

# ***Multipath Mitigation Algorithm Results using TOA Beacons for Integrated Indoor Navigation***

**ION GNSS 2008**

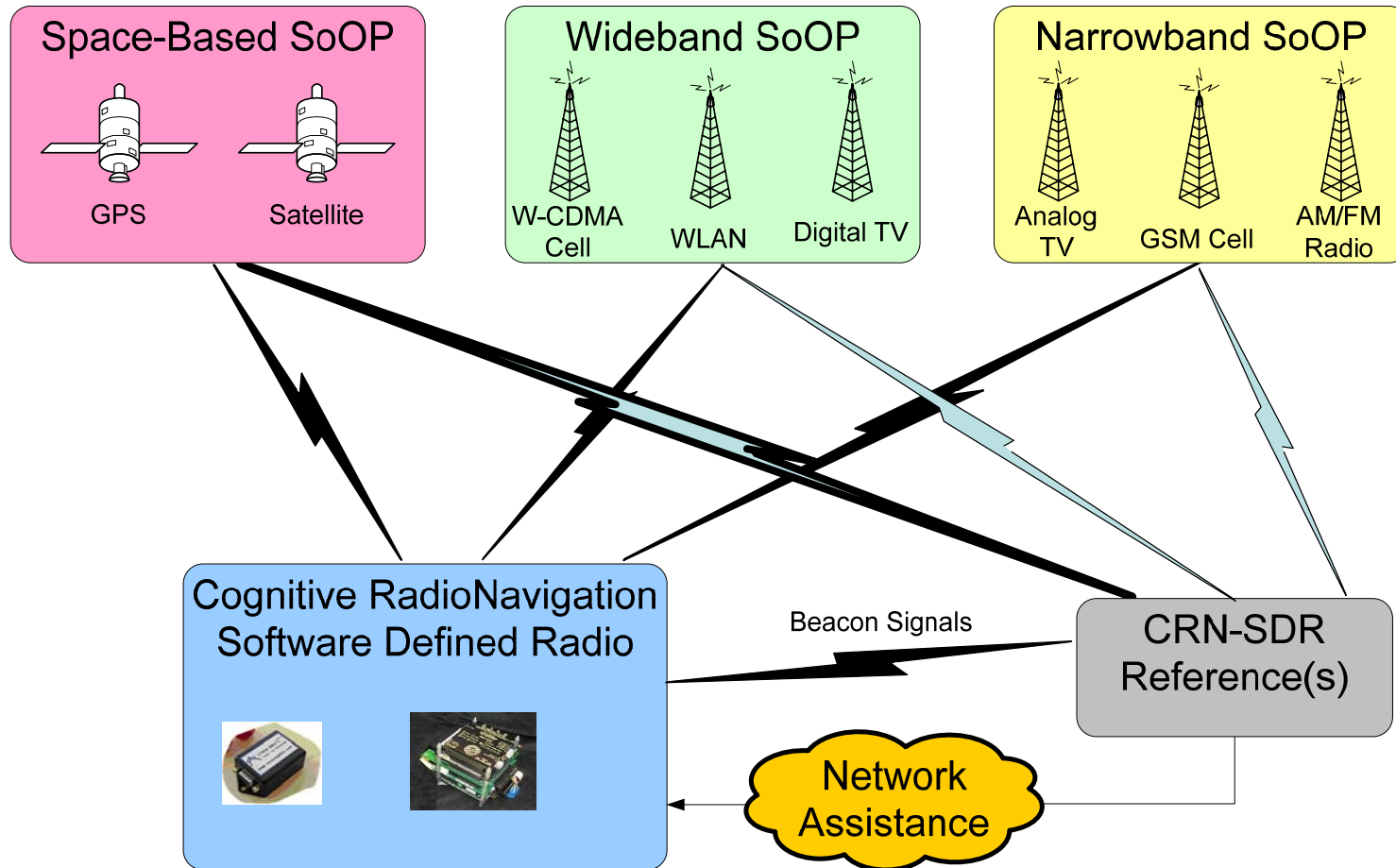
**September 16, 2008**

**Session: FOUO - Military GPS & GPS/INS  
Integration 2**

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# Cognitive RadioNavigation Concept

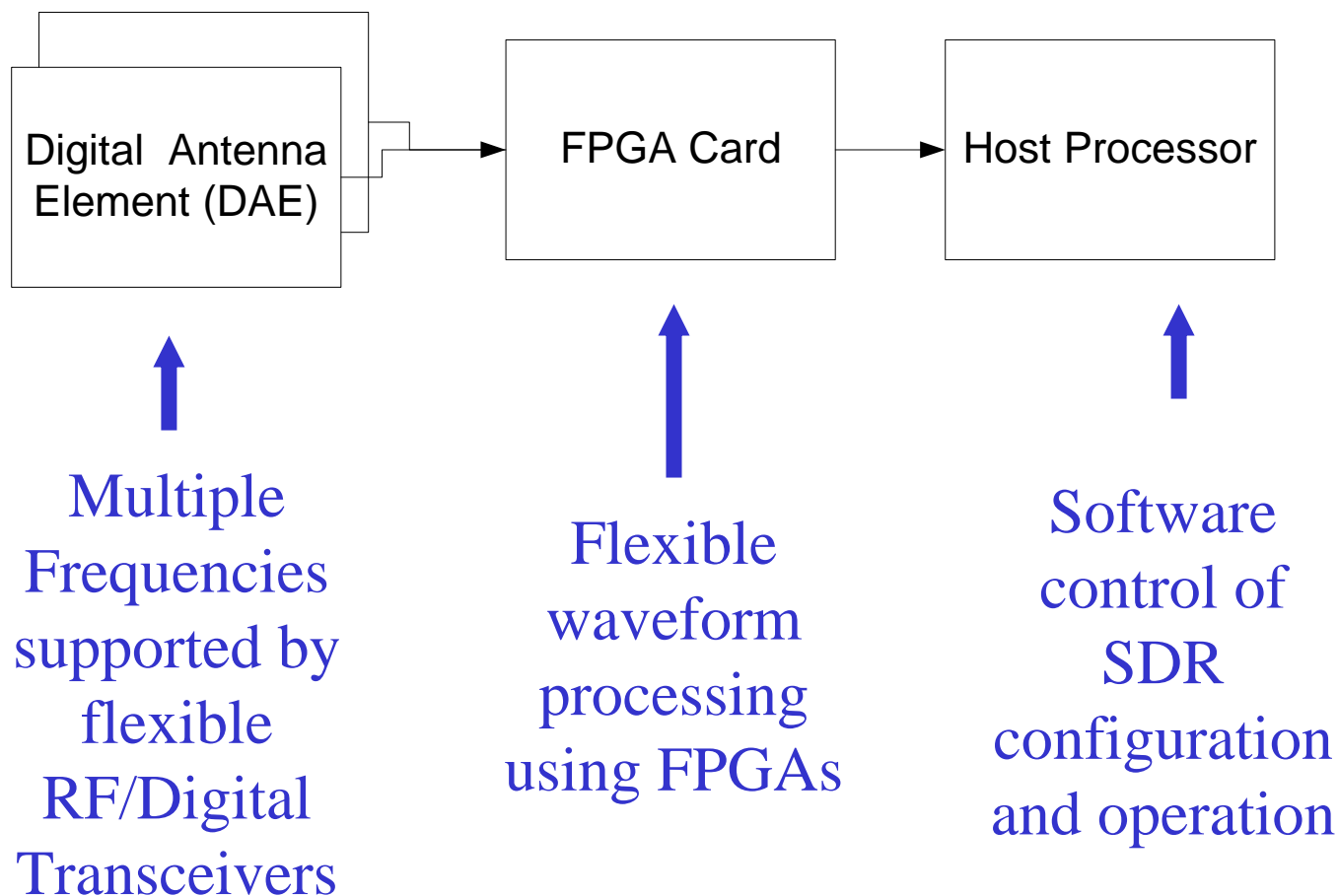


CRN-SDRs use GPS waveform to provide precise “virtual clock” to all Reference units, which enables combination of SoOP and Beacon signals for Nav

