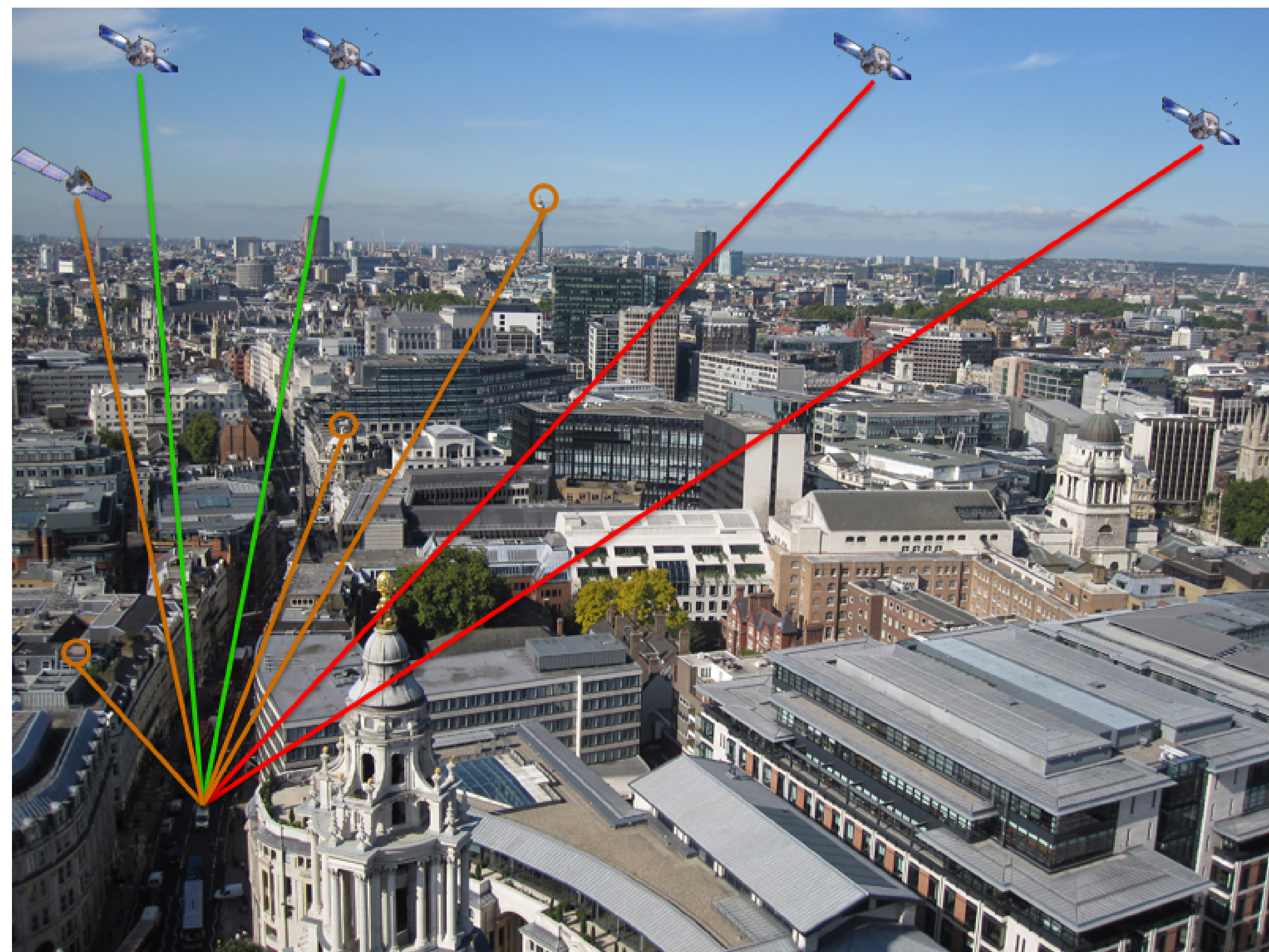


THE PROBLEM

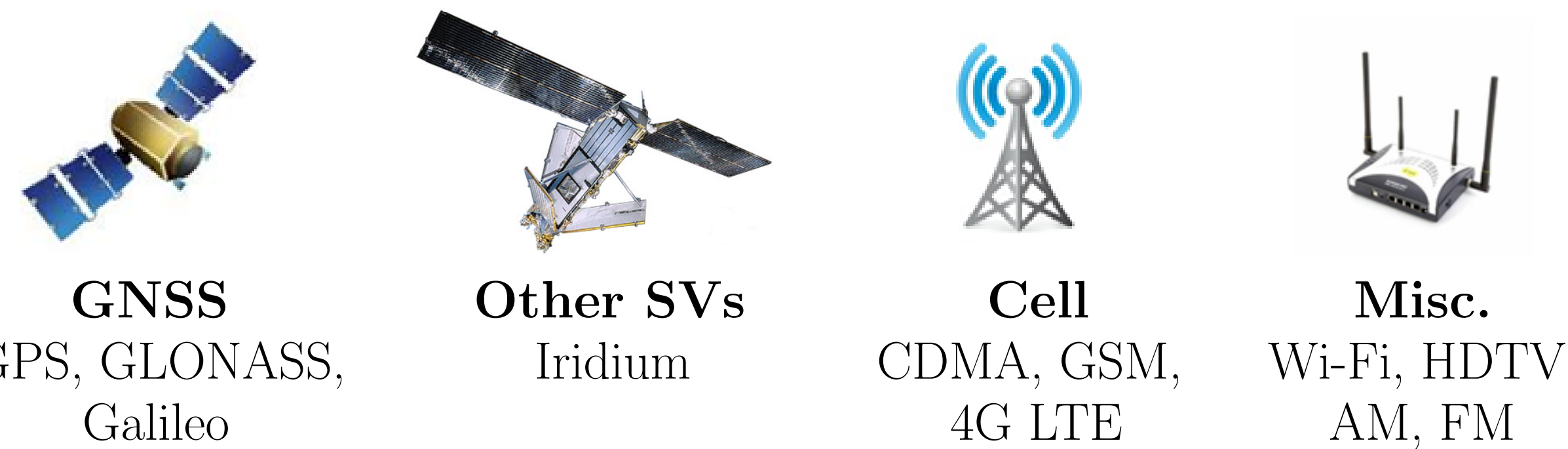
GNSS signals are insufficient for anytime, anywhere navigation, particularly in deep urban canyons, indoors, and environments experiencing intentional jamming, as they attenuate $\sim 30\text{--}50\text{ dB}$.

SOLUTION: EXPLOIT SOPs

Ambient signals of opportunity (SOPs) may enhance and assist conventional navigation techniques.



POTENTIAL SOPs



SOP COMPARISON

SOP	Signal power (dBW)	Freq. stability	Tx position known?	Tx timing offset known?
GNSS	~ -150	10^{-12}	✓	✓
CDMA	~ -110	10^{-10} – 10^{-11}	Sometimes	Rough sync. $\sim \mu\text{sec}$
Iridium	~ -130	10^{-10} – 10^{-11}	$\sim 100\text{m}$	✗

