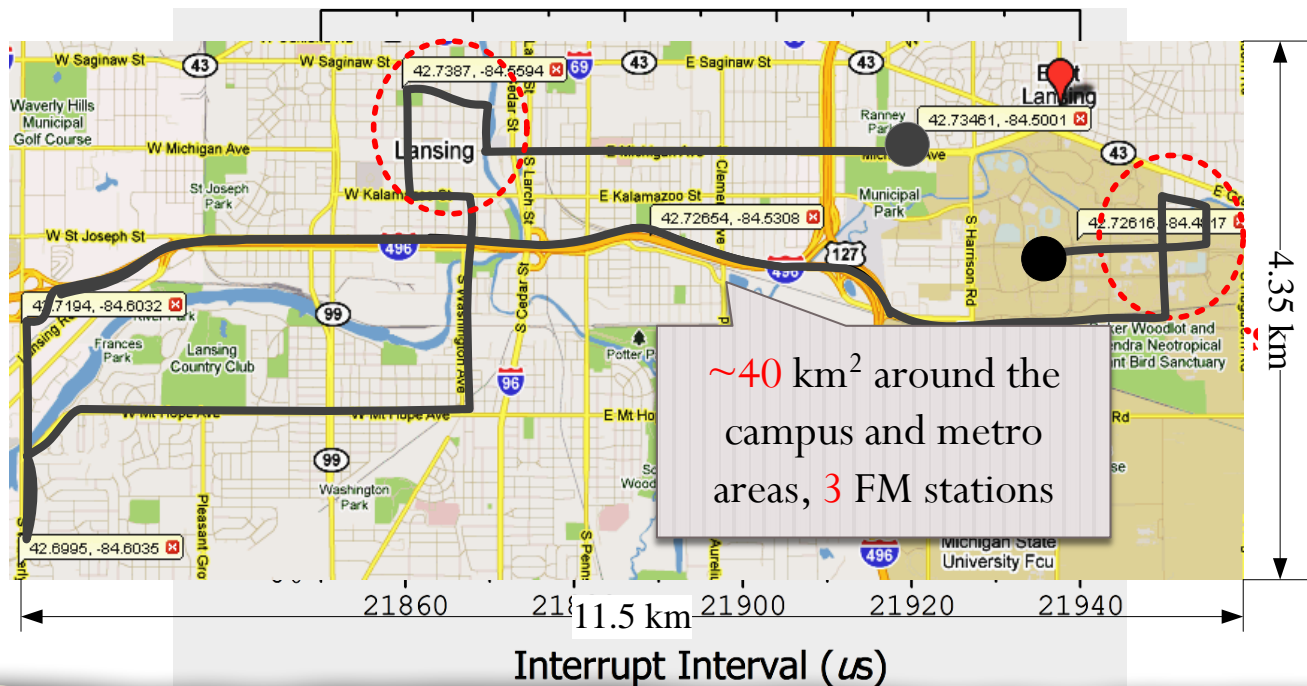


- Extracting periodic clock from RDS signal



Stability & Coverage