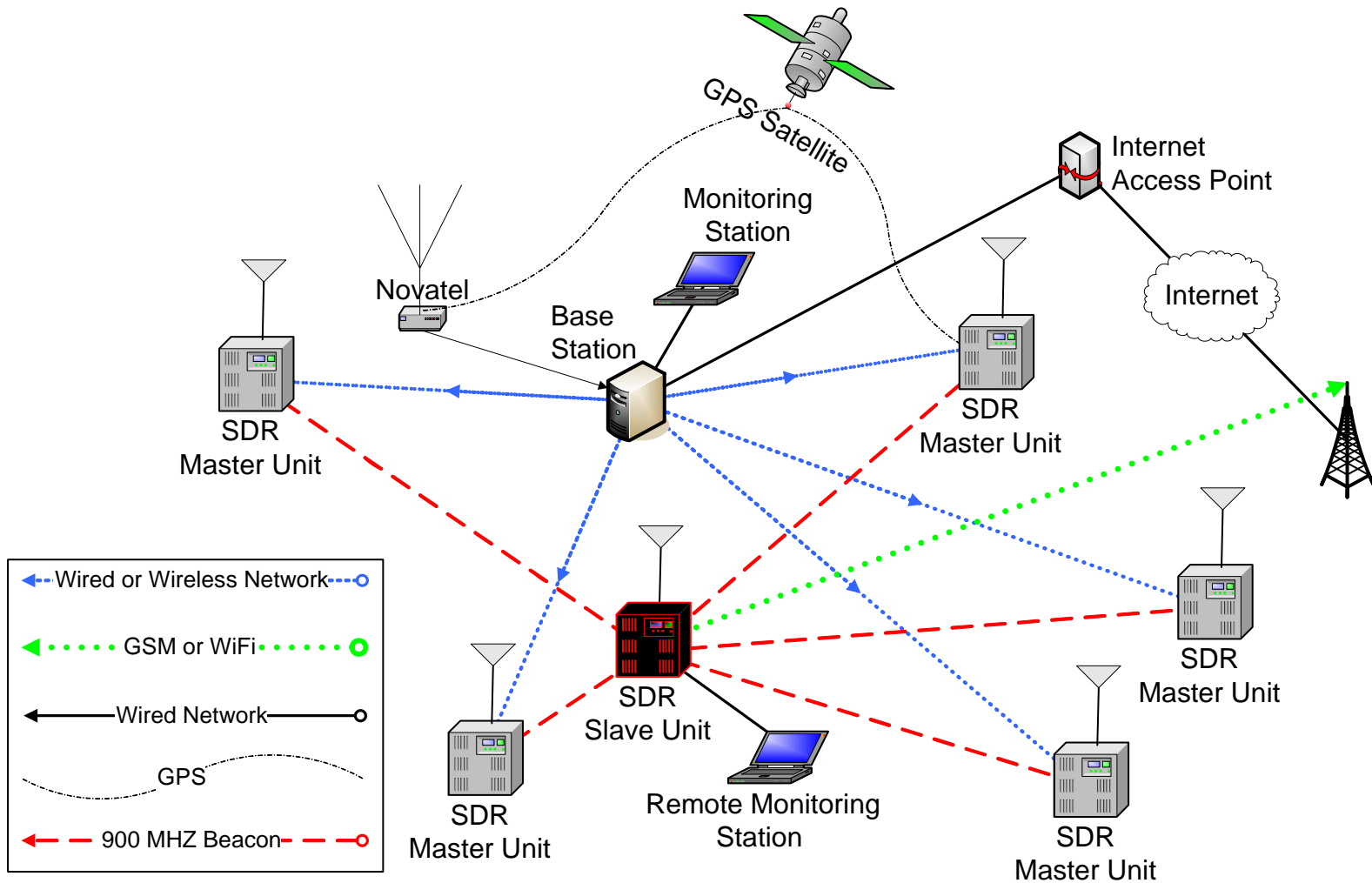
# *Use of SDR Beacons in RSN*

- SDR Beacons broadcast TOA signal for RF ranging
  - Enables navigation in the absence of GPS and other signals-of-opportunity
- SDR Reference Units provide common time-base
  - Uses GPS waveform to create a precise “virtual clock” to reference SoOP observations
  - Allows multiple signal sources to be combined in a common navigation solution
- SDR Mobile Units demonstrate inertial-aided multipath mitigation
  - 900 MHz TOA waveform with 10.23 Mbps modulation
  - Enhanced MLE algorithm with inertial/clock-aiding for direct/multipath signal resolution
  - Enhanced fault detection and exclusion (FDE) for GPS and beacon measurements

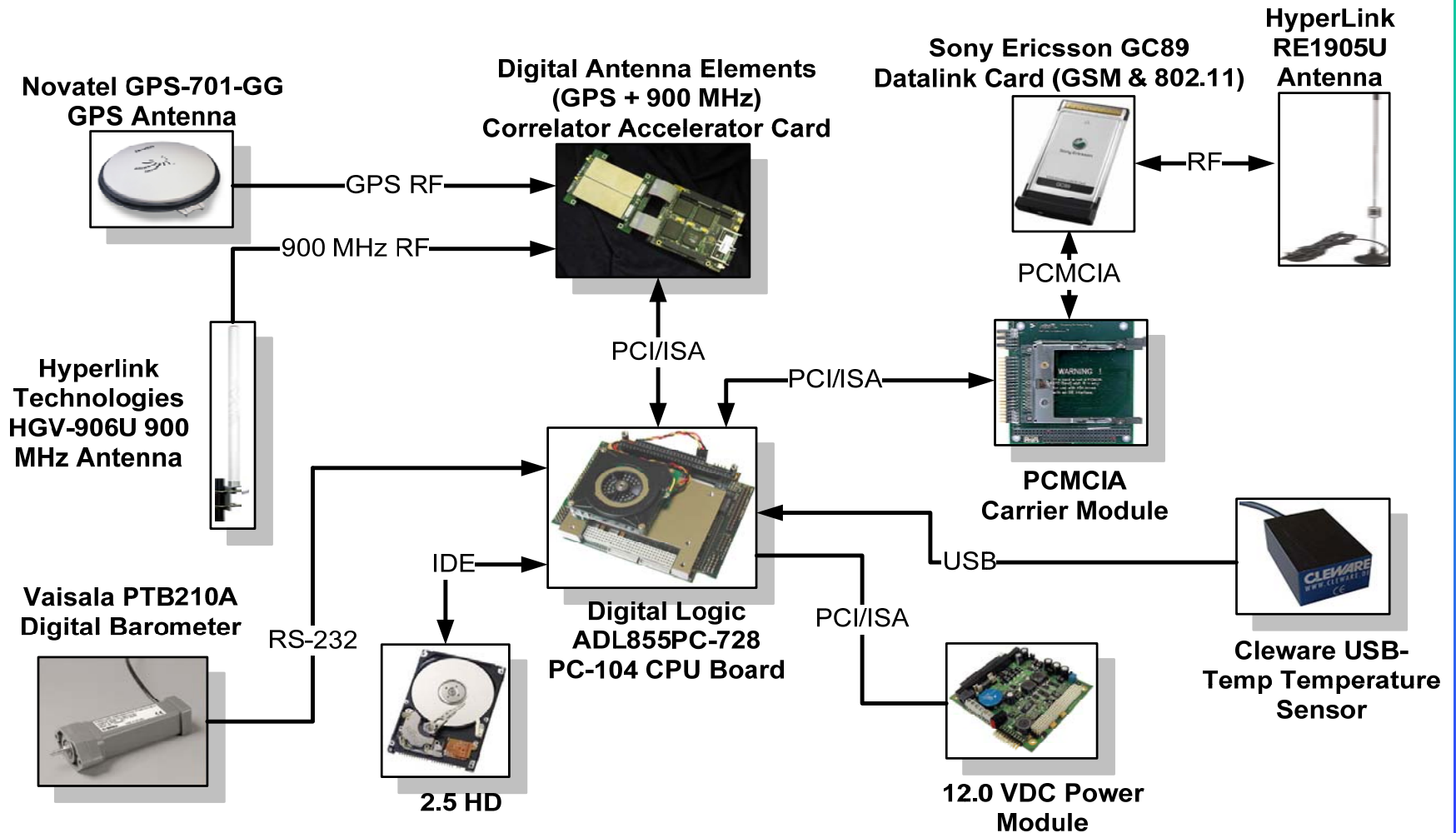
# Benefits of a Software Defined Radio (SDR)