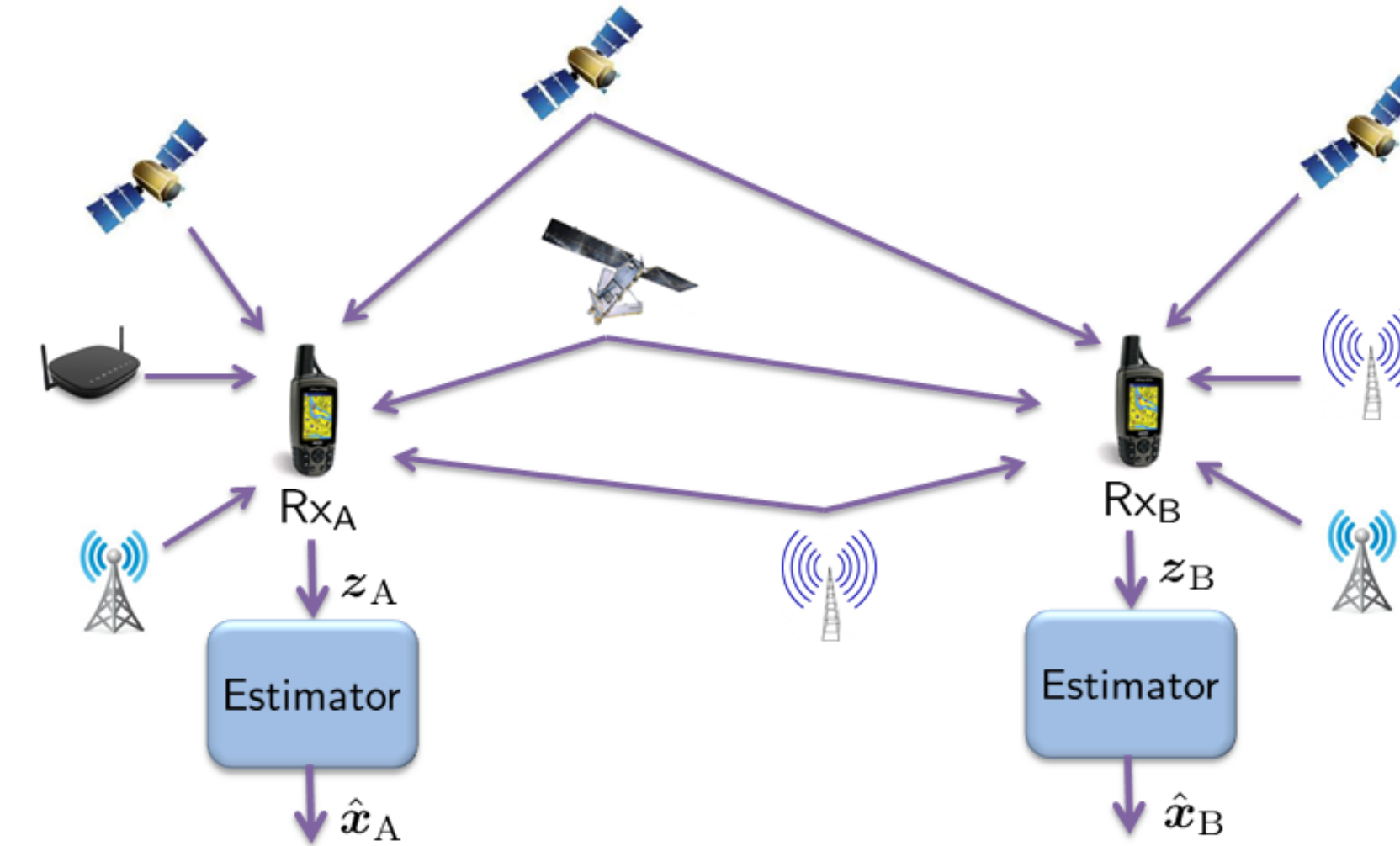
STATE DEFINITION

$$\text{State: } \mathbf{x}_r = \left[\mathbf{r}_r^T, \dot{\mathbf{r}}_r^T, \delta t_r, \dot{\delta t}_r, \gamma_{0,r,s_1}, N_{r,s_2}, \dots, N_{r,s_m} \right]^T$$

