Assessment of Positioning Accuracy for Cooperative Intelligent Transport Systems

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What Positioning Performance is Really Required

GM TESTS V2V TECHNOLOGY IN SAFETY PROGRAM

nd receive information such
llisions and congestion.

STANDING COUNCIL
ON TRANSPORT AND INFRASTRUCTURE

Policy Framework for Intelligent Transport Systems in Australia

Google driving to be driverless

Google's modified Toyota Prius uses an array of sensors to navigate public roads without a human driver. Other components, not shown, include a GPS receiver and an inertial motion sensor.

Laser-guided mapping
A rotating sensor with lasers called a LIDAR on the roof scans more than 200 feet in all directions to generate a precise three-dimensional map of the car's surroundings.

Position estimator
A sensor mounted on the left rear wheel measures small movements made by the car and helps to accurately locate its position on the map.

Video camera

such as pedestrians and bicyclists.

Radar
Four standard automotive radar sensors, three in front and one in the rear, help determine the positions of distant objects.

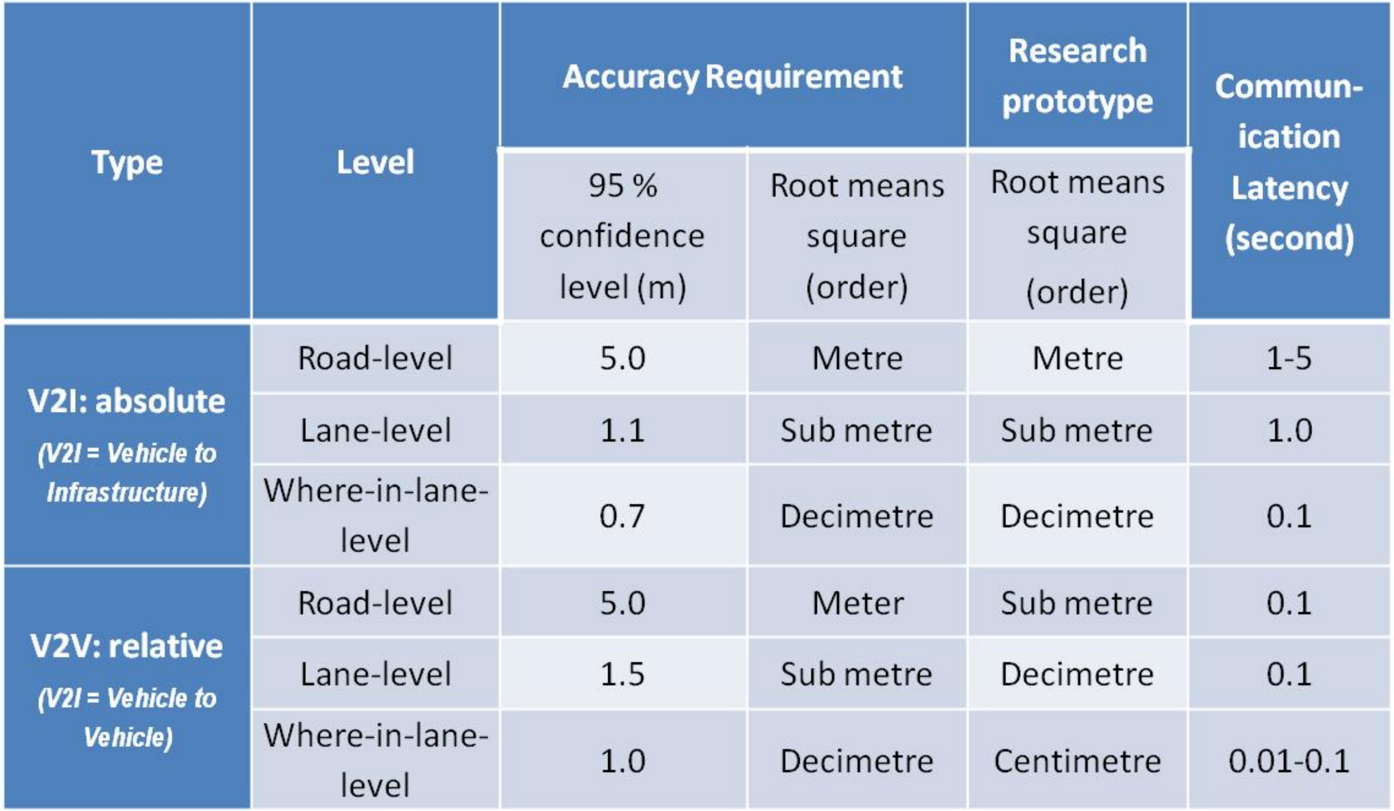
Source: Google

NEW YORK TIMES; PHOTOGRAPHS BY RAMIN RAHIMIAN FOR THE NEW YORK TIMES

6. **Digital Mapping and Positioning:** Different types of cooperative ITS application require different levels of accuracy from positioning technologies and on-board digital maps. It is probable that current GPS alone could not deliver the degree of accuracy required for more stringent cooperative systems. However, if used in conjunction with other methods, sufficient accuracy could be attained.

