Tightly-Coupled Opportunistic Navigation for Deep Urban and Indoor Positioning

Wireless Networking & Communications Group

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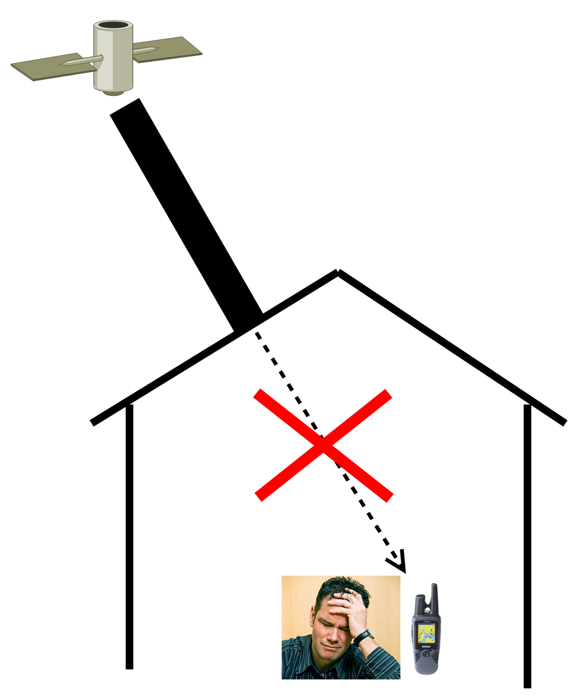
The Problem

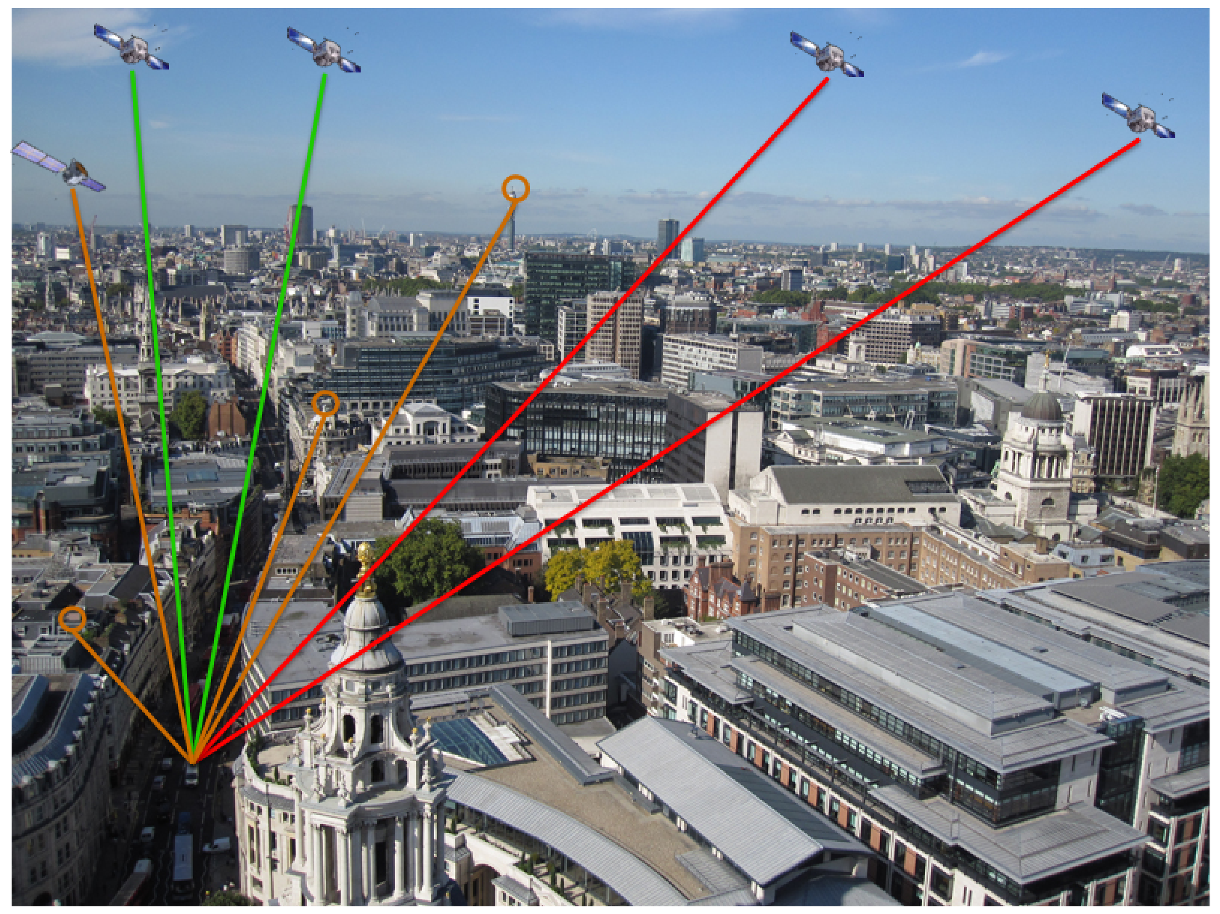
GPS signals are insufficient for deep urban canyon and indoor navigation as they attenuate **30–50 dB**.