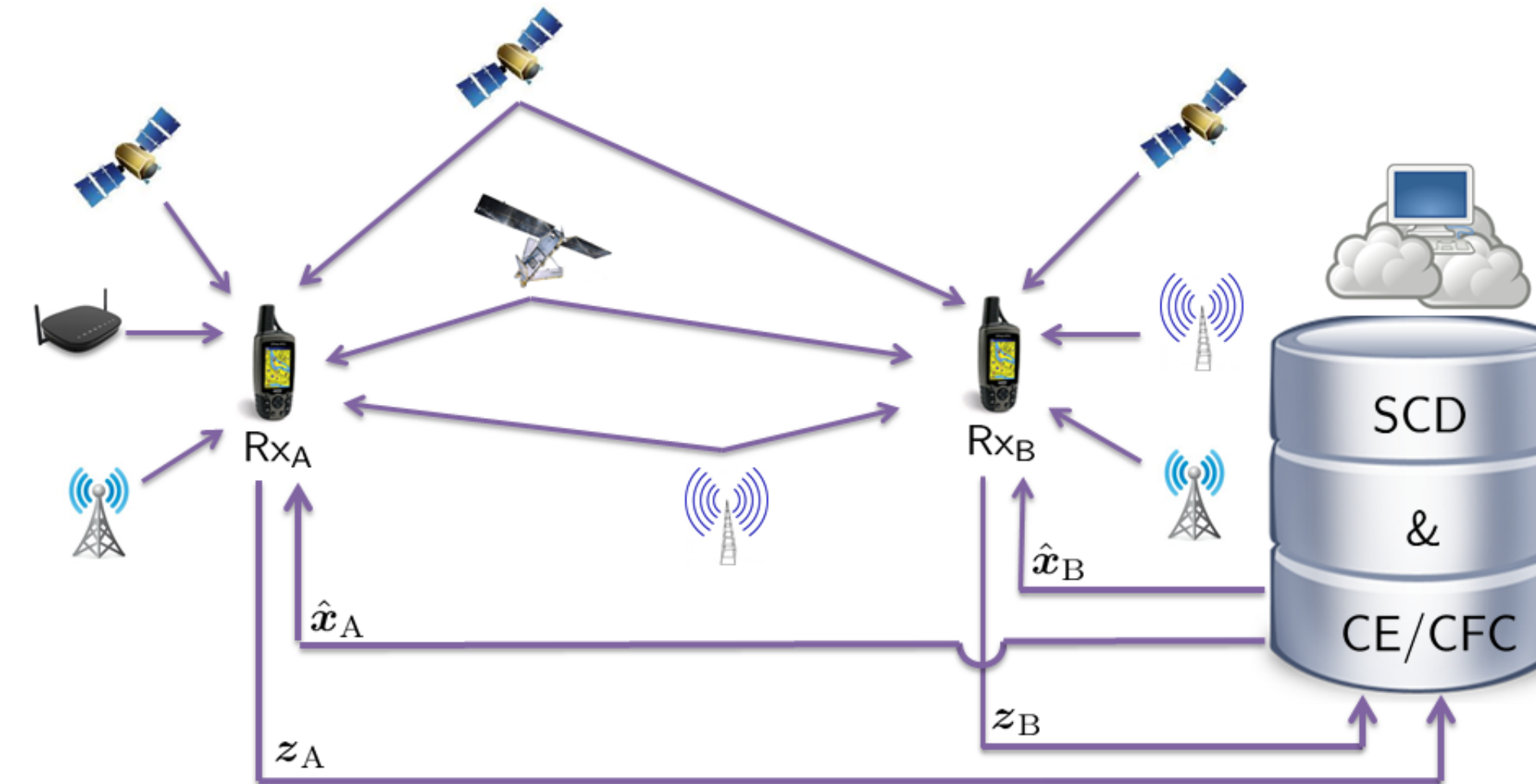
$$\mathbf{x}_{s_i} = \left[\mathbf{r}_{s_i}^T, \delta t_{s_i}, \dot{\delta t}_{s_i}, \psi_{0,i} \right]^T, \quad i = 1, 2, \dots, m$$