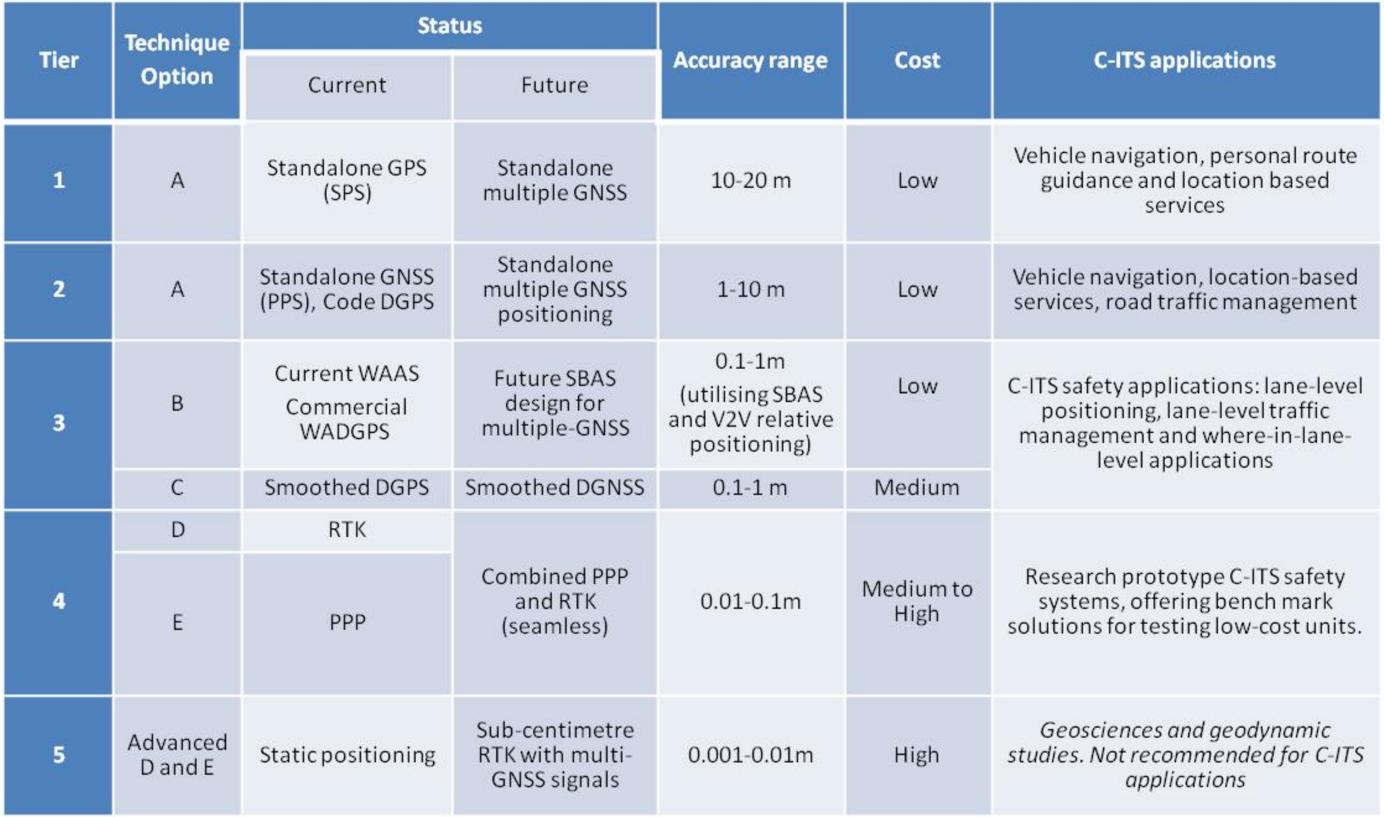
Availability Accuracy Integrity Timeliness

What Positioning Performance is Really Required



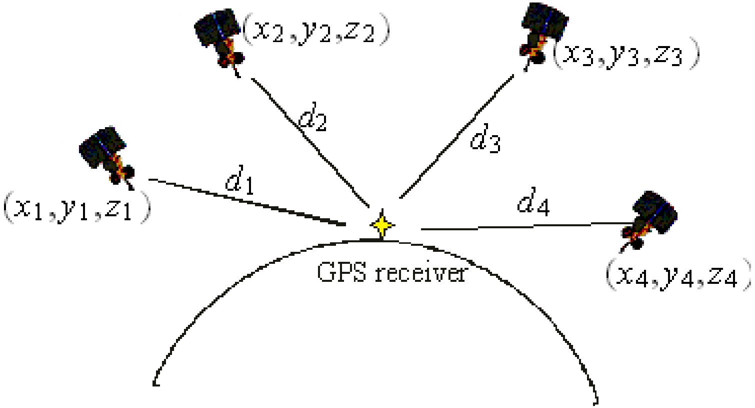
Type	Level	Accuracy Requirement		Research prototype	Commun-ication Latency (second)
		95 % confidence level (m)	Root means square (order)	Root means square (order)	
V2I: absolute *(V2I = Vehicle to Infrastructure)*	Road-level	5.0	Metre	Metre	1-5
	Lane-level	1.1	Sub metre	Sub metre	1.0
	Where-in-lane-level	0.7	Decimetre	Decimetre	0.1
V2V: relative *(V2I = Vehicle to Vehicle)*	Road-level	5.0	Meter	Sub metre	0.1
	Lane-level	1.5	Sub metre	Decimetre	0.1
	Where-in-lane-level	1.0	Decimetre	Centimetre	0.01-0.1

Is GPS the Answer?

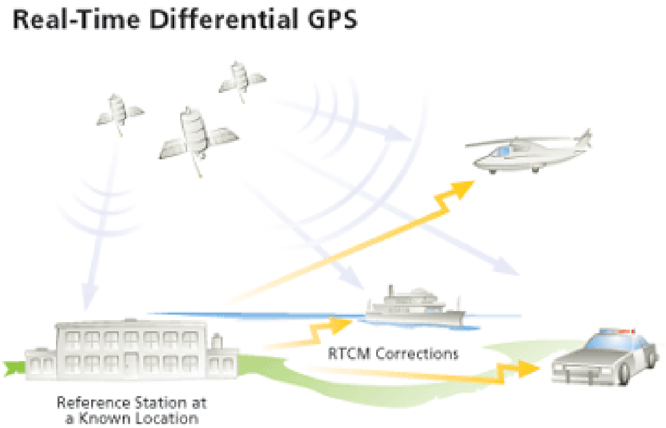


Tier	Technique Option	Status		Accuracy range	Cost	C-ITS applications
		Current	Future			
1	A	Standalone GPS (SPS)	Standalone multiple GNSS	10-20 m	Low	Vehicle navigation, personal route guidance and location based services
2	A	Standalone GNSS (PPS), Code DGPS	Standalone multiple GNSS positioning	1-10 m	Low	Vehicle navigation, location-based services, road traffic management
3	B	Current WAAS Commercial WADGPS	Future SBAS design for multiple-GNSS	0.1-1m (utilising SBAS and V2V relative positioning)	Low	C-ITS safety applications: lane-level positioning, lane-level traffic management and where-in-lane-level applications
	C	Smoothed DGPS	Smoothed DGNSS	0.1-1 m	Medium	
4	D	RTK	Combined PPP and RTK (seamless)	0.01-0.1m	Medium to High	Research prototype C-ITS safety systems, offering bench mark solutions for testing low-cost units.
	E	PPP				
5	Advanced D and E	Static positioning	Sub-centimetre RTK with multi-GNSS signals	0.001-0.01m	High	*Geosciences and geodynamic studies. Not recommended for C-ITS applications*