GPS receivers can't acquire or track indoors with a $C/N_0 \approx 7$ dB-Hz.

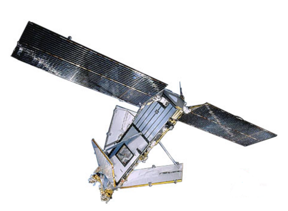
Solution: Exploit SOPs

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



Potential SOPs

GNSS
GPS, GLONASS, Galileo



Other SVs
Iridium

Cell
CDMA, GSM, 4G LTE

Misc.
Wi-Fi, HDTV AM, FM

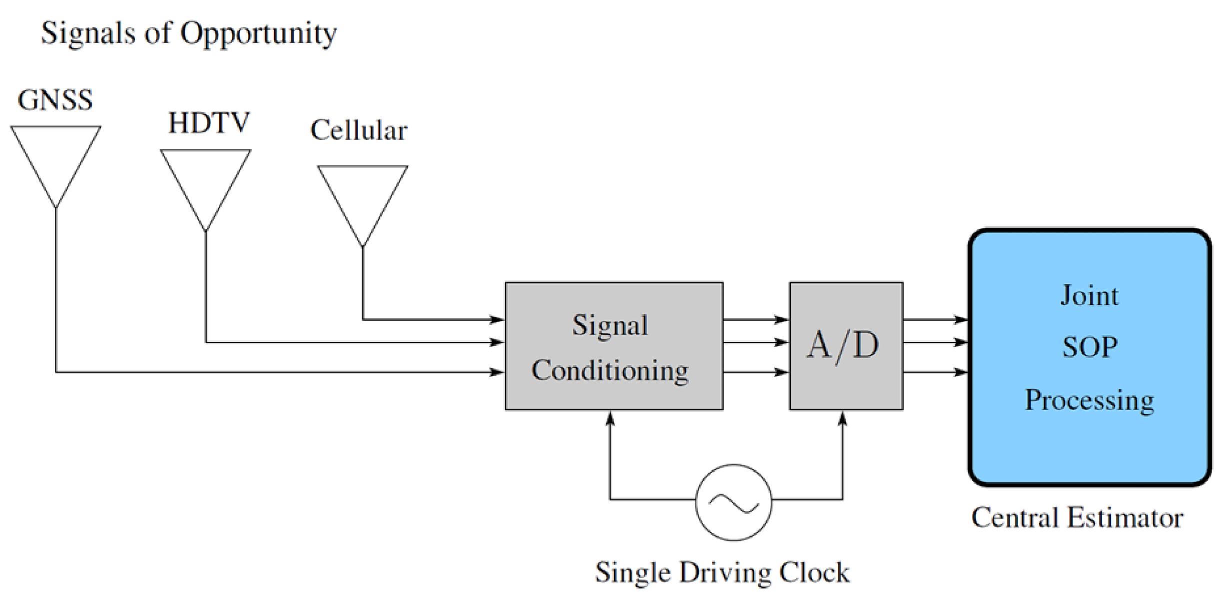
Desirable Characteristics

- Known or predictable timing offset
- Stable transmitter clock
- Known or predictable location
- High received signal power
- Wide bandwidth
- Continuous carrier
- Known signal structure

SOP Comparison

SOP	Signal Power (dBW)	Freq. Stability	Tx Pos. known?	Tx timing offset known?
GNSS	$\sim$ -150	10^{-12}	✓	✓
CDMA	$\sim$ -110	10^{-10} – 10^{-11}	Not always	Rough sync. $\sim \mu$sec
Iridium	$\sim$ -130	10^{-10} – 10^{-11}	~100m	×