# Beacon System Architecture



# SDR Master Unit Hardware Design



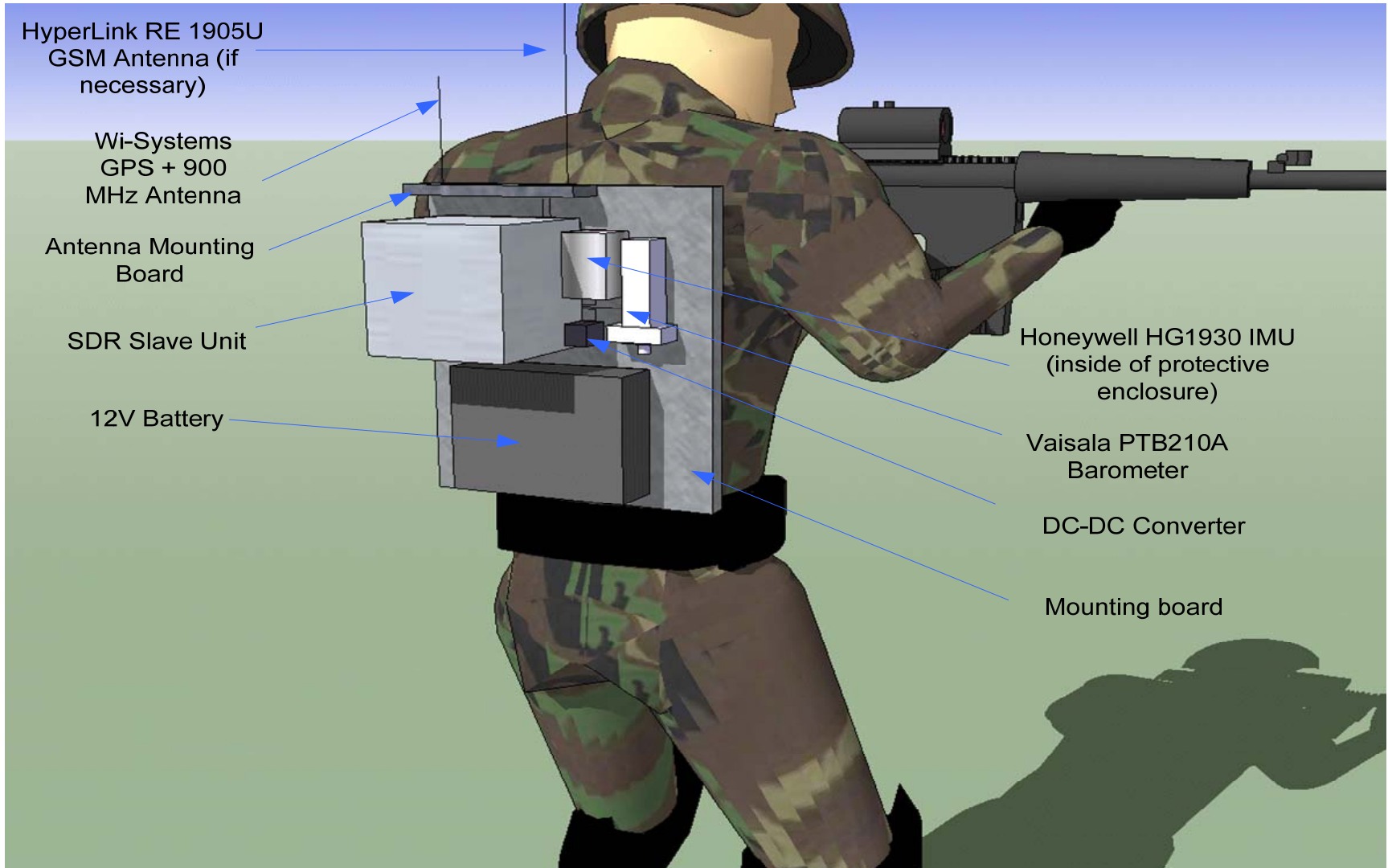
# 900 MHz TOA Broadcast

- Waveform selection
  - CDMA (PRN code modulated)
  - FDMA (Frequency selectable in firmware)
  - TDMA (Slot selected in firmware)