Standalone GPS



Differential GPS/Real Time Kinematic GPS




ENC 2013
The European Navigation Conference
April 23–25 Vienna, Austria

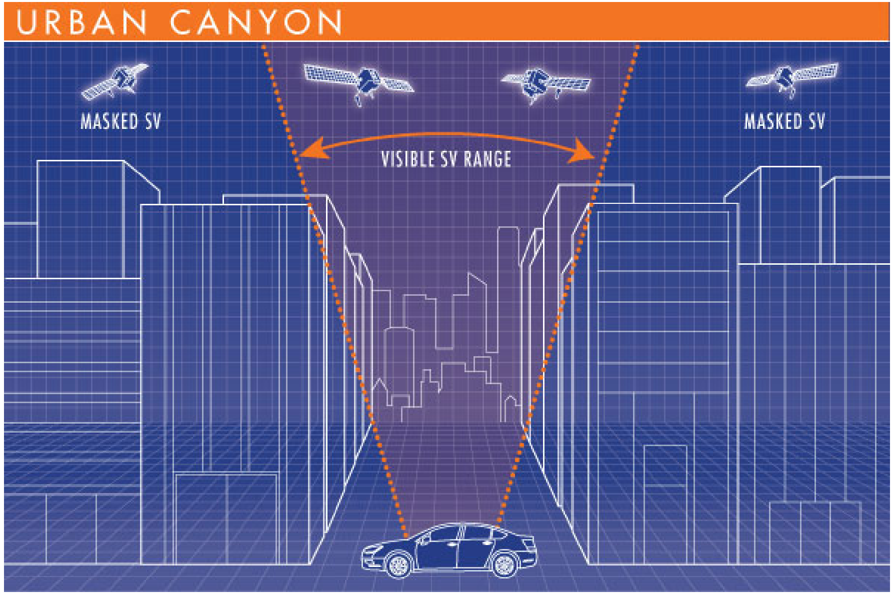
Network RTK for Intelligent Vehicles

by GPS World staff on January 30, 2013 with 0 Comments in Road

Accurate, Reliable, Available, Continuous Positioning for Cooperative Driving

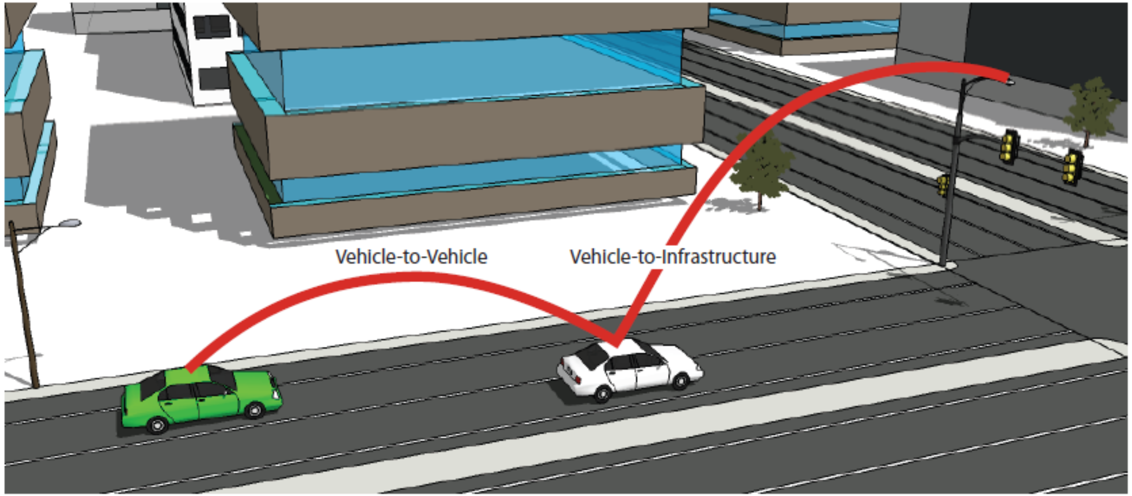
The Reality!

In many environments, such as tunnels, in built up urban areas, or in the presence of signal interference or spoofing, GNSS performance rapidly deteriorates. GNSSs *on their own* cannot therefore satisfy the “high performance positioning” needs of applications that are either liability-critical or life-critical.

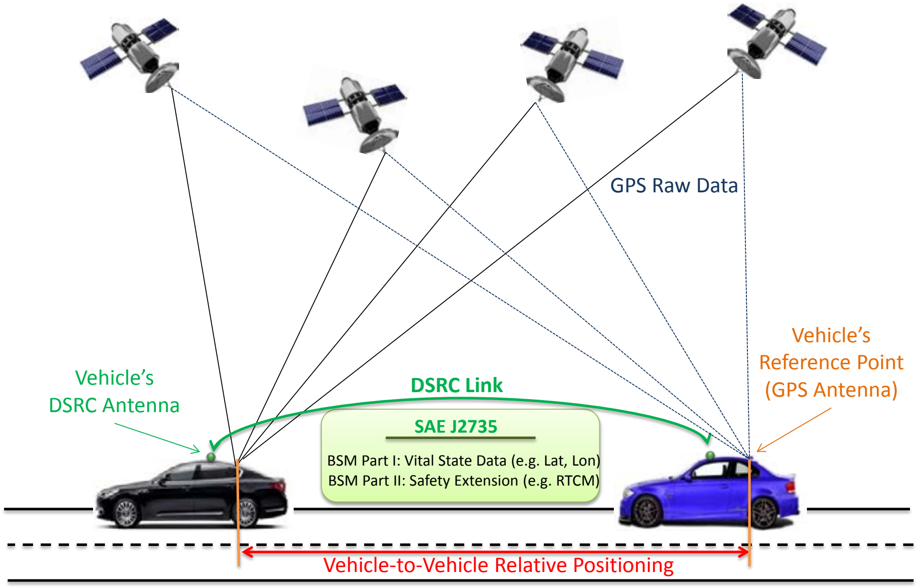


Enablers for C-ITS

It is the convergence of high performance positioning (HPP), communications and information technologies that will deliver the full promise of ITS.

