Fast radio interferometric measurement on low power COTS radio chips

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TÁMOP-4.2.2.A-11/1/KONV-2012-0073:
Telemedicine oriented research in the fields of mathematics, informatics and medical sciences

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Localization Ontology

Physical phenomena:

- radio (GPS, radar, WiFi, etc)
- acoustic (ping, ultrasonic)
- optical (pics, video, laser)
- inertial (accelerometer, gyro)
- magnetic & pressure

Ranging:

- time based (TOF, TDOA)
- amplitude based (RSSI)
- map based (RSSI)
- angle based
- phase based

Tradeoffs:

- precision (proximity vs. cm)
- coverage (global vs. local)
- responsiveness (immediate)
- infrastructure (anchors)
- stealth and security (yes/no)
- mobile vs. static
- processing (centralized/local)
- localization vs. tracking
- indoor vs. outdoor

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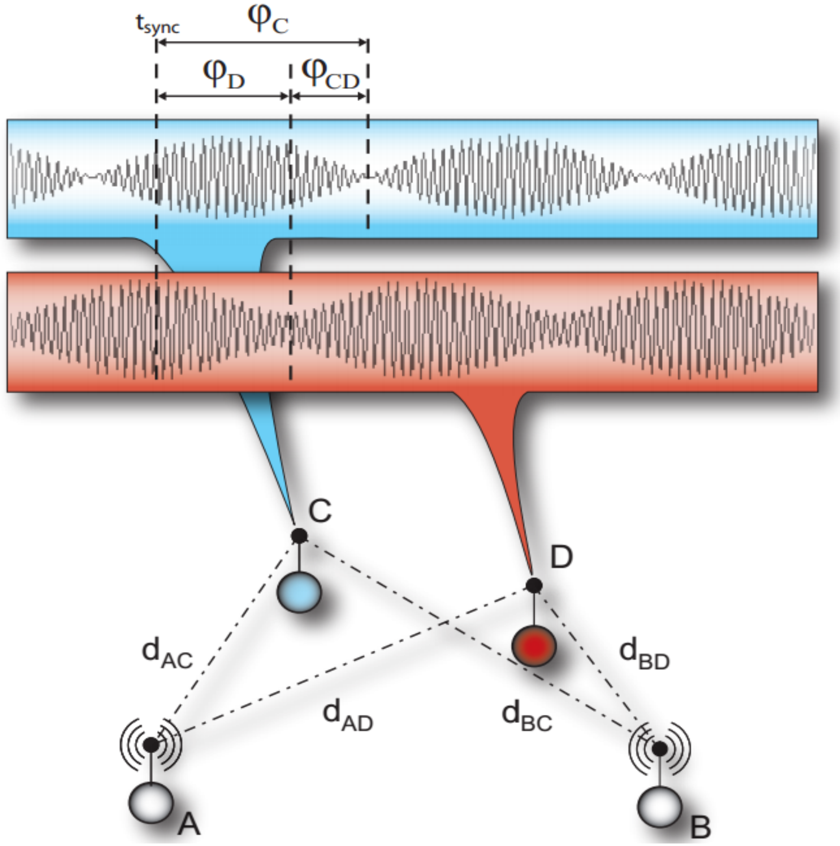
Today: radio interferometric sensor tracking indoors