TOA Acknowledge Message broadcast by Pseudolites

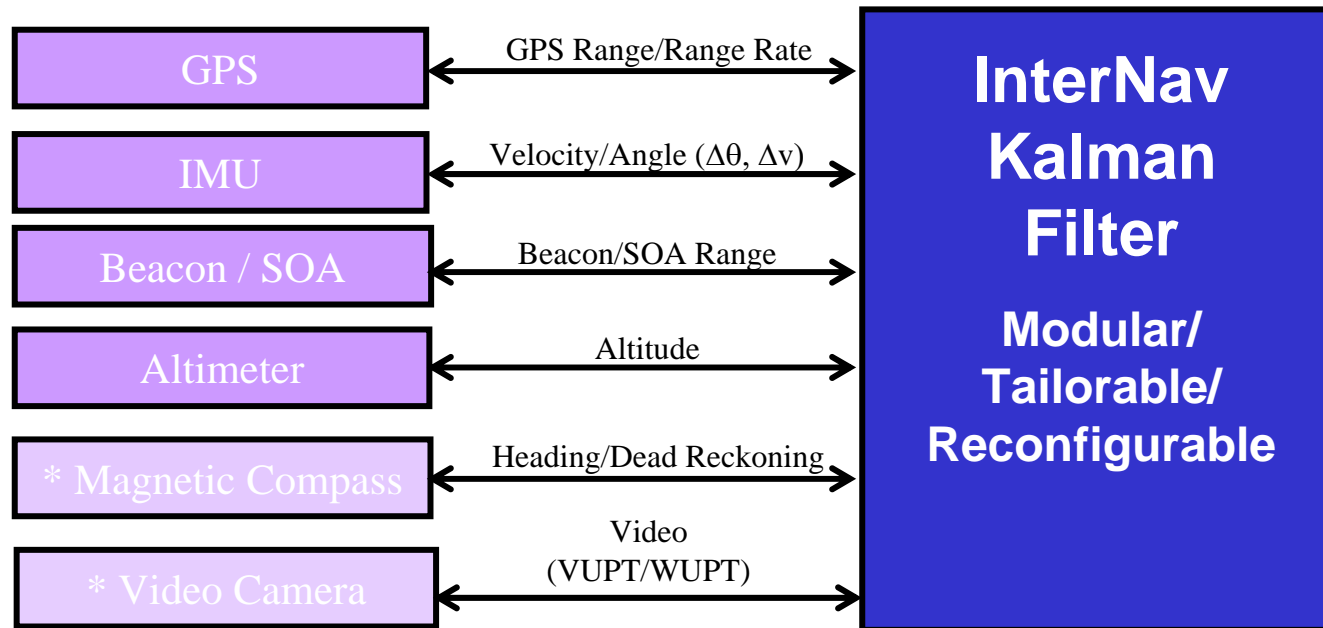
Field Name	Units	Description
Time	Week, secs	GPS time of week in msec of first TOA being transmitted
PRN		ID of PRN code broadcast by pseudolite.
Signal Period	ms	Interval between TOA ranging signals on RF link (0 means transmission will stop)
Signal Duration	ms	Duration of TOA ranging signal on 900MHz link
Signal Freq	MHz	Nominal RF Frequency of TOA ranging signal

# SDR Slave Unit Hardware Design





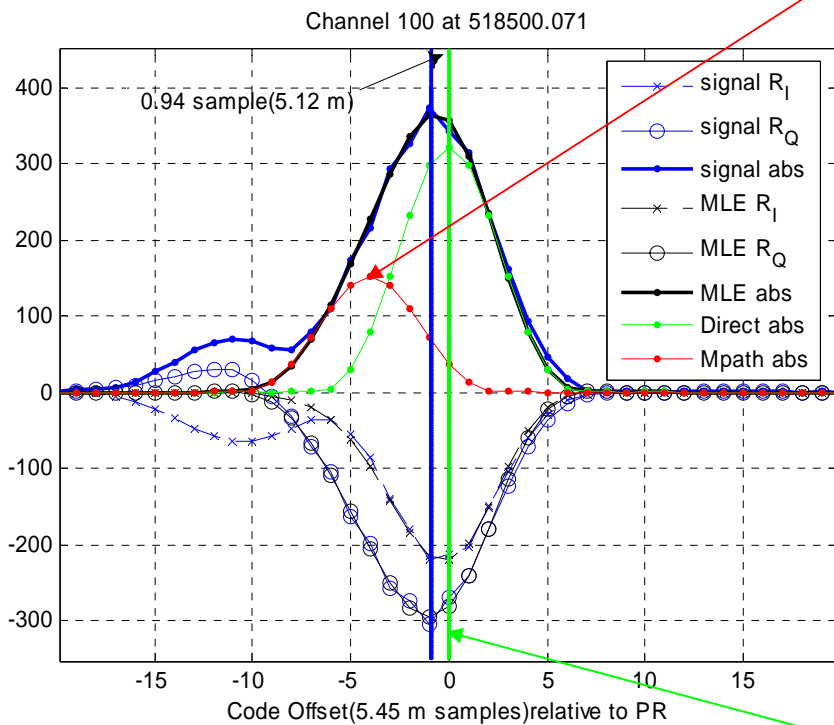
# Integrated SDR Navigation Filter



- Under RSN effort, additional functionality was added to the SDR processing to handle beacon and GPS multipath effects
  - MLE-UTC filtering uses inertially aided tracking loops to enable tracking under low power and high multipath conditions
  - GTI-RAIM uses redundant GPS/beacon measurements to perform FDE