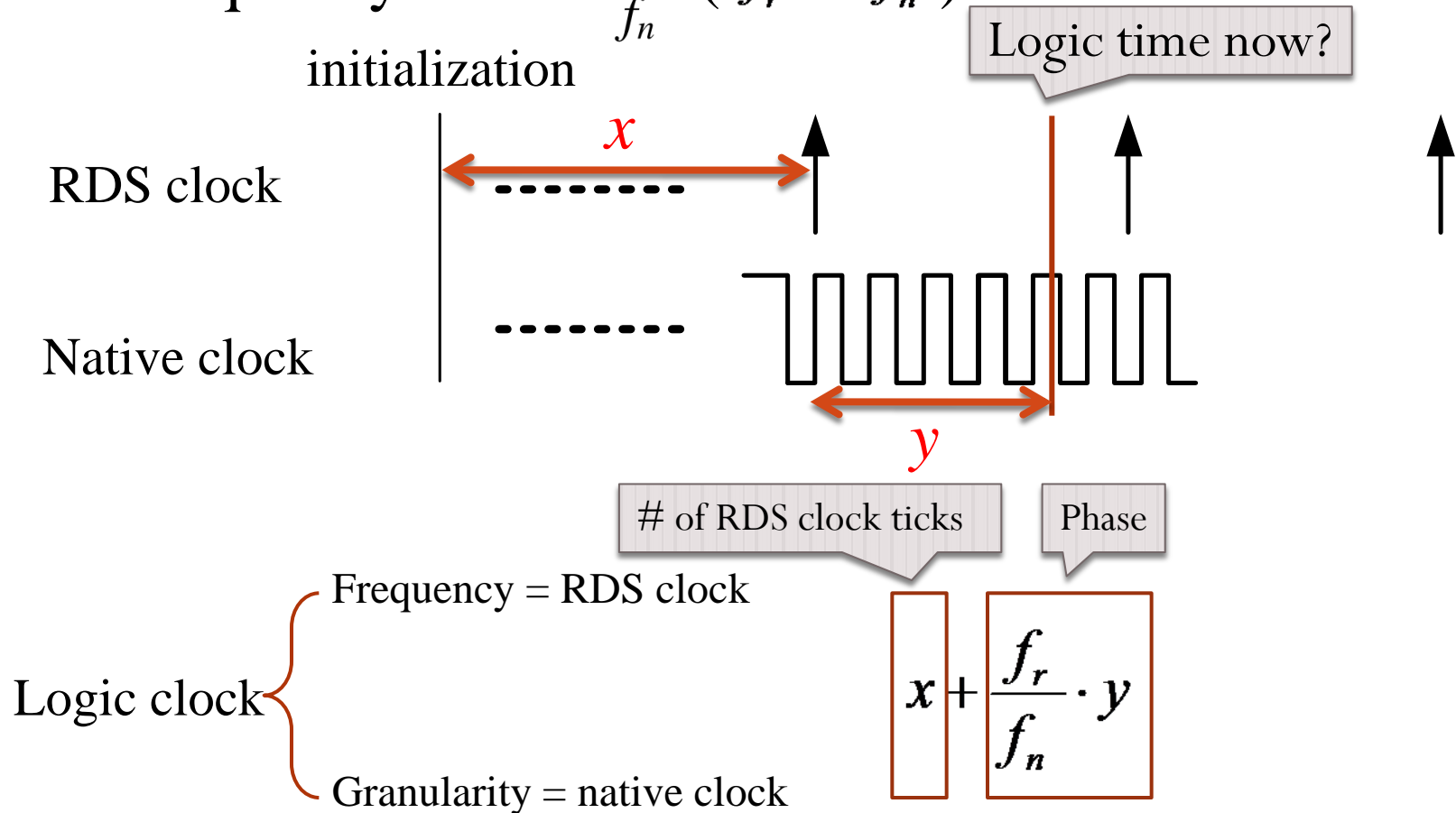
- Temporal stability of RDS clock (FM receiver+ GPS, 6 days)
- Spatial coverage of RDS signal