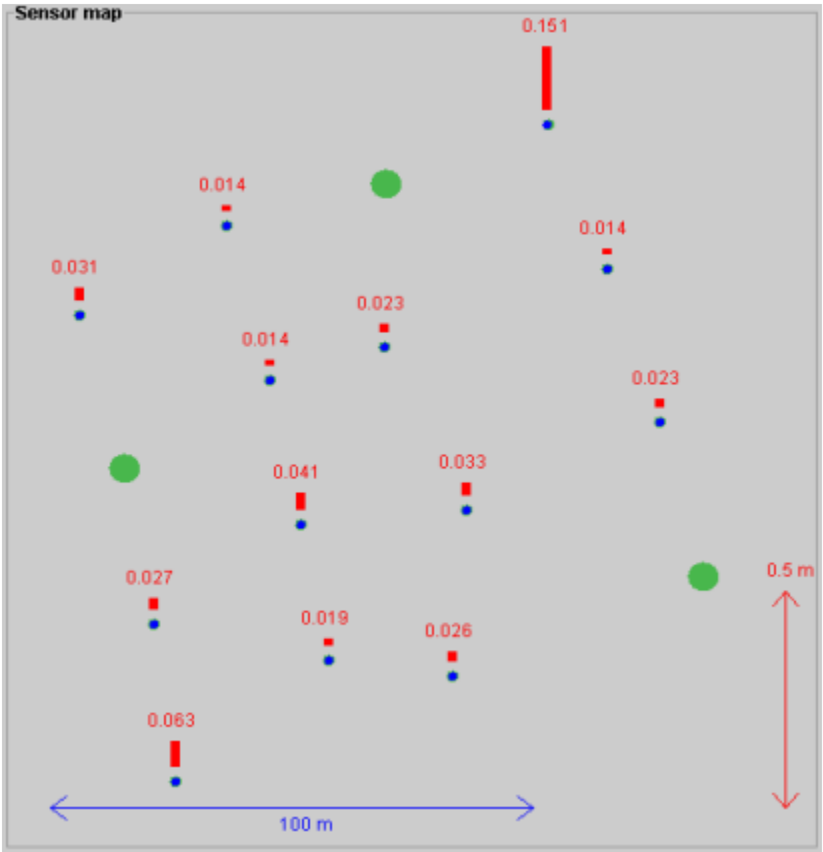
Radio Interferometric Ranging



$$(d_{AC} - d_{BC} + d_{BD} - d_{AD}) \bmod \lambda = \varphi_{CD} \bmod 2\pi$$

- Two transmitters (A and B) simultaneously send unmodulated sine waves at slightly different frequencies
- The interference is a high frequency amplitude modulated by a low frequency beat signal
- Two receivers (C and D) measure the phase of the beat signal at the same time
- Relative phase offset depends on the distances between A, B, C and D

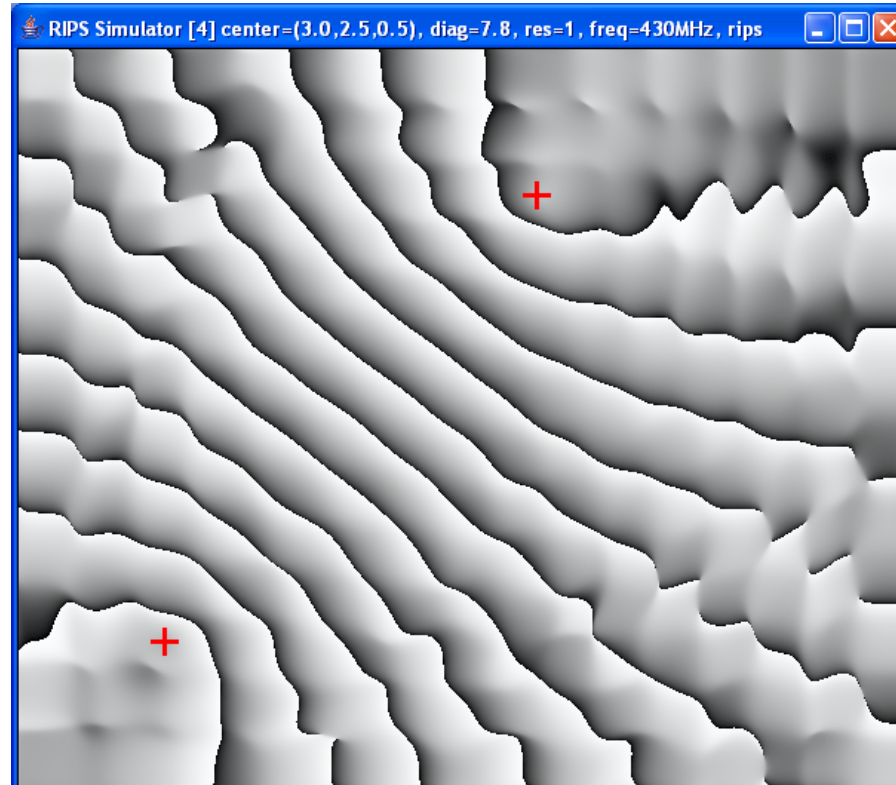
Radio Interferometric Ranging



- Test mode of COTS radio gives unmodulated sine wave
- Beat signal can be measured as signal strength (RSSI)
- Quad range: linear combination of four ranges
- Outdoor experiment:
  - 100 x 120m on football field
  - 16 XSM (CC1000) nodes
  - 400-460 MHz carrier
  - Avg. localization error: 4cm
  - Took 50 minutes long

