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A Multi-Channel Soundcard as an Acoustic Sensor Node

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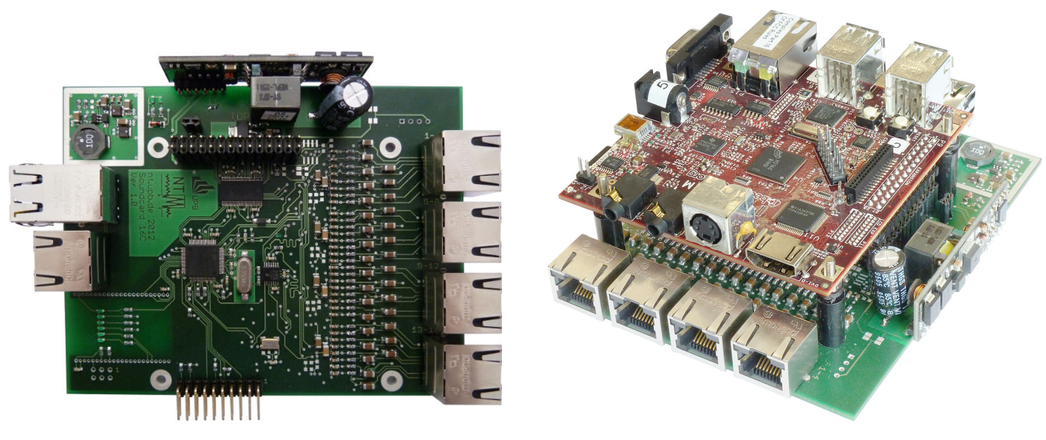
Introduction

- Wireless acoustic sensor network (WASN)
  - Task: Sensor network for cooperative signal processing
  - Problem: Diverging clocks cause sampling rate mismatch
- Our Approach
  - Sensor clock synchronization via time stamp exchange
  - Kalman filter for improved state estimation

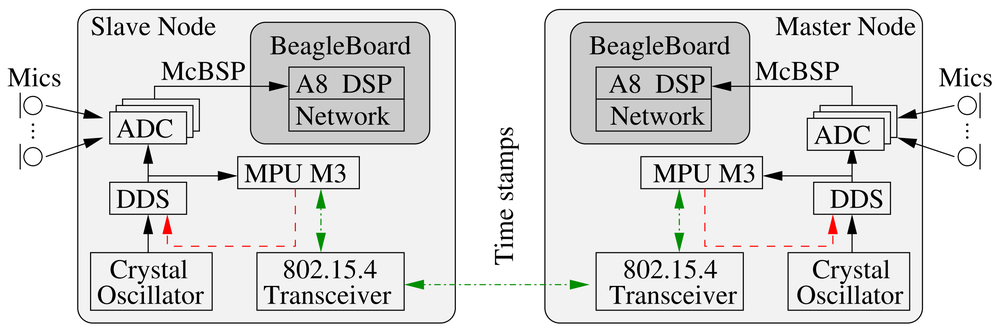
Hardware platform



(a) Printed circuit board assembly (b) Sensor node with mounted Beagleboard

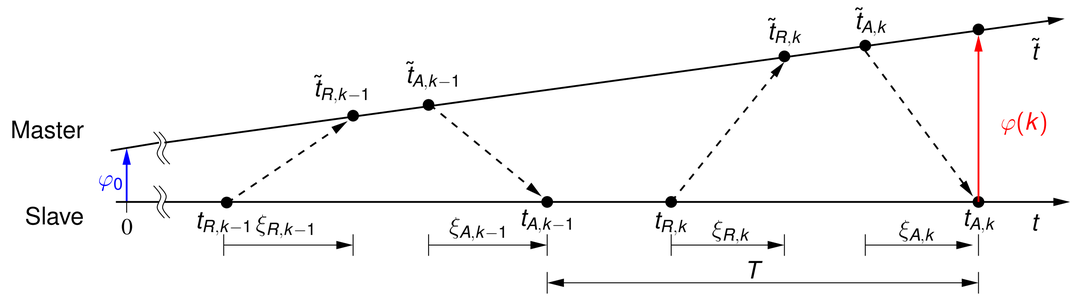
- Ethernet jacks for connecting 4 microphone boards
  - Microphones per board: 4
  - Analog signal transmission
- POE power supply
- ZigBee transceiver (802.15.4)
- Sigma-delta analog-digital converter
- Direct digital synthesis (DDS) circuit
  - Generates sampling frequency (8.192 MHz)
  - Frequency adjustable by $\pm 0.0279\,\text{Hz} \widehat{=} 0.003\,41$ ppm
- ARM Cortex-M3 microprocessor unit
  - Estimates frequency deviation and phase offset
  - Implementation of Kalman filter
- Mountable BeagleBoard-xM (ARM Cortex-A8 & DSP)
  - Multichannel buffered serial ports (McBSP) for communication
  - Signal transmission via wired network
  - Implementation of signal processing algorithms
- Synchronization independent of signal processing

Platform components



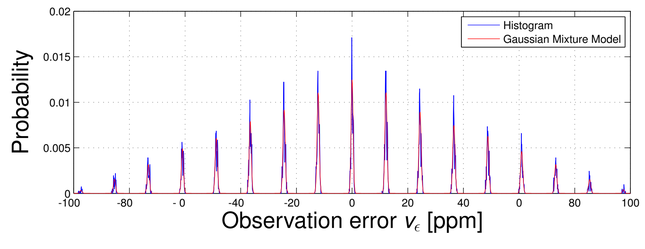
- Crystal oscillator drives DDS circuit
  - Triggers ADCs
  - Oscillations counted by MPU and used as time stamps
- Precise time stamp generation with low latency and jitter
- M3 MPUs exchange time stamps via ZigBee
- MPUs estimate the frequency deviation and phase offset
- Slave readjusts DDS via serial peripheral interface to match master frequency