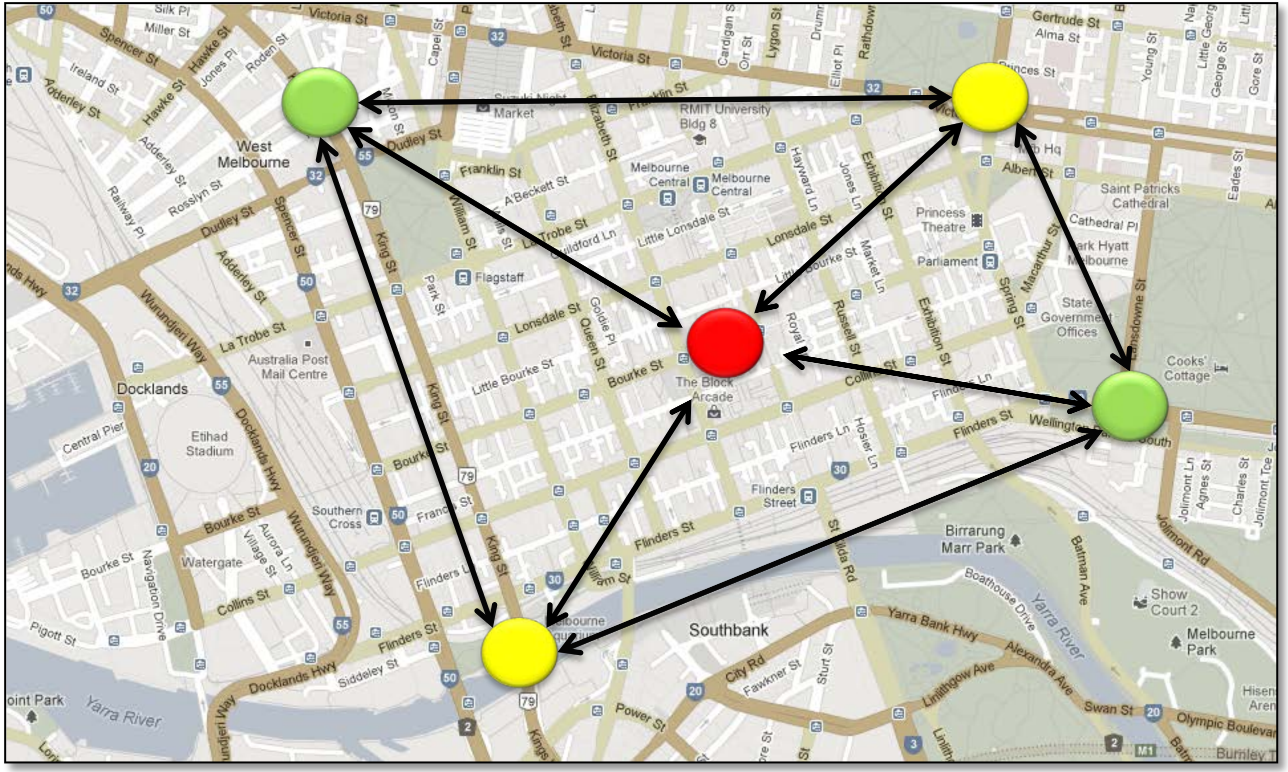


New Positioning Algorithms



- GNSS+
- Locata
- Multi Sensor Fusion
- Augmentation
- Collaborative Positioning
- Fitness for purpose

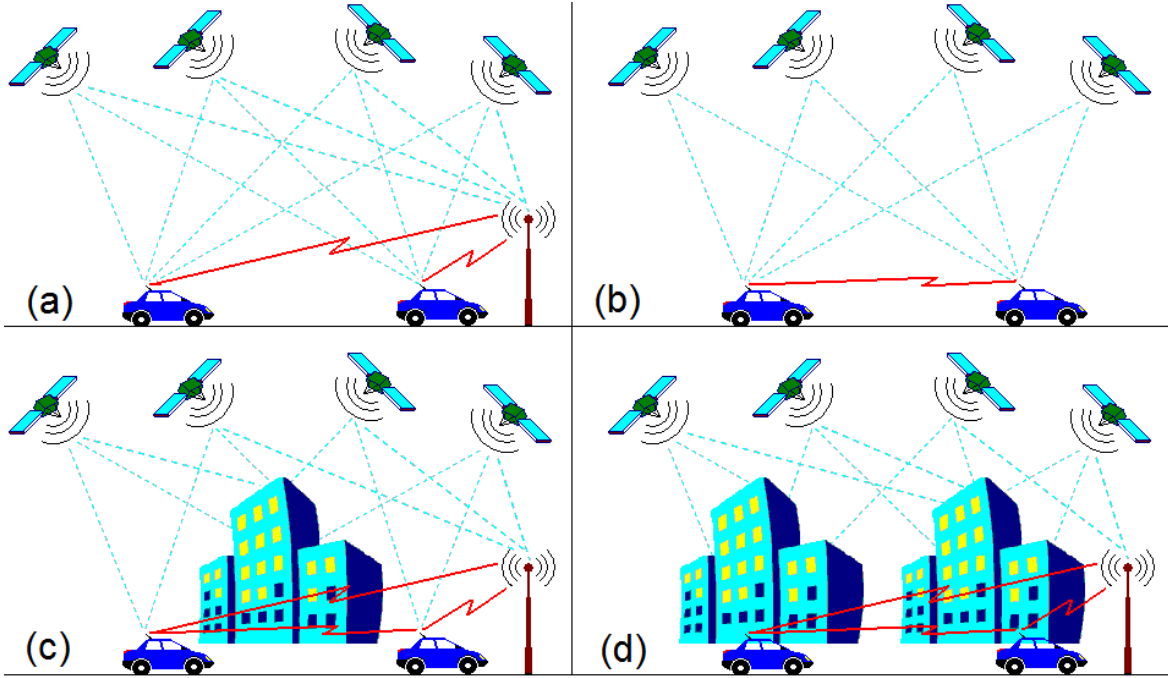
Concept of Cooperative Positioning



Dedicated Short Range Communication - DSRC

- Wireless communication for vehicle-vehicle (V-V) and vehicle-infrastructure (V-I)
- U.S. Federal Communication Commission (FCC) bandwidth of 75 MHz in the 5.850-5.925 GHz band
- European Telecommunications Standards Institute (ETSI) bandwidth of 30 MHz in the 5.9 GHz band.
- Applications includes intelligent transportation system (ITS), traffic management, safety and efficiency
- Low latency, high speed communication, strong and relative close proximity signals

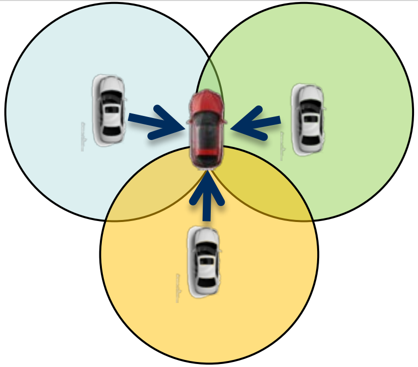
DSRC



Techniques: CP based on Radio Range

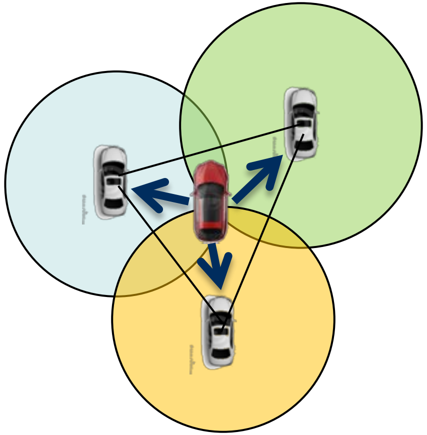
Time of Arrival (TOA)

- Measures the time flight of signal
- Requires accurate time synchronization
- Not viable, as its base protocol IEEE 802.11only accurate in order of micro-seconds whereas nano-seconds is needed