Indoor Radio Interferometry

- Outdoor solution does not work indoors
- Phase error depends on carrier frequency
- CC1000 radio is no longer available
- IDEA:
  - RFA1 vs. CC1000
  - 2.4 GHz vs. 430 MHz
  - Single freq tracking
  - Significant speedup
  - TDMA like schedule



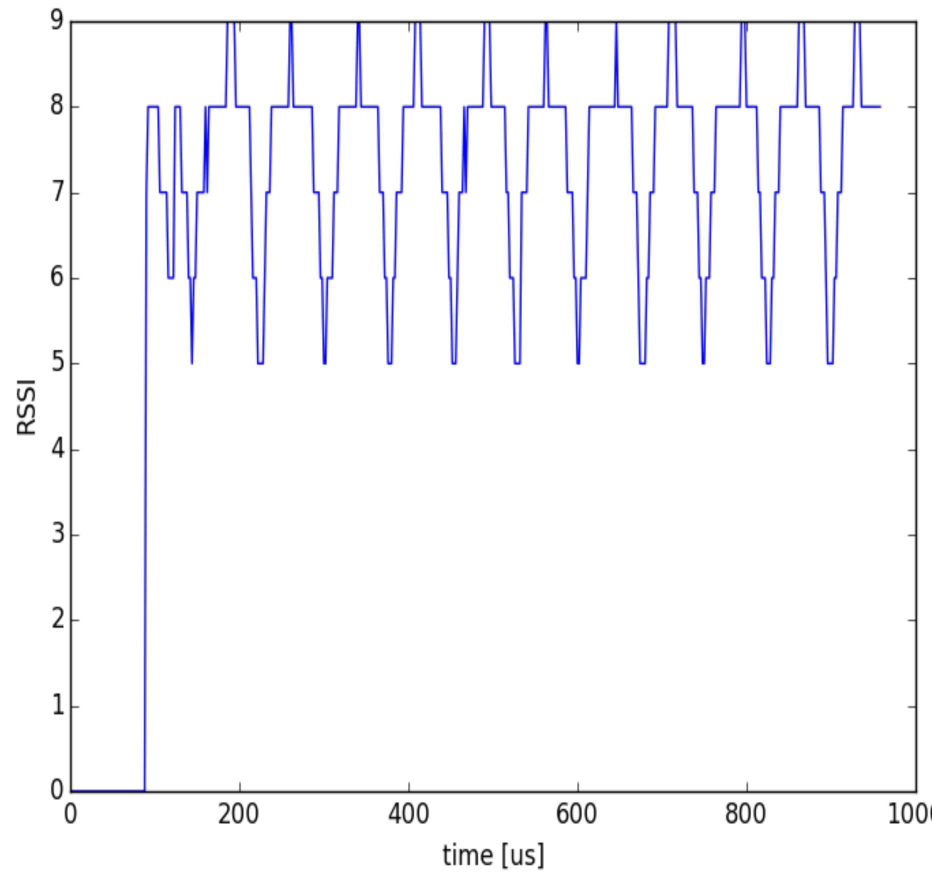
Step 1: Sensor and RF Measurement

- UCMote Proton A DRD
- Atmega128RFA1 primary radio with chip antenna
- 8-bit 16 MHz microcontroller
- 128 KB ROM, 16 KB RAM

- IEEE 802.15.4 compliant COTS radio chip
- Test mode: unmodulated wave
- Fixed carrier frequencies
  - need 50-100 KHz offset
  - trim the load capacitance
- Unpredictable carriers: ±40 KHz
- Slow reset (switch to test mode)
- Measure RSSI signal
  - designed for CCA and LQ
  - low resolution (28 steps)
  - good refresh rate (500 KHz)
- One measurement: 1 ms

Step 2: Signal Processing

- Low resolution (28 steps)
- Time synchronization
  - default is not precise
  - use rising edge
- Unpredictable beat freq
  - depends on carrier offset
  - we expect 20-100 KHz
- Dynamic range
  - depends on TX powers
  - very small (1-5 steps)
- Device dependent noise
- 0.65 ms processing time