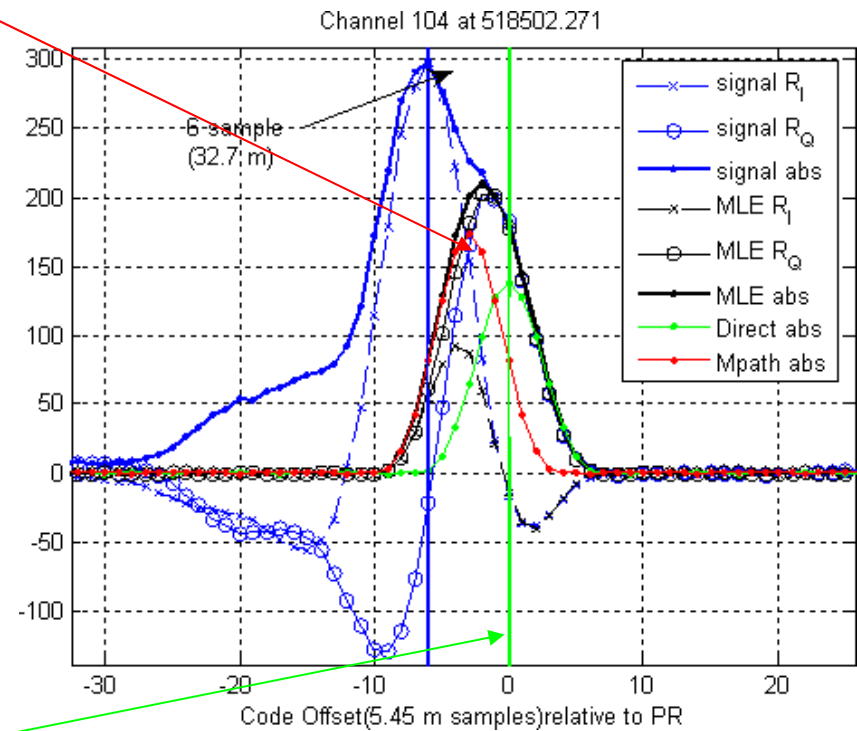
# MLE-UTC Filtering Algorithm

## Multipath Rake Tracking



Close-In Multipath

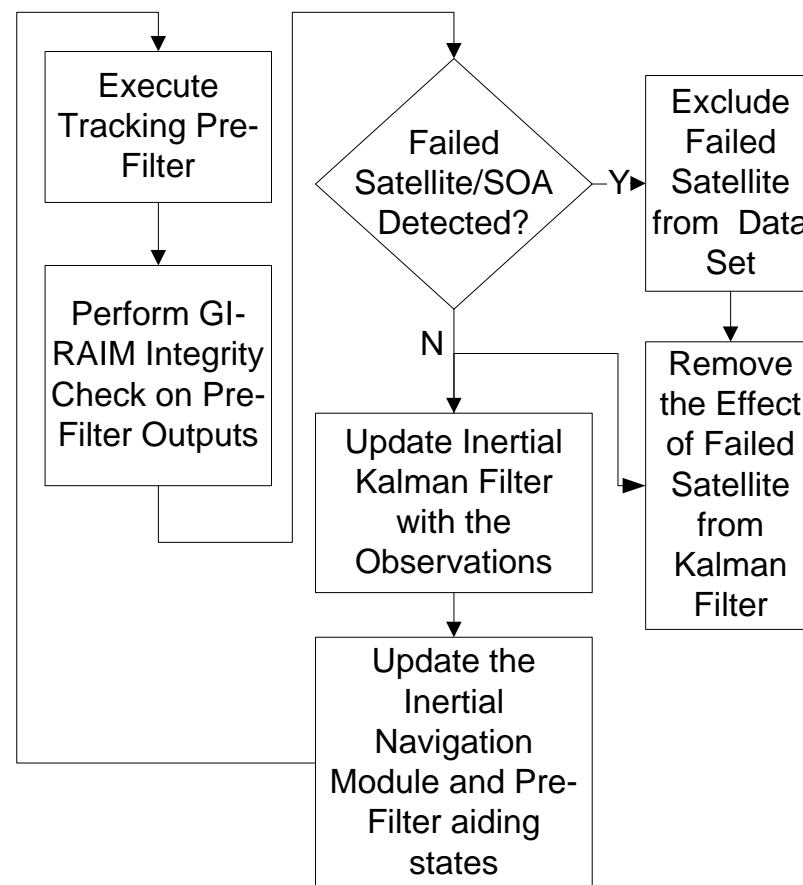
UTC Direct  
Path Aiding



Far-Away Multipath

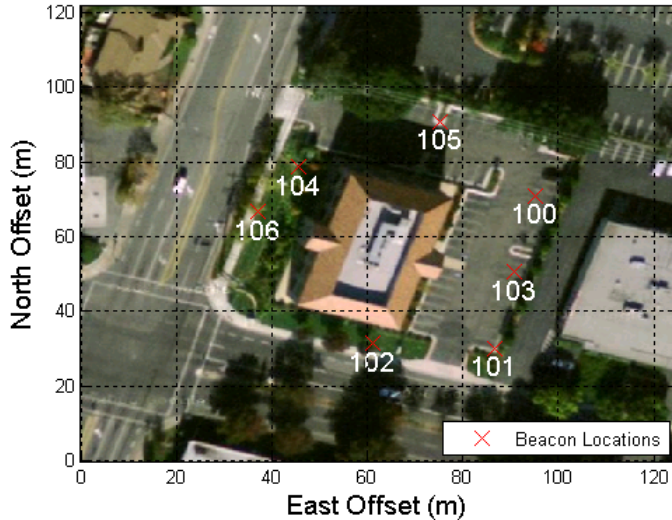
# GTI-RAIM Algorithm

- GI-RAIM was previously used to detect and remove out-of-tolerance GPS faults before they are applied to the blended KF solution
- For RSN, FDE solution was extended to detect and reject TOA errors (GTI-RAIM)
- Approach can also be extended to other SoOP using blended RSN solution



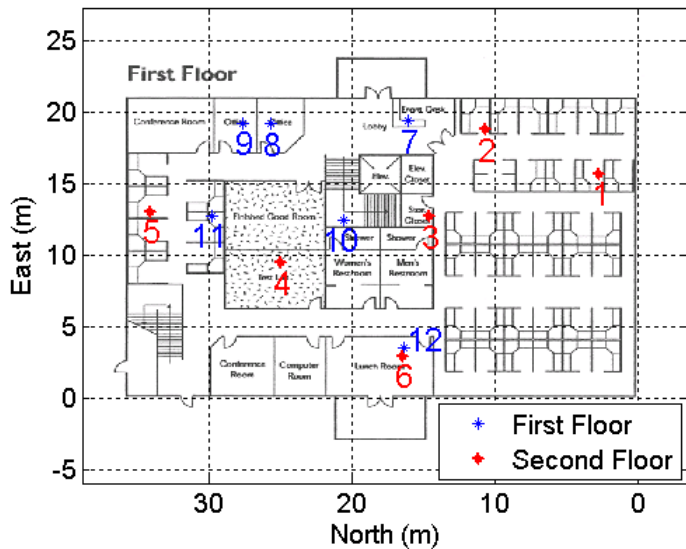
# Testing Overview

Overhead Image



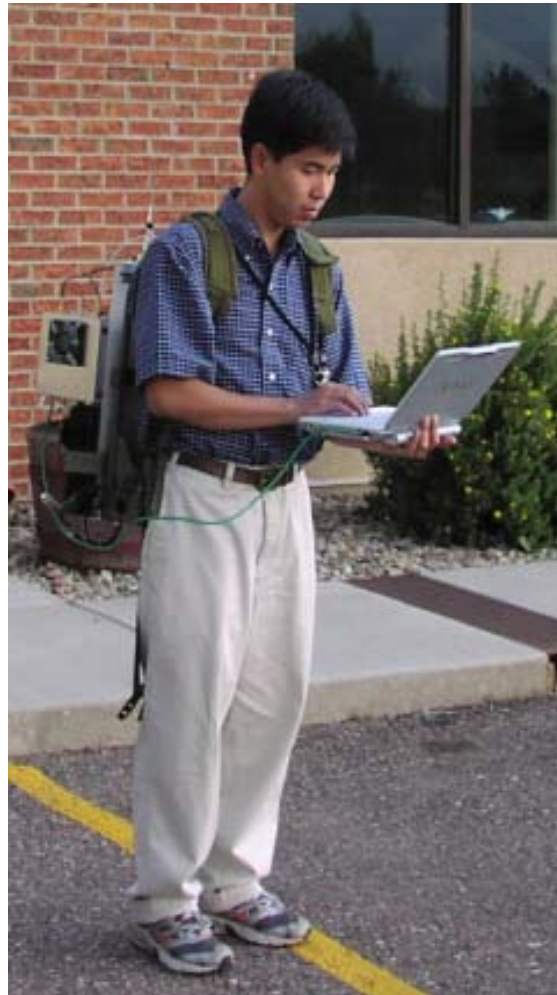
East Offset (m)

Building layout



- 7 beacons operating in TDMA mode
  - 2 second frame length
  - 200ms slot length
  - Broadcasting at ~23 dBm
- 1 backpack-mounted receiver with GPS, TOA, IMU and baro
- 12 indoor survey points