ESTIMATION ARCHITECTURES

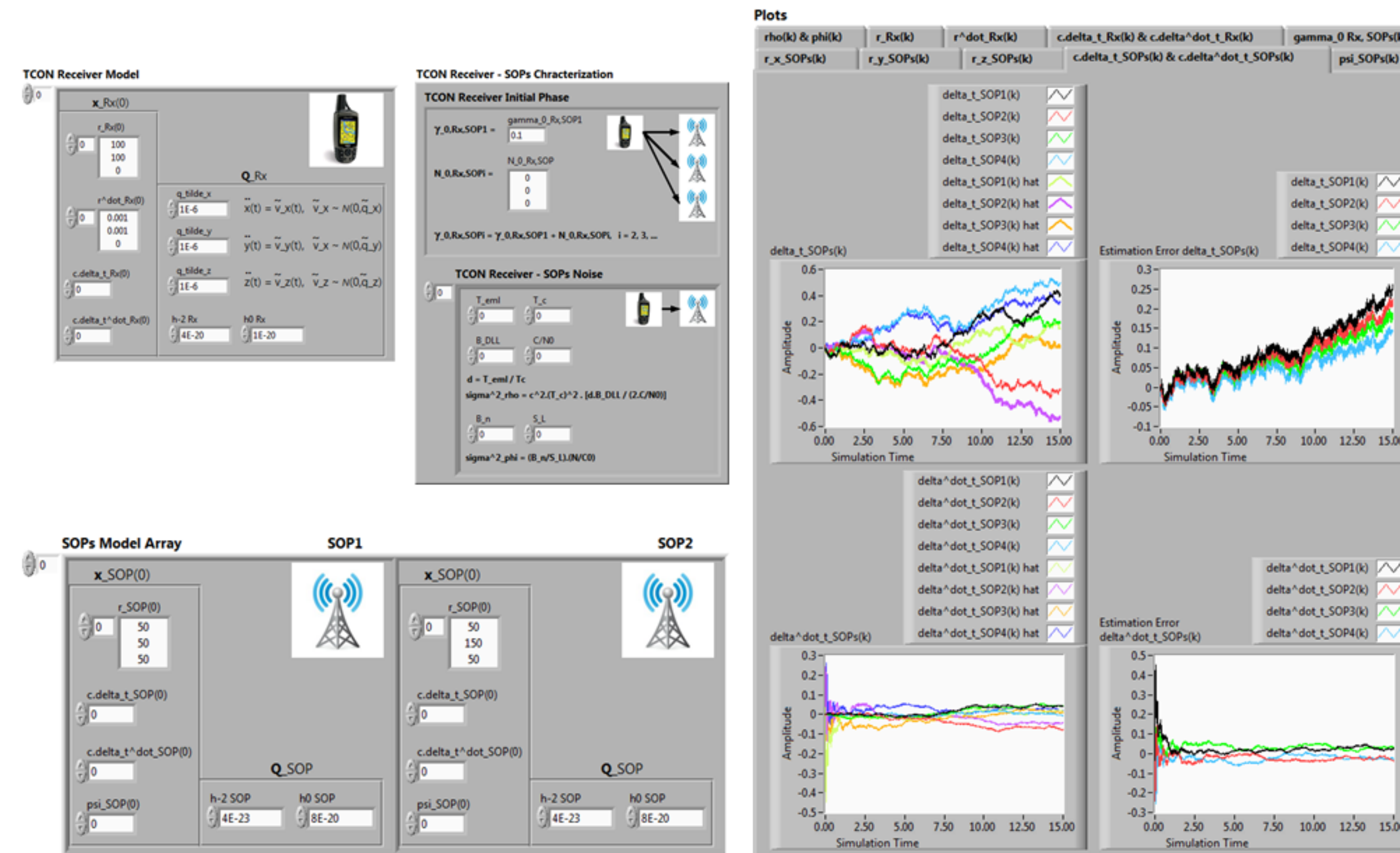
(i) Non-collaborative, Decentralized



(ii) Collaborative, Centralized/Hierarchical



COPNAV SIMULATOR



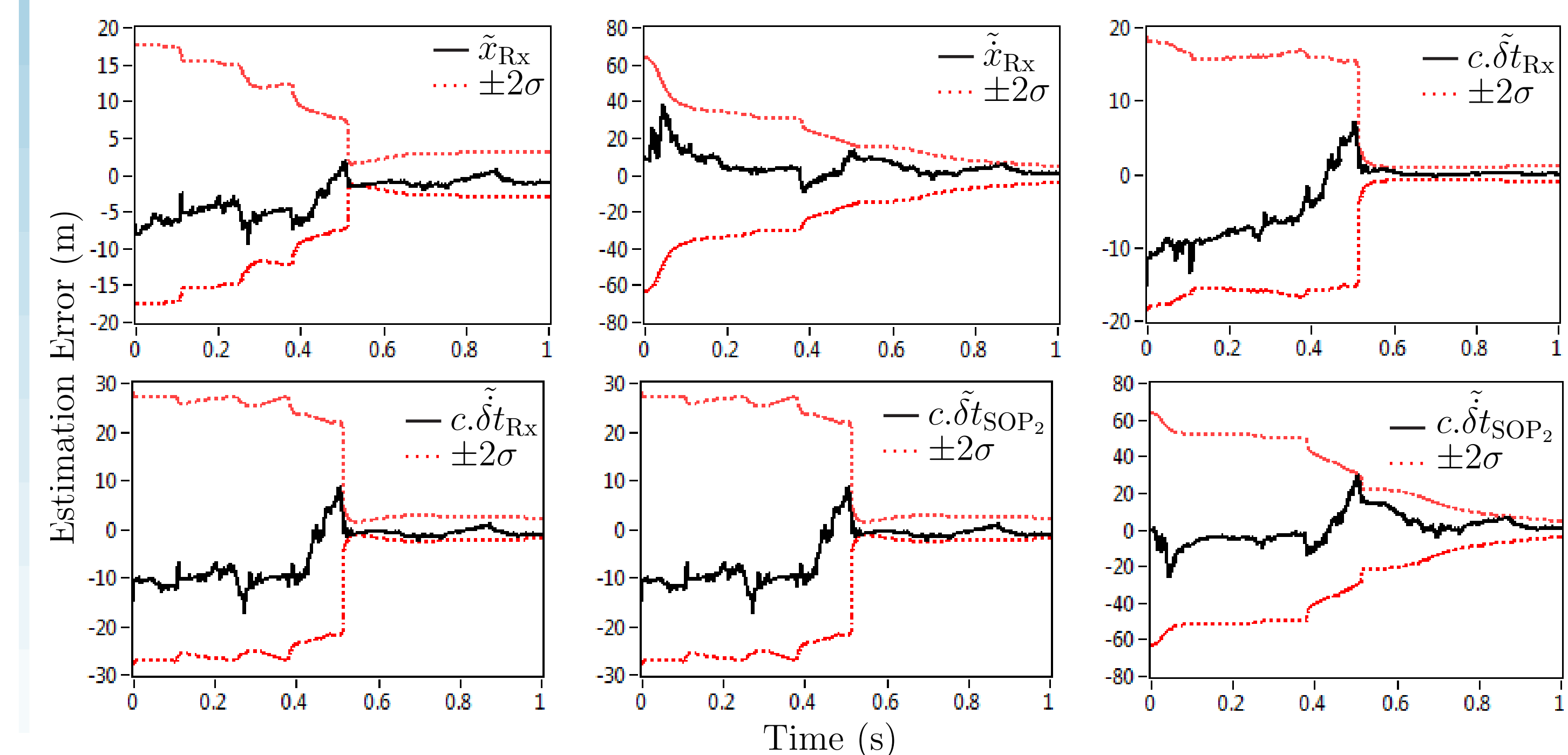
OBSERVABILITY ANALYSIS

Theorem: A collaborative opportunistic navigation environment consisting of n receivers with velocity random walk dynamics making pseudorange observations on m stationary SOPs is completely observable if and only if the initial state(s) of at least