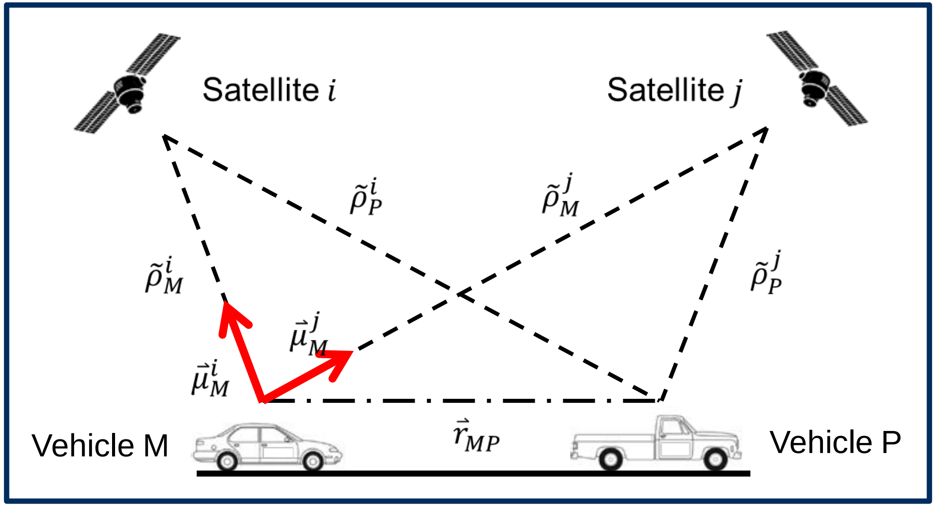


Time Difference of Arrival (TOA)

- Difference between the time the anchor nodes receive the transmitted signals from non-anchor nodes. Compute the difference of angles and use known baselines between anchor nodes to compute ranges to the non-anchor node.
- Severe effect of multipath can cause overlapping cross-correlation which makes time difference estimation not possible
- Can only be realised when two nodes are using the same bandwidth. This severely limits deployment in medium to high density VANET



Techniques: CP based on Non-Radio Range



- Code based double difference measurements
- Requires vehicles to observe common satellites
- Possibly susceptible in high multipath environments

Techniques: CP based on Range-Rate

- Based on Doppler shift between vehicles
- Less used due to the lower amount of location related information
- Calculated using the carrier frequencies of the vehicles
- Affected by DSRC’s clock drift
- Not affected by multipath as much as range based techniques
- Needs resolution of 100 Hz for 5.9 GHz frequency
- Only useful when relative mobility between vehicles is above the level of range-rate noise, which is usually not achievable when vehicles are travelling in the same direction

Algorithms for CP Enablement

Kalman Filter

- Optimal, in a minimum variance sense estimate of the state
- Used in applications such as localization and integrated systems

Monte Carlo Localization (MCL)

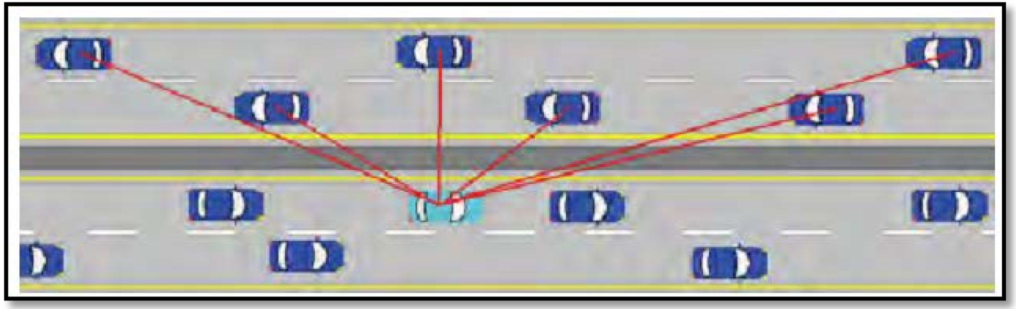
- Fast sampling technique to represent belief
- Able to represent multi-modal distribution and easy to implement

SPAWN

- Factor graph + sum product algorithm (SPA)
- Truly distributed algorithm, highly suitable for CP

CP based on range-rates

- Avoid complexities of radio based ranges
- GNSS positions and inter vehicle range-rates: loosely coupled
- Uses Doppler shift, which can only be effetely observed when vehicles are travelling in the opposite direction

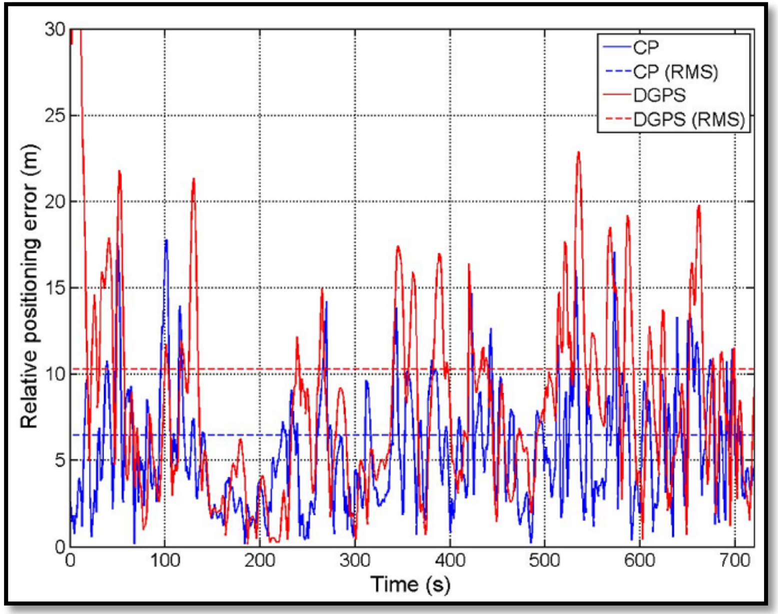


- Improved precision between 27% (7.2 m) and 47% (5.3 m) compared to standalone GNSS (10 m)