RDS clock is highly stable and has a city-scale coverage

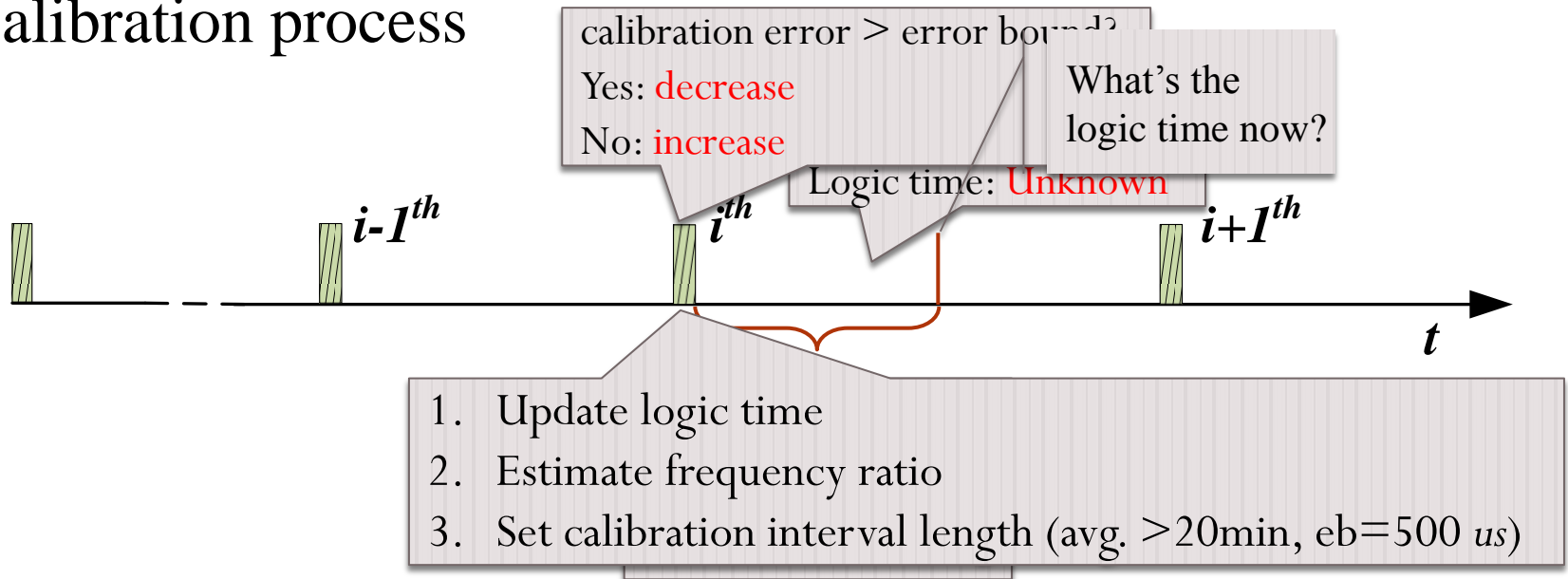
Basic Idea

- Logic clock = RDS clock + native clock
- Frequency ratio = $\frac{f_r}{f_n}$ ($f_r \ll f_n$)



Duty-cycled Clock Calibration

- Calibration process

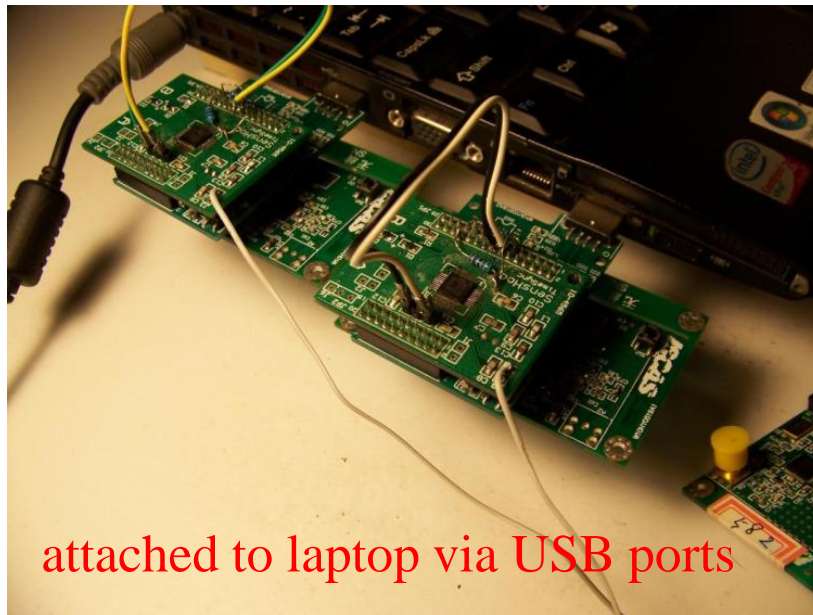


• Q1: How to predict the logic time during calibration intervals?

• Q2: How to trade off calibration accuracy vs. energy efficiency?