TCON Architecture



TCON Attributes

Tightly-Coupled
Signals are downmixed and sampled with the same clock and signal observables are fused at the carrier phase level allowing absolute time correspondence at the nanosecond level

Opportunistic
Receiver continuously searches for signals from which to extract navigation and timing information. The receiver employs on-the-fly signal characterization to estimate:

- Clock stability
- Clock offset
- Carrier-to-noise ratio C/N_0
- Transmitter location

Collaborative
The receiver may collaborate with other receivers through an SOP characterization database (SCD). The database delivers upon request SOP characterizations and associated probability distributions.

Central Estimator

State Vector:

$$\boldsymbol{x}_{\text{rec}} = \begin{bmatrix} \mathbf{r} \\ \delta_t \\ \dot{\mathbf{r}} \\ \dot{\delta}_t \end{bmatrix}, \quad \boldsymbol{x}_{\text{SOP}} = \begin{bmatrix} \mathbf{r}_{\text{SOP}} \\ \delta_{t,\text{SOP}} \\ \dot{\delta}_{t,\text{SOP}} \\ \gamma_{\text{SOP}} \end{bmatrix}, \quad \boldsymbol{x} = \begin{bmatrix} \boldsymbol{x}_{\text{rec}} \\ \boldsymbol{x}_{\text{SOP},1} \\ \vdots \\ \boldsymbol{x}_{\text{SOP},N} \end{bmatrix}$$

Dynamics Model:

$$\boldsymbol{x}(k+1) = \boldsymbol{\Phi}(k)\boldsymbol{x}(k) + \boldsymbol{\Gamma}(k)\boldsymbol{w}(k), \; \boldsymbol{w}(k) \sim \mathcal{N}\left[\mathbf{0}, \mathbf{Q}(k)\right]$$

Observation Model:

i) GPS Carrier Phase

$$\begin{aligned}\phi_G(t_R) = & \frac{1}{\lambda}\|\underline{\mathbf{r}(t_R)} - \mathbf{r}_{SV}(t_R - \delta t(t_R) - \delta t_{TOF})\| \\ & + \frac{c}{\lambda}[\underline{\delta t(t_R)} - \delta t_{SV}(t_R - \delta t(t_R))] + \underline{\gamma_G} \\ & + \epsilon_{iono}(t_R) + \epsilon_{tropo}(t_R) + \nu_{\phi_G}(t_R)\end{aligned}$$