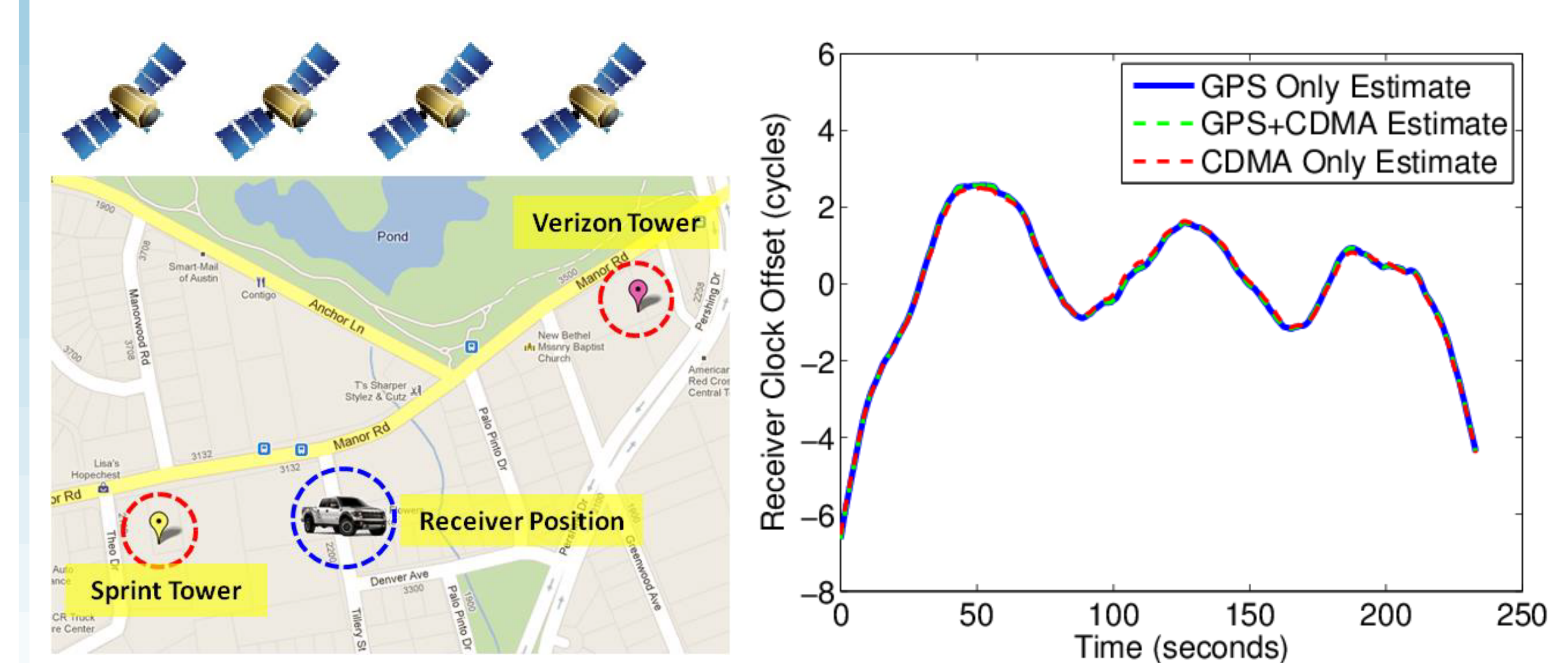
- one receiver is fully-known, or
- one receiver is partially-known and one SOP is fully-known, or
- one SOP is fully-known and one SOP is partially-known

SIMULATION RESULTS

Environment with 1 fully-known SOP and 1 partially-known SOP



EXPERIMENTAL RESULTS



REFERENCES

[1] Z.M. Kassas and T. Humphreys, "Observability Analysis of Opportunistic Navigation with Pseudorange Measurements," *AIAA GNC 2012*
 [2] K. Pesyna, Z.M. Kassas, J. Bhatti, and T. Humphreys. "Tightly-Coupled Opportunistic Navigation for Deep Urban and Indoor Positioning," *ION 2011*