Frequency deviation estimation

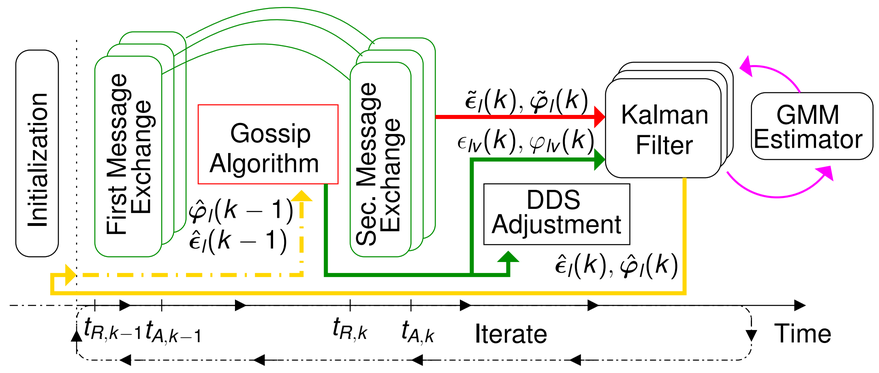


- Two-way message exchange algorithm [Chaudari 2012]) to estimate frequency deviation $\epsilon(k)$ and phase offset $\varphi(k)$

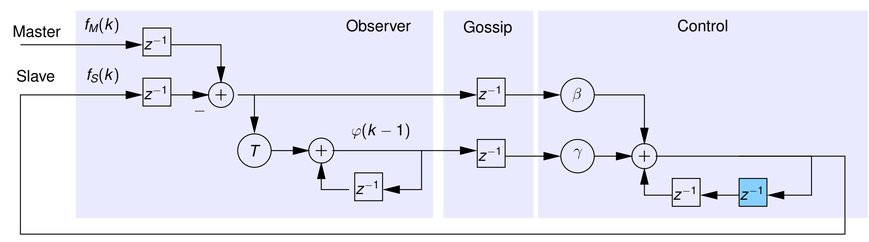
$$\tilde{\epsilon}(k) \approx \epsilon(k) + \underbrace{\frac{(\xi_{R,k} - \xi_{R,k-1}) + (\xi_{A,k-1} - \xi_{A,k})}{(t_{R,k} - t_{R,k-1}) + (t_{A,k} - t_{A,k-1})}}_{v_\epsilon(k)} \qquad \tilde{\varphi}(k) \approx \varphi(k) + \underbrace{\frac{1}{2}(\xi_{R,k} - \xi_{A,k})}_{v_\varphi(k)}$$



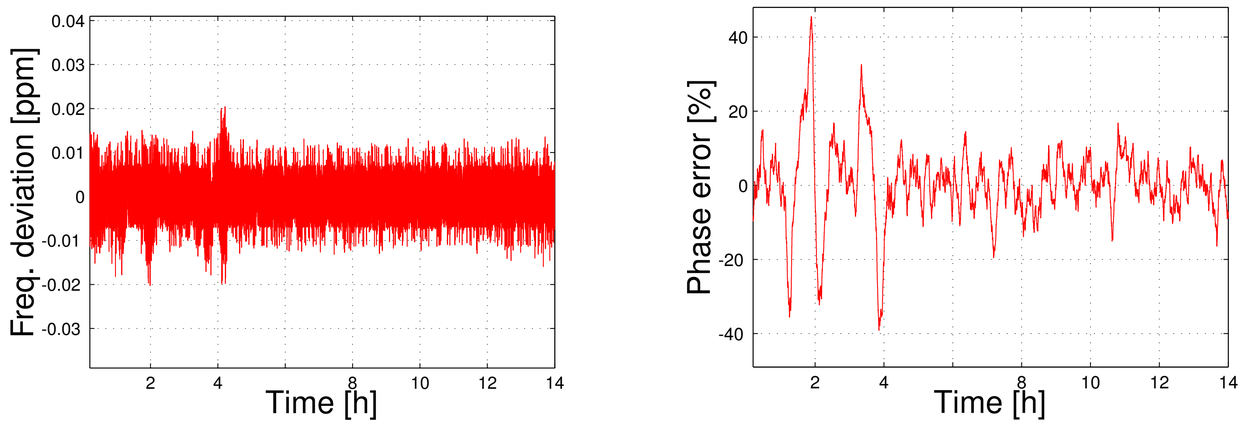
Sensor network



- Iteration scheme and information flow
  - System uses gossiping for information exchange
  - Kalman filter for improved estimates
- DDS adjustment requires control mechanism



Experiments



(c) Frequency deviation between nodes (d) Phase error between nodes

- Long term experiment showing the synchronization of a slave to a master clock

Publications

[1] Schmalenstroeer, et al., "Online Observation Error Model Estimation for Acoustic Sensor Network Synchronization", ITG 2014
[2] Schmalenstroeer, et al., "A Gossiping Approach to Sampling Clock Synchronization in Wireless Acoustic Sensor Networks", ICASSP 2014
[3] Schmalenstroeer, et al., "A combined hardware-software approach for acoustic sensor network synchronization", Signal Processing, 2014