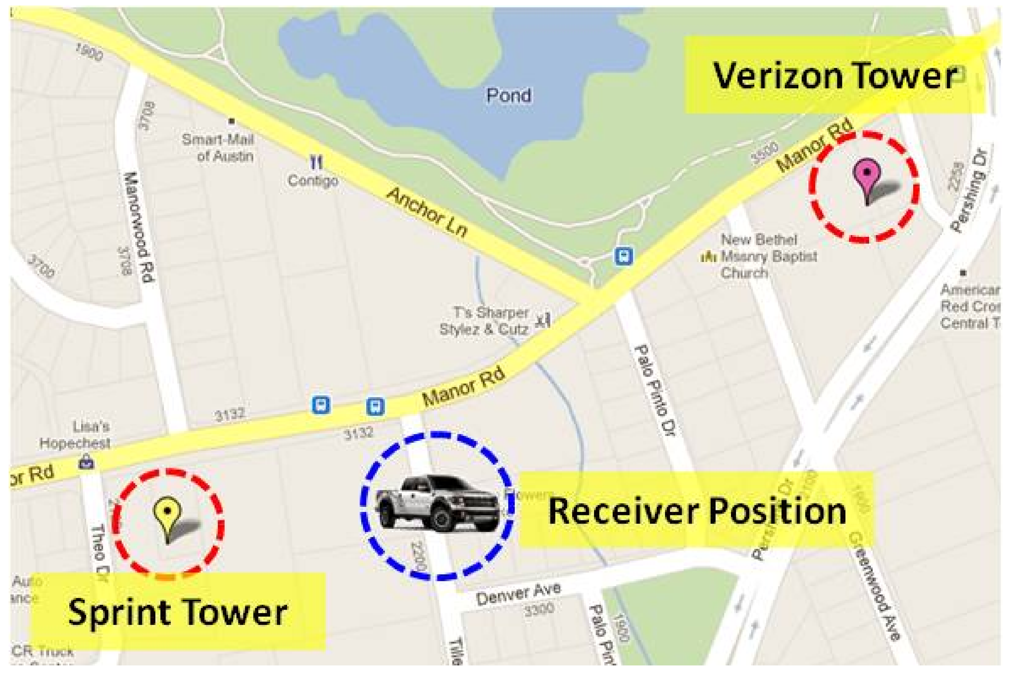
ii) CDMA Carrier Phase

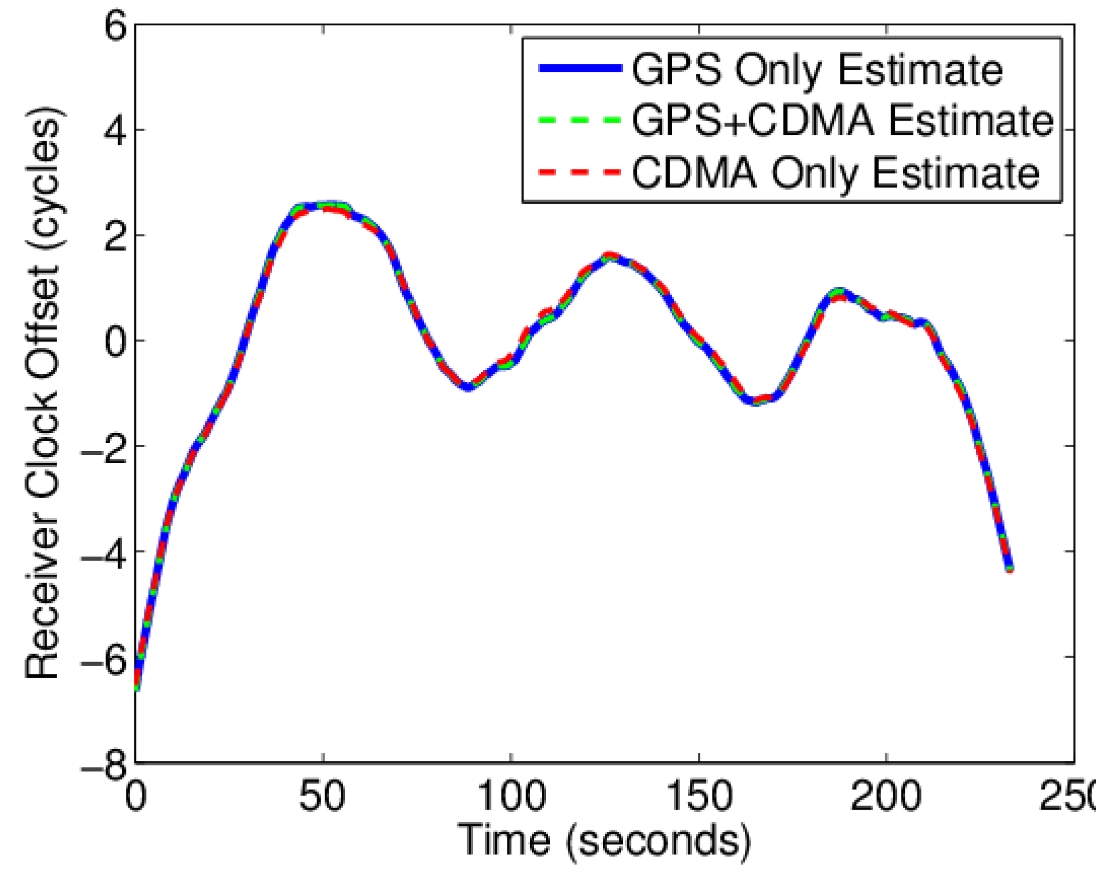
$$\begin{aligned}\phi_C(t_R) = & \frac{1}{\lambda}\|\underline{\mathbf{r}(t_R)} - \underline{\mathbf{r}_C}\| + \frac{c}{\lambda}[\underline{\delta t(t_R)} \\ & - \underline{\delta t_C(t_R - \delta t(t_R))}] + \underline{\gamma_C} + \nu_{\phi_C}(t_R)\end{aligned}$$