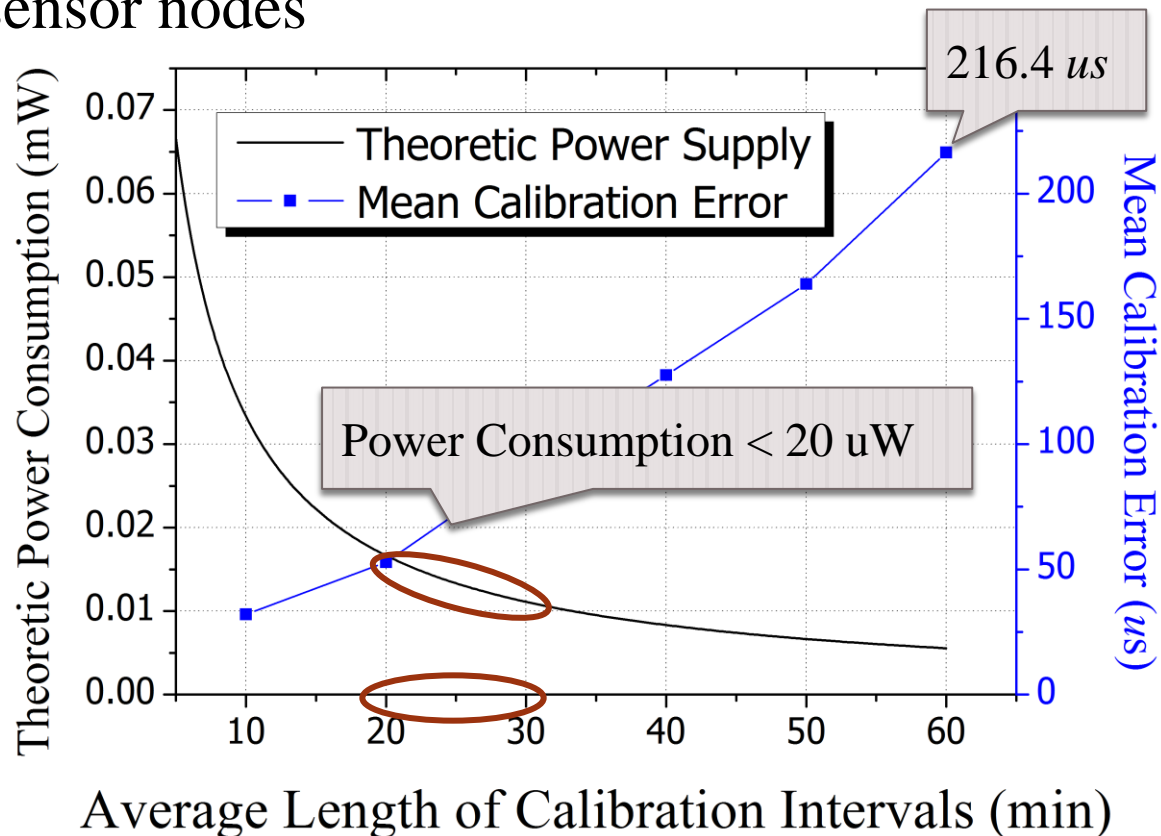
Experimental Setup

- TinyOS 2.1x on a Telosb-compatible platform (/32.768 KHz crystal)
- 12 motes, laptops, and GPS modules
- Metrics: power consumption, calibration error, pair-wise offset