# ***SDR Units in the Field***



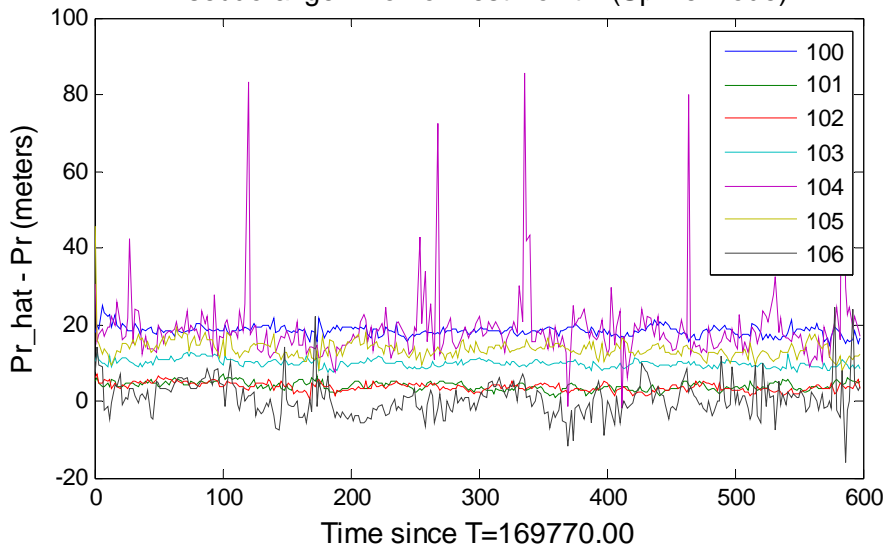
# UTC MLE-Aided Filtering Results

## Ranging Error

### Test Point 1

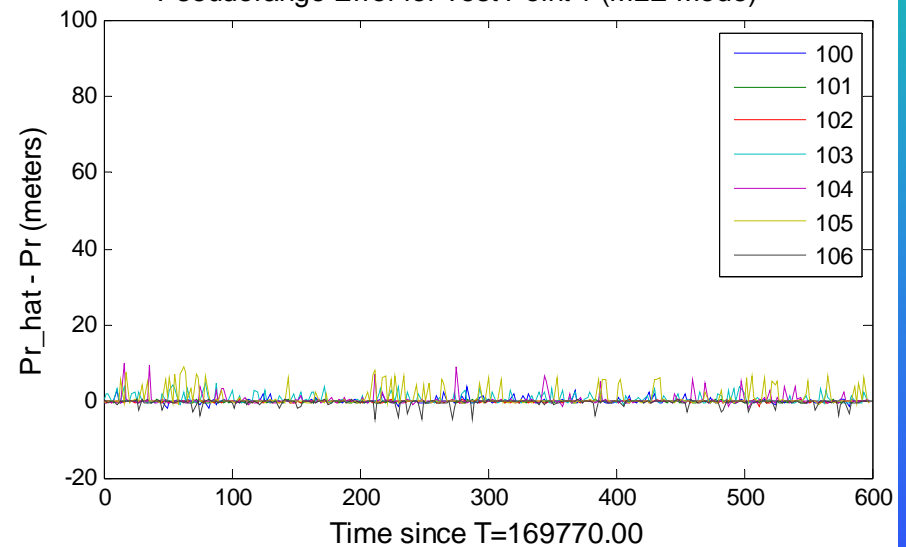
#### Spline-Based Peak Detection

Pseudorange Error for Test Point 1 (Spline Mode)



#### UTC MLE Peak Detection

Pseudorange Error for Test Point 1 (MLE Mode)