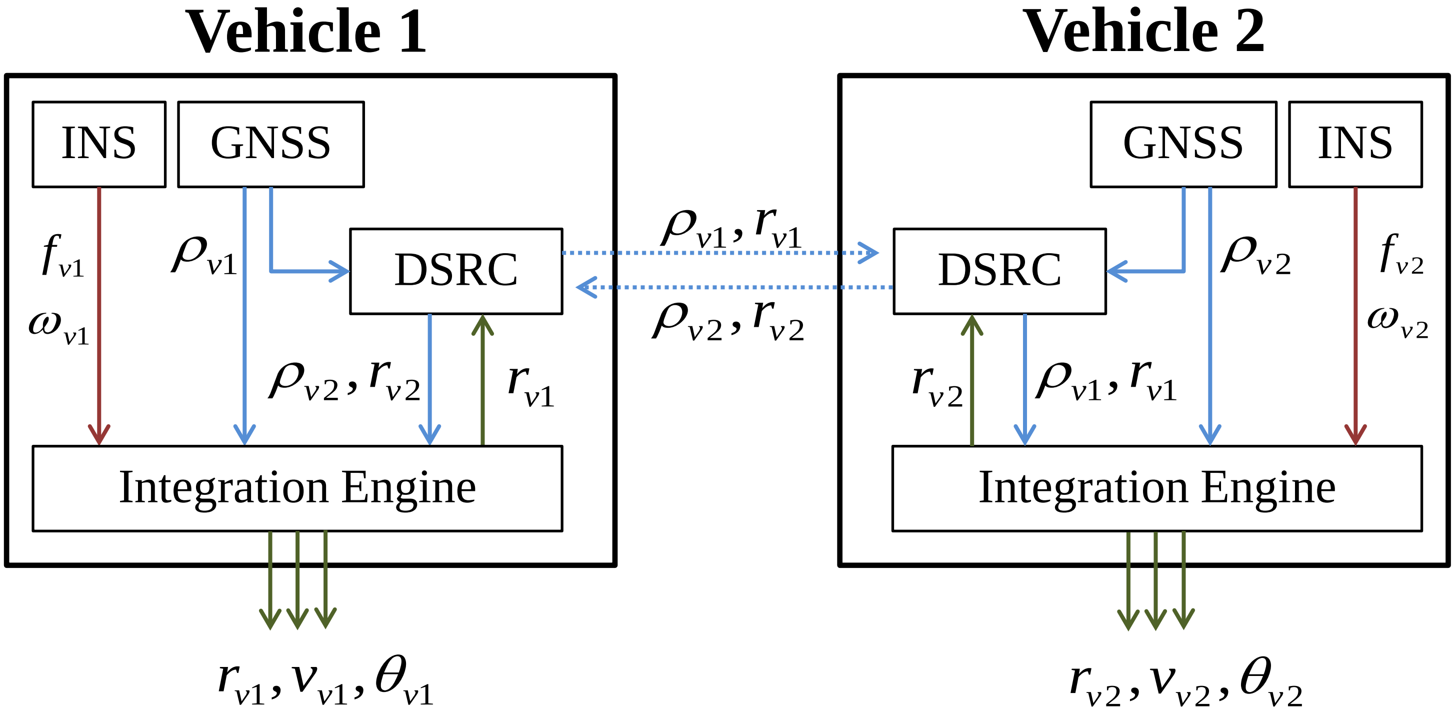
CP based on non-radio range

Relative Positioning in VANET

- Code based double difference better accuracy DGPS
- Eliminates fixed infrastructure
- Performance against DGPS
  - CRLB : 30%
  - RMSE : 37%
- Requires at least 4 common satellites



Innovative Algorithm



Vehicle 1

INS

GNSS

DSRC

Integration Engine

f_{v1} ω_{v1}

ρ_{v1}

ρ_{v2}, r_{v2}

r_{v1}

$r_{v1}, v_{v1}, \theta_{v1}$

ρ_{v1}, r_{v1}

ρ_{v2}, r_{v2}

Vehicle 2

GNSS

INS

DSRC

Integration Engine

ρ_{v2}

f_{v2} ω_{v2}

r_{v2}

ρ_{v1}, r_{v1}

$r_{v2}, v_{v2}, \theta_{v2}$

Innovative Algorithm

Measurements

Inertial Sensor

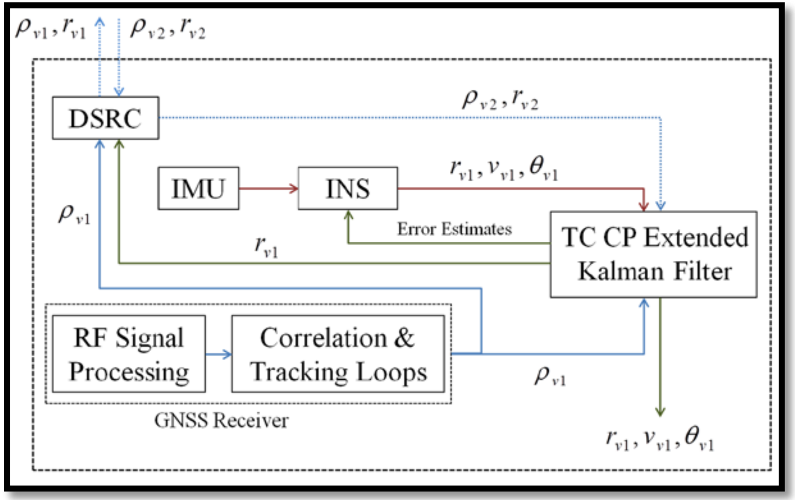
$$\dot{r}^e_{eb} = v^e_{eb} \qquad \dot{C}^e_b = C^e_b \Omega^b_{ib} - \Omega^e_{ie} C^e_b$$

GNSS

$$\tilde{\rho}^i = \rho(x, p^i) + E^i + c\delta t^i - c\delta T^i$$

Double Difference

$$\tilde{\rho}^{ij}_{MP} = \left[\vec{\mu}^i_M - \vec{\mu}^j_M\right]^T \vec{r}_{MP} + \nu^{ij}_{MP}$$



Current work by joint FIG and IAG WG

- Joint FIG WG 5.5 & IAG WG 1.1 – Ubiquitous Positioning
- Six Universities: UOM, UNSW, UON, NTUA, OSU, VU
- Website : http://www.ubpos.net

Collaborative Positioning Dataset Collection (1/2)

- University of Nottingham, 2012
- Collaborative Positioning: Indoor, Outdoor and transitions

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Collaborative Positioning Dataset Collection

- Introduction
- Techniques
  - Range
  - Range-Rate
  - Algorithms
- **Current Work**
  - Range-Rate
  - Non-Radio
  - Algorithm
  - **Dataset**
- Future Work
- Summary

Various Platforms

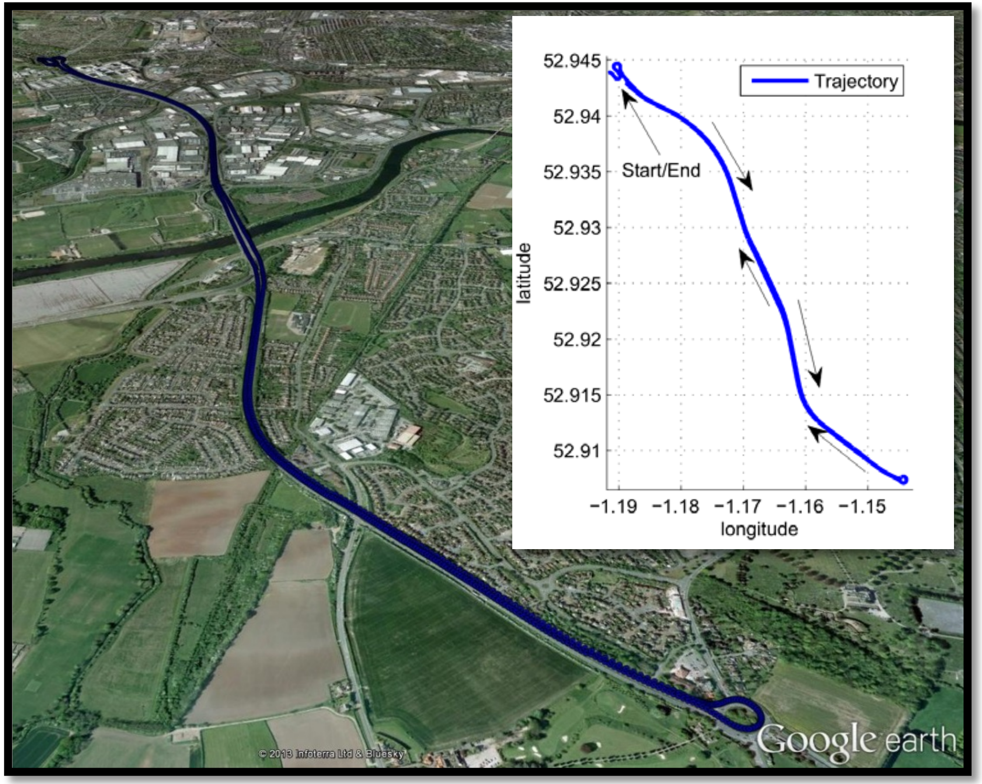
- Train
- Personal Navigator
- Mobile mapping vans