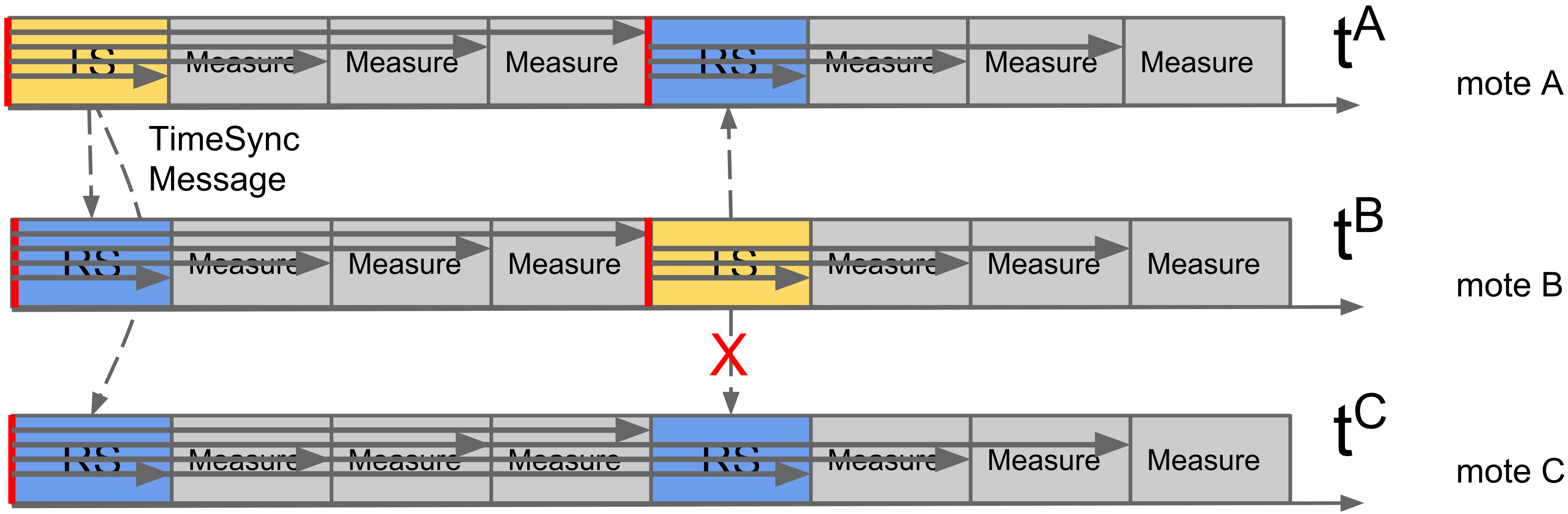


Step 3: Distributed Schedule

A	RS	TX	TX	TX	TS	TX	RX	RX	RS	TX	RX	RX	RS	TX	RX	RX	RS
B	RS	TX	RX	RX	RS	TX	TX	TX	TS	RX	TX	RX	RS	RX	TX	RX	RS
C	RS	RX	TX	RX	RS	RX	TX	RX	RS	TX	TX	TX	TS	RX	RX	TX	RS
D	TS	RX	RX	TX	RS	RX	RX	TX	RS	RX	RX	TX	RS	TX	TX	TX	TS