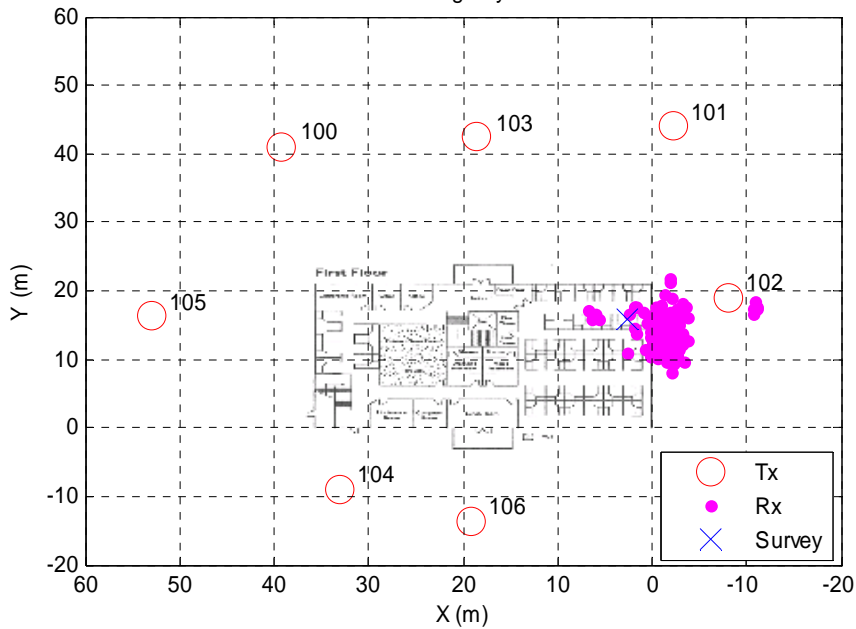
# UTC MLE-Aided Filtering Results

## Positioning Error

### Test Point 1

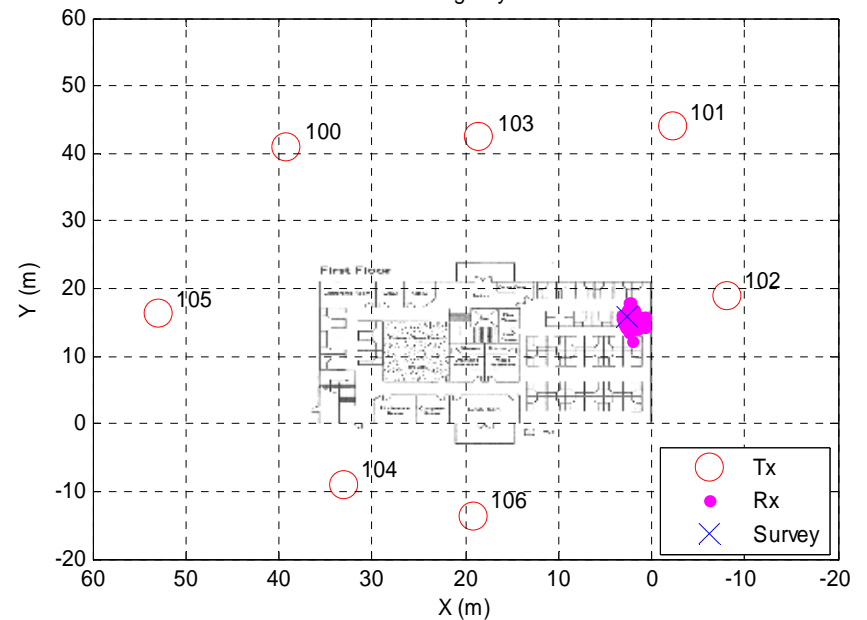
#### Spline-Based Peak Detection

Navigation Results using Spline Mode for Test Point 1  
Building Layout



#### UTC MLE Peak Detection

Navigation Results using MLE Mode for Test Point 1  
Building Layout

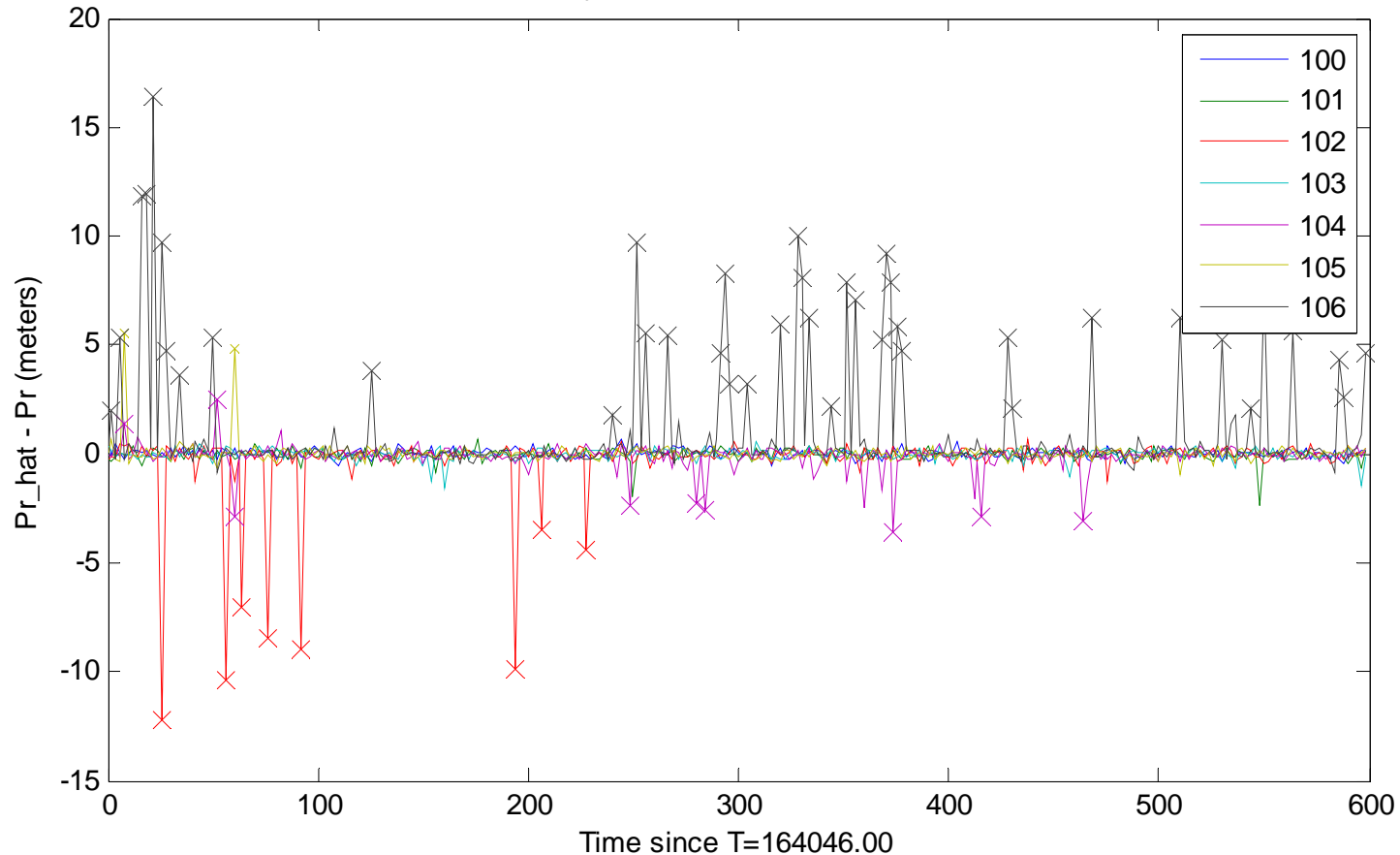


# GTI-RAIM Results

## Rejected Range Measurements

### Test Point 8

Pseudorange Error for Test Point 8 (MLE Mode w/ RAIM)  
X denotes rejected measurement