Multi sensor

- MEMS, Navigational INS
- High grade GNSS
- DSRC, UWB
- Camera
- Total Station

Collaborative Positioning Dataset Collection

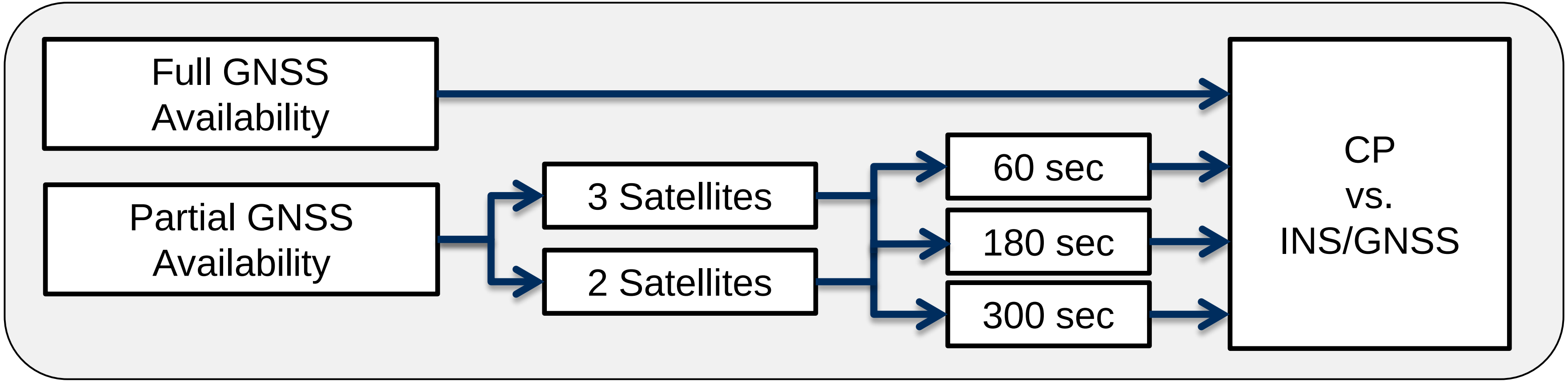
Trajectory	
Length	12 kms
Velocity	0 - 115 km/h
Time	16 minutes
GNSS availability	95 %



CP Dataset Collection - Equipment

Equipment	Vehicle 1	Vehicle 2
MEMS IMU	Xsens MTi-G	Xsens MTi-G
High grade IMU	Novatel SPAN IMU	Honeywell CIMU
GNSS receivers	Novatel SPAN	Leica GS10
DSRC	MK24 DSRC	MK24 DSRC