TS xmit sync   RS rcv sync   TX xmit wave   RX rcv rssi

Step 4: Time Synchronization



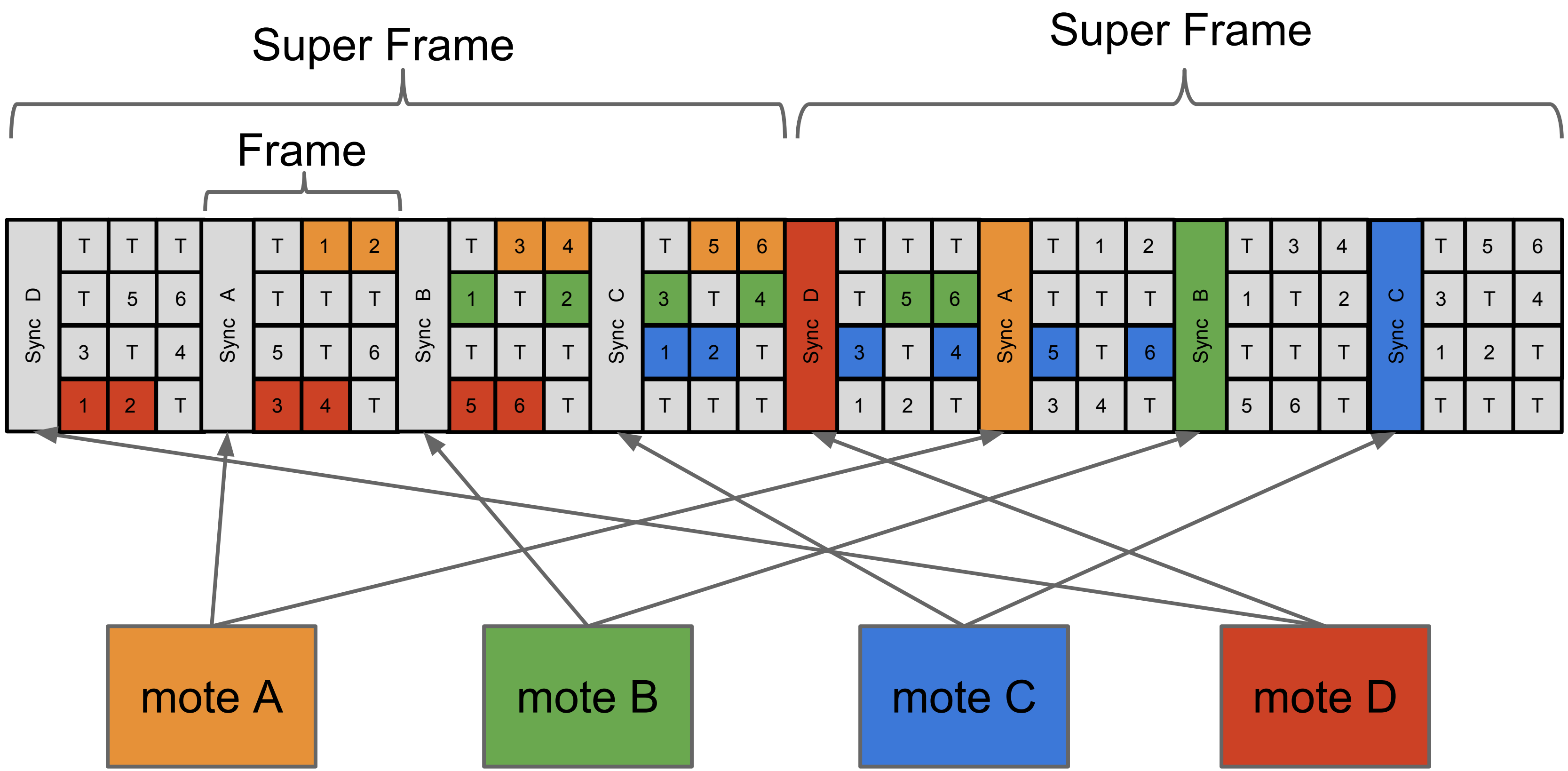
- Periodically send synchronization messages to keep in sync
- Scheduling of measurements on different motes (50 µs precision)
- Messages can be lost, motes turned on/off, local time drifts

Step 5: Data Extraction and Timing

SLOT ID	PERIOD1	...	PERIOD N	PHASE 1	...	PHASE N	TIME-STAMP

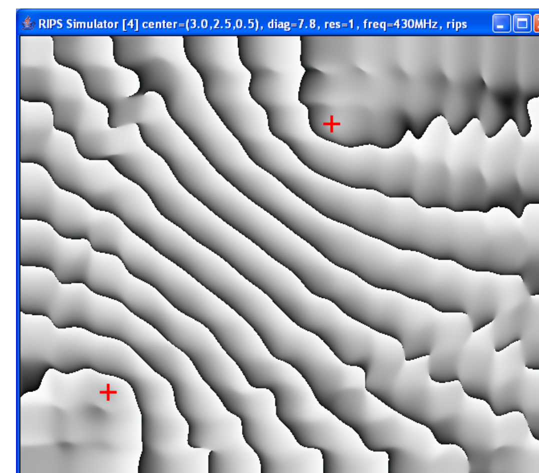
- All measurements (8-bit period and 8-bit phase) in a frame are packed into a single synchronization message
- Data is arriving out of order to the base station
- Measurement timing
  - Single measurement: 1 ms
  - Synchronization msg: 2.5 ms
  - Processing and runtime overhead: 3 ms
  - SuperFrame (4 sync msg, 12 measurements): 25 ms
  - One relative phase per pair of transmitters: 12.5 ms (80 Hz)