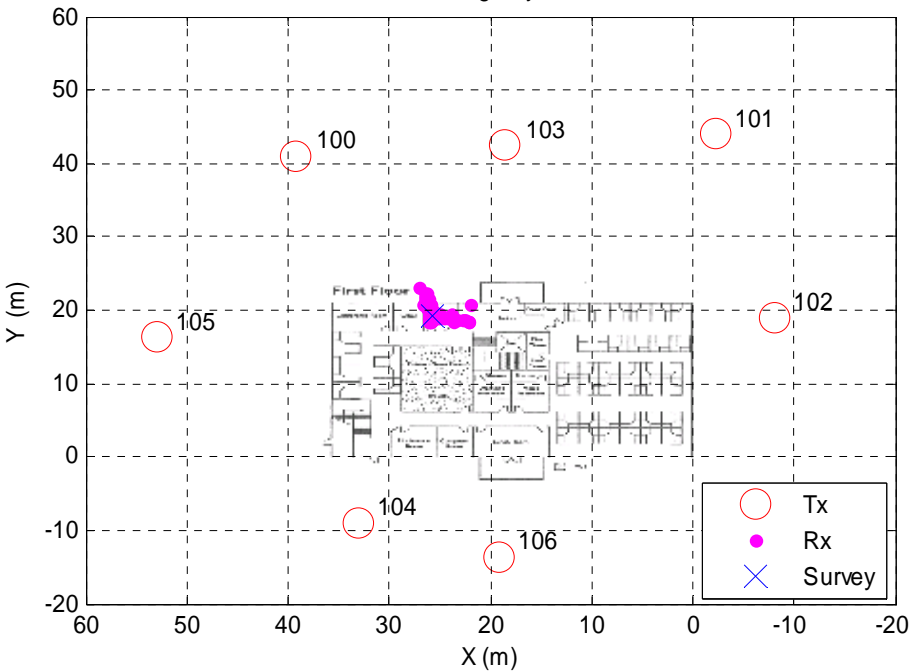
# GTI-RAIM Results

## Positioning Error

### Test Point 8

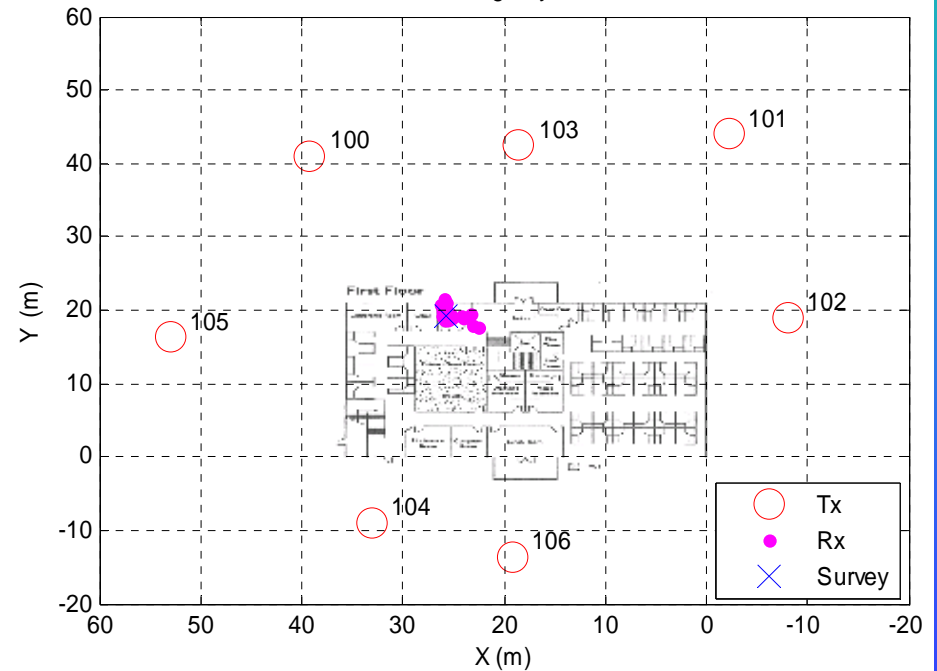
Without GTI-RAIM

Navigation Results using MLE Mode for Test Point 8  
Building Layout



With GTI-RAIM

Navigation Results using MLE Mode w/ RAIM for Test Point 8  
Building Layout



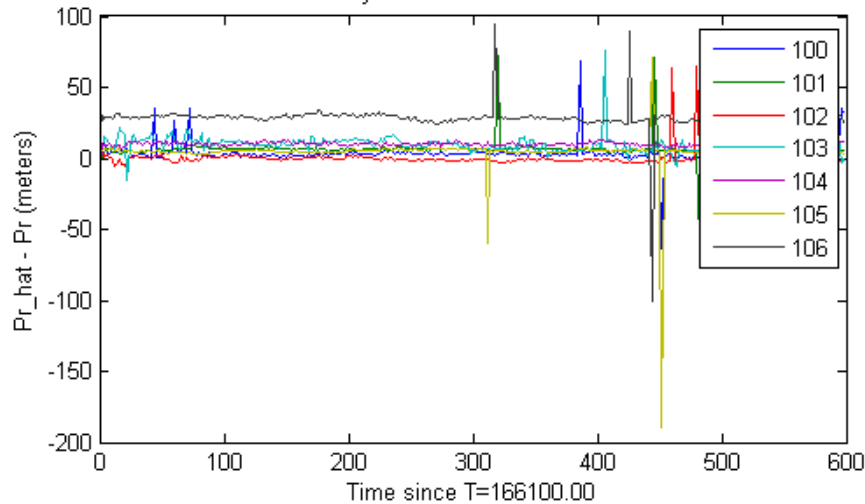
# UTC MLE + GTI-RAIM

## Ranging Error

### Test Point 10

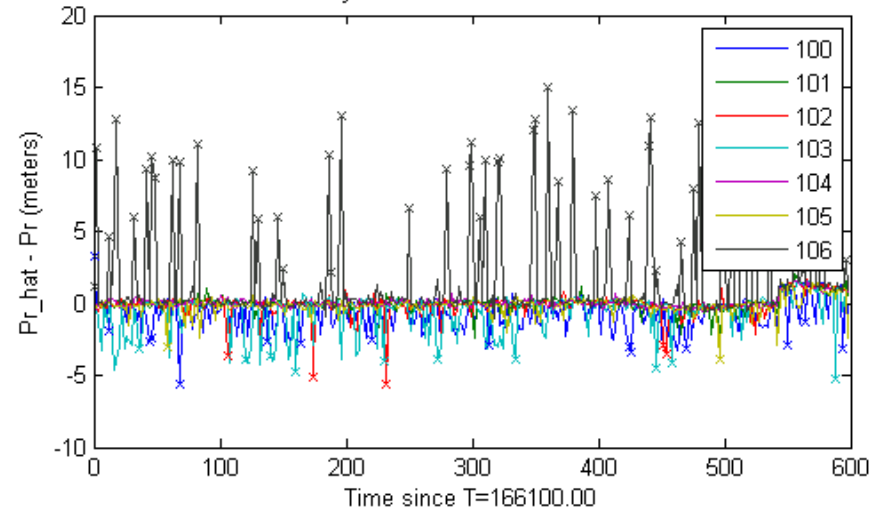
#### Standard Spline without RAIM

Pseudorange Error for Test Point 10 (Spline Mode)  
X denotes rejected measurement



#### UTC MLE with RAIM

Pseudorange Error for Test Point 10 (MLE Mode w/ RAIM)  
X denotes rejected measurement



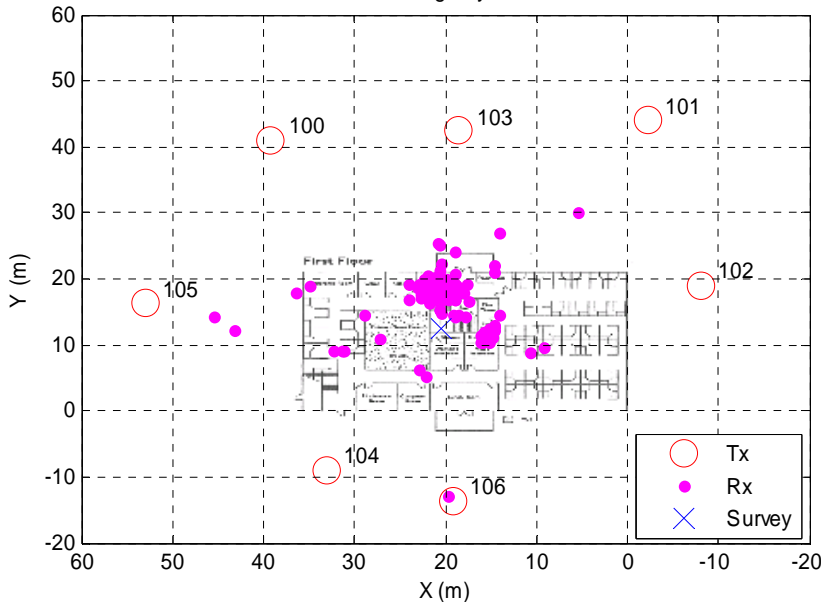
# UTC MLE + GTI-RAIM

## Positioning Error

### Test Point 10

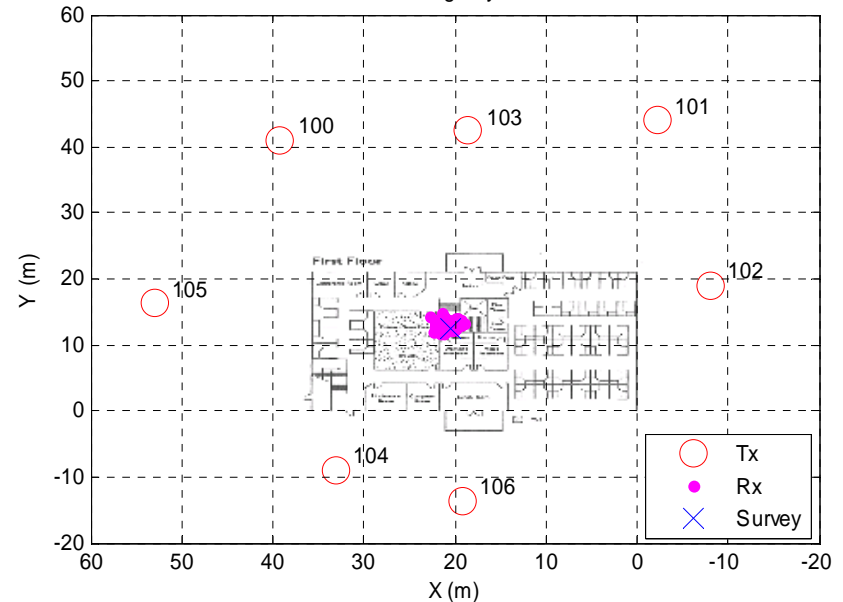
#### Standard Spline without RAIM

Navigation Results using Spline Mode for Test Point 10  
Building Layout



#### UTC MLE with RAIM

Navigation Results using MLE Mode w/ RAIM for Test Point 10  
Building Layout



# Conclusion

- 900 MHz TOA Assistance
  - Can provide augmented navigation to units operating inside buildings and in urban environments
  - Algorithms developed for use on 900 MHz beacons can be easily adapted to handle other signals of opportunity in indoor and urban environments
- UTC-MLE Tracking
  - Enables direct path tracking under very strong fading conditions and in high multipath environments
- GTI-RAIM
  - Redundant measurements allow for FDE algorithms to prevent multipath interference from corrupting the integrated solution
- Potential Applications
  - Military Operations in Urban Terrain
  - First Responder geolocation