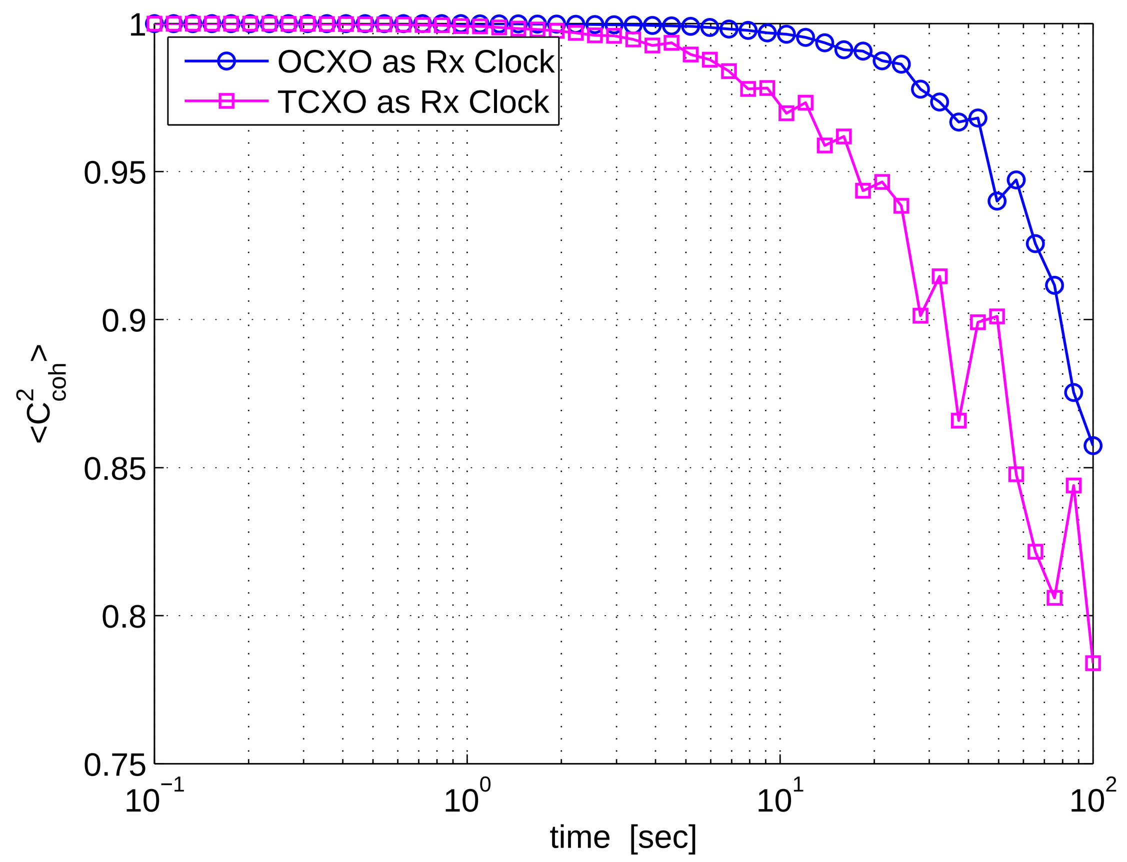
iii) Iridium Carrier Phase

$$\phi_I(t_R) = \begin{cases} \frac{1}{\lambda}\|\underline{\mathbf{r}(t_R)} - \mathbf{r}_I(t_R - \delta t(t_R) - \delta t_{TOF})\| \\ +\frac{c}{\lambda}[\underline{\delta t(t_R)} - \underline{\delta t_I(t_R - \delta t(t_R))}] + \underline{\gamma_I} \\ +\frac{1}{M}\underline{\eta(t_R - \delta t(t_R) - \delta t_{TOF})} + \epsilon_{iono}(t_R) \\ +\epsilon_{tropo}(t_R) + \nu_{\phi_I}(t_R), & \text{within a burst} \\ 0, & \text{between bursts} \end{cases}$$

Simple TCON Demo







$$\text{SNR}_{\text{PD}}(\tau) = \langle C^2_{\text{coh}}(\tau)\rangle \cdot \tau \cdot C/N_0.$$

Example: $\tau = 100$s, $\text{SNR}_{\text{PD}}(\tau) = 11$dB
$\Rightarrow C^2_{\text{coh}}(\tau) \approx 0.8$ and $C/N_0 = -8$dB-Hz

References

[1] K. Pesyna, Z.M. Kassas, J. Bhatti, T. Humphreys. "Tightly-Coupled Opportunistic Navigation for Deep Urban and Indoor Positioning," *ION 2011*