Step 6: Sort Data on Basestation

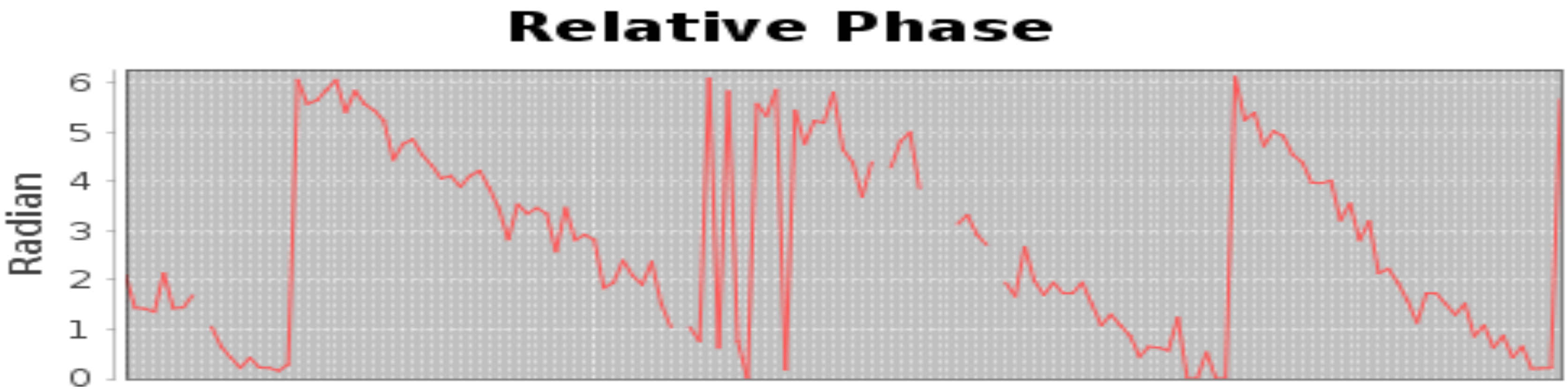


Step 7: Calculate Relative Phases

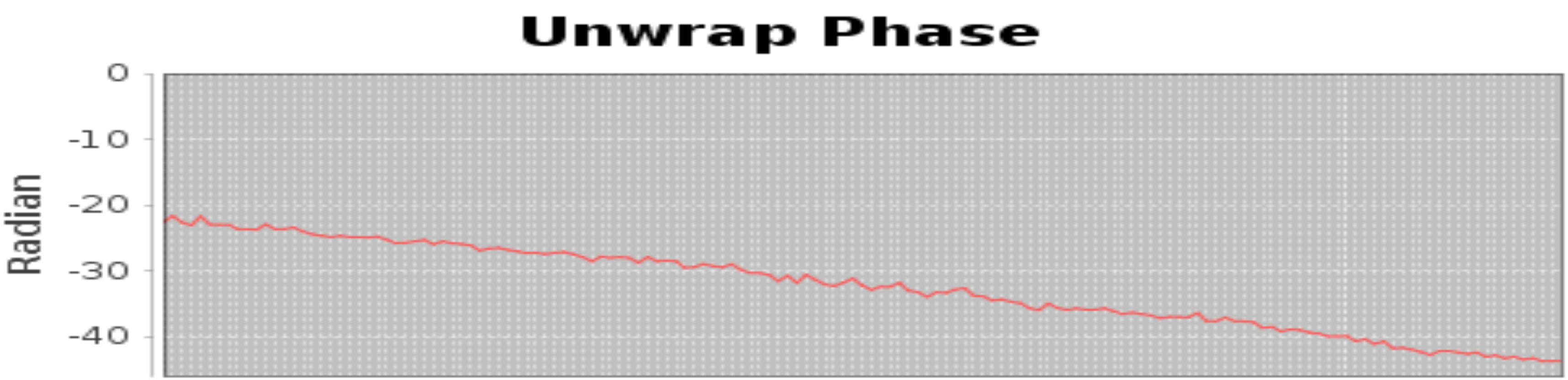
- Find matching pair of absolute phase measurements
- Filter out incorrect measurements
  - different error codes from signal processing unit
  - the two periods are not close enough
- Calculate relative phase: this is between 0 and 2π
- Unwrap relative phases to a number
  - Calculate speed (difference of two consecutive relative phases)
  - Filter out big speed jumps
  - Integrate to get unwrapped phase
- The unwrapped phase is the level on the surface with the hyperbolic geodesics



Demo:



Relative Phase
Radian
6
5
4
3
2
1
0



Unwrap Phase
Radian
0
-10
-20
-30
-40

Thank you!

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