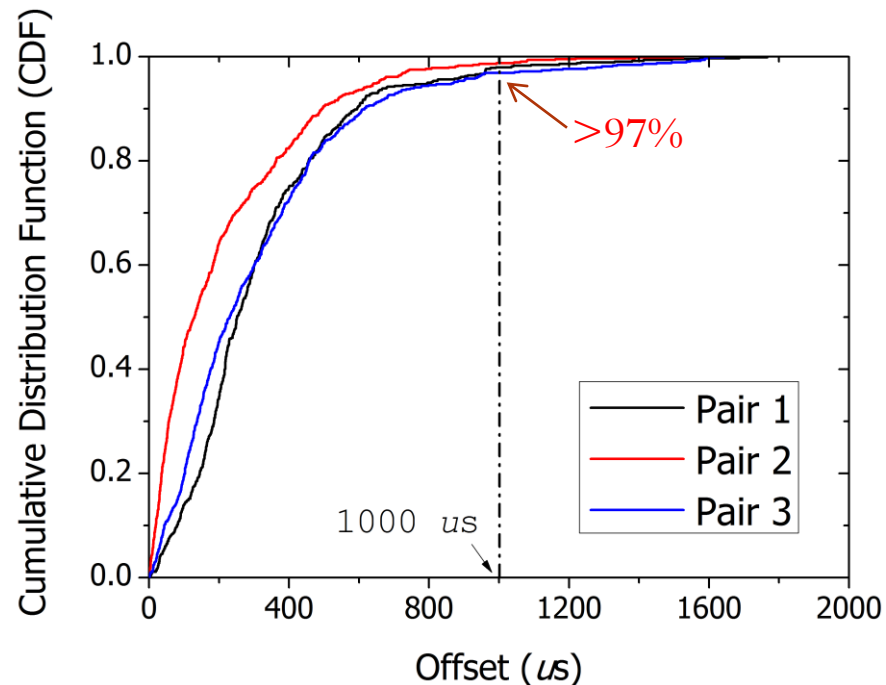
Energy Consumption & Calibration Error

- Trace-based Evaluation
 - Total length > 100 hours
 - 6 sensor nodes



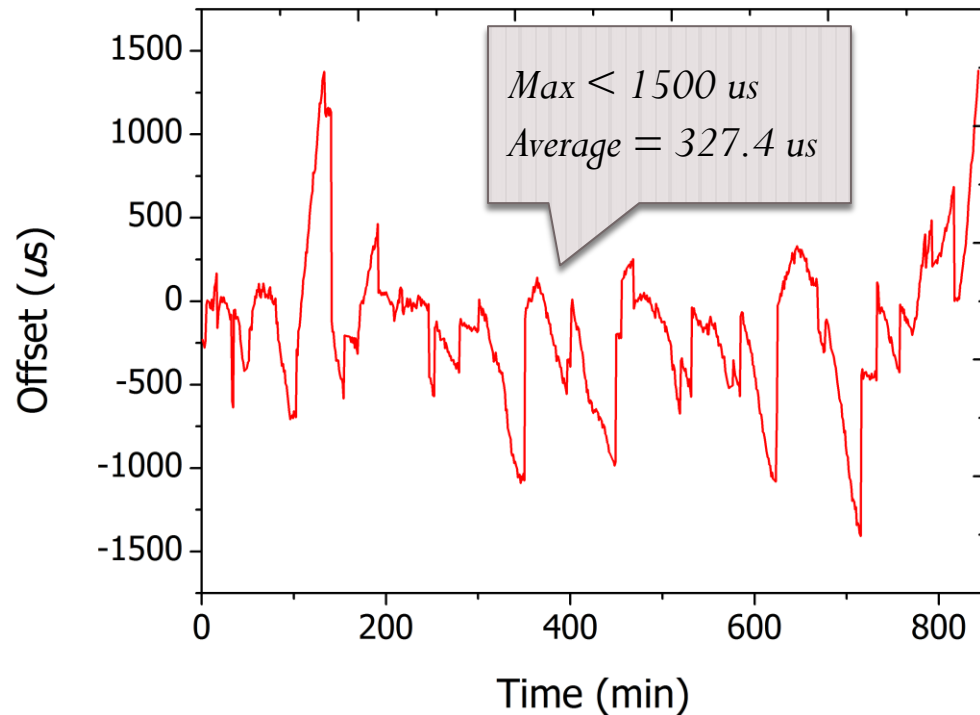
Pair-wise Logic Clock Offset

- Offset between three pairs of nodes
 - Initial offset = 0
 - error bound = 500 μs



Clock Offset (cont.)

- Two nodes 2.8 km from each other over 14 hours



Conclusion

- A hardware FM receiver integrated with existing sensor platforms
- Extensive measurements on stability and coverage of the RDS signal
- An adaptive method for clock calibration achieving both calibration accuracy and energy efficiency

Thanks. Q/A 😊