Precision Timing in Smart Cities

microPNT For Autonomous Vehicles

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