**InPhase:**
**No-Cost Phase-Based Ranging and Localization**
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**Active-Reflector-Ranging**
- Off-the-shelf IEEE 802.15.4 radios with Phase Measurement Unit
- Software can be retrofitted to existing WSN hardware
- One pair of sensor nodes executes the AR-Ranging at a time:
  1. Node A: Sends Continuous-Wave signal
  2. Node B: Measures phase angle \( \varphi \)
  3. Swap roles and execute 1. and 2. again
  4. Switch to next frequency and start at 1.
  5. Transmit results

**Phase Information**
- **Phase response** \( \Phi \) of the 2.4 GHz band is gathered
- Spectrum is sampled from 2,400 to 2,500 MHz in 500 kHz steps
- Maximum distance at 500 kHz step size: 150 m
- Radios report phase angle \( \varphi \) as signed 8-Bit value in range \([-\pi, \pi]\]
- Measurements from both nodes are subtracted (AR-Principle)
- Phase response \( \Phi \) resembles a sawtooth signal
- Measurement is disturbed by other signals and noise
- Steepness of slope is proportional to distance

**Distance Estimation**
- Dominant frequency of \( \Phi \) contains distance information
- Noise in \( \Phi \) is suppressed via auto correlation:
  \[ \Psi_{\Phi \Phi}(j) = \sum \Phi_n \cdot \Phi_{n-j} \]
- Frequency is recovered via Fast-Fourier-Transform: \( FFT(\Psi_{\Phi \Phi}) \)
- Distance is proportional to FFT bin index of maximum peak
- Peak height is used as Distance Quality Indicator (DQI)
- Low DQI indicates Non-Line-of-Sight/Multipath propagation

**Localization**
- Distances to anchor nodes with known positions are measured
- Anchor nodes are chosen in round-robin fashion
- Measurement rate: ~10 Hz
- Particle filter solves the localization problem
- DQI is used as additional weighting factor
- Non-Line-of-Sight measurements are weighted less due to DQI
- Real-time operation and visualization as web application