Analysis Methodology



Full GNSS Availability

Partial GNSS Availability

3 Satellites

2 Satellites

60 sec

180 sec

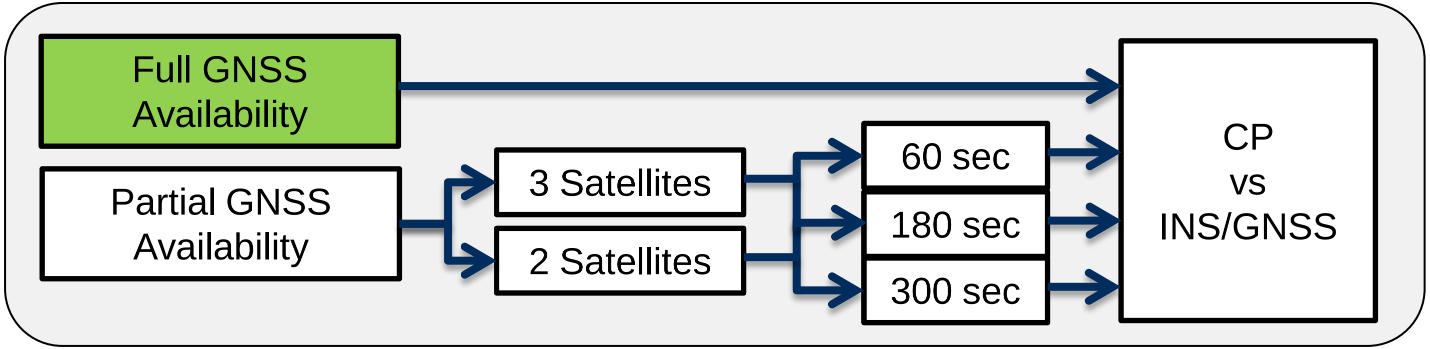
300 sec

CP
vs.
INS/GNSS

Improvement (%) of CP over INS/GNSS

$$= 100 \text{ x } 1 - \frac{RMSE_{CP}}{RMSE_{INS/GNSS}}$$

Results – Full GNSS Availability



Full GNSS Availability

Partial GNSS Availability

3 Satellites

2 Satellites

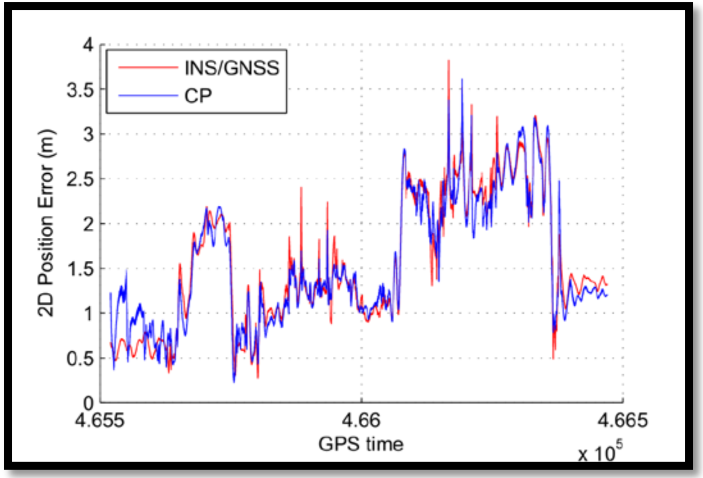
60 sec

180 sec

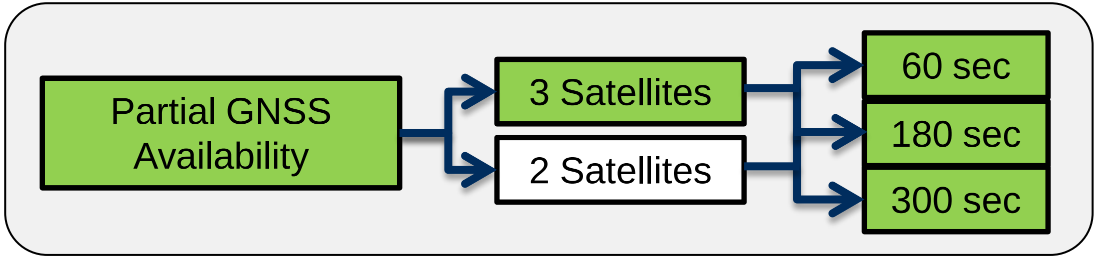
300 sec

CP
vs
INS/GNSS

2D	RMSE (m)	Max Error (m)
INS/GNSS	1.55	3.83
CP	1.54	3.61
Improvement	**0.50 %**	**5.56 %**



Results – Partial GNSS Availability



Partial GNSS Availability

3 Satellites

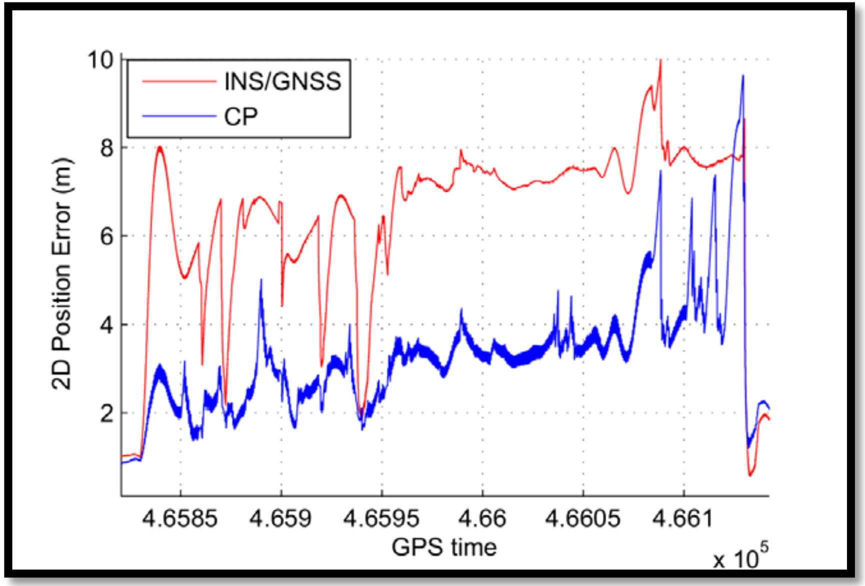
2 Satellites

60 sec

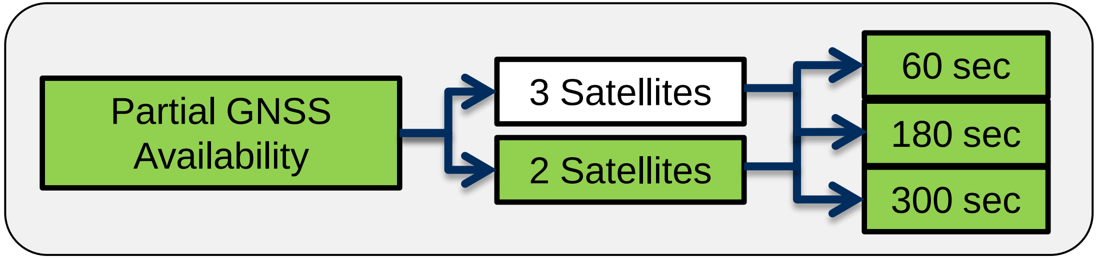
180 sec

300 sec

2D	3 Satellites	RMSE (m)	Max Error (m)
60 Seconds	INS/GNSS	5.66	8.02
	CP	2.23	5.00
	Improvement	**60 %**	**37 %**
180 Seconds	INS/GNSS	6.12	8.02
	CP	2.73	5.01
	Improvement	**55 %**	**37 %**
300 Seconds	INS/GNSS	6.74	9.99
	CP	3.36	9.63
	Improvement	**50 %**	**3 %**



Results – Partial GNSS Availability



Partial GNSS Availability

3 Satellites

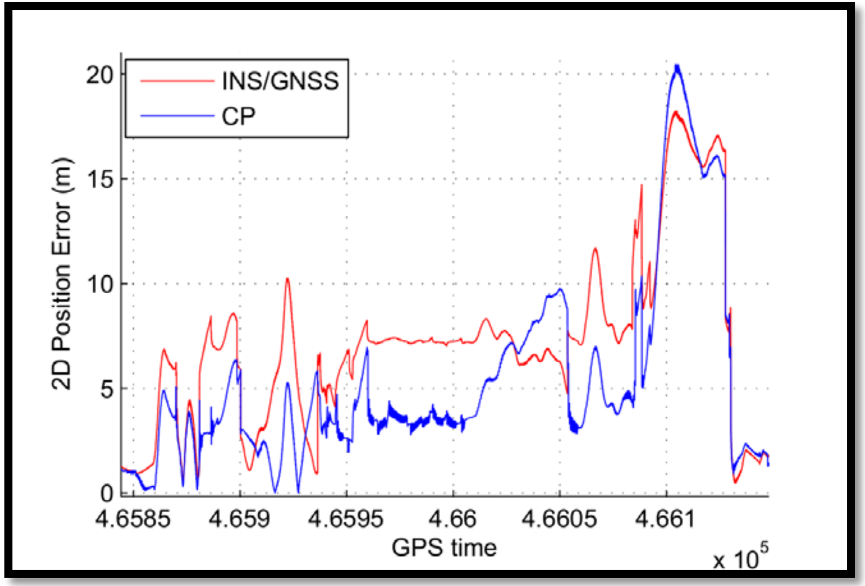
2 Satellites

60 sec

180 sec

300 sec

2D	3 Satellites	RMSE (m)	Max Error (m)
60 Seconds	INS/GNSS	3.14	8.44
	CP	1.87	5.09
	Improvement	**40 %**	**39 %**
180 Seconds	INS/GNSS	5.12	10.27
	CP	2.88	6.94
	Improvement	**43 %**	**32 %**
300 Seconds	INS/GNSS	7.15	18.21
	CP	5.40	20.43
	Improvement	**24 %**	**-12.31 %**



Future Work

General aim: Improve DSRC observations, smarter algorithms, incorporating other types of sensors

- Hybrid of radio and non-radio range based CP
- Incorporating other sensors such as vision based system
- Improve dynamic modelling and integration algorithms
- Incorporate map matching techniques such as Bayesian, fuzzy logic and set membership methods
- Investigate effects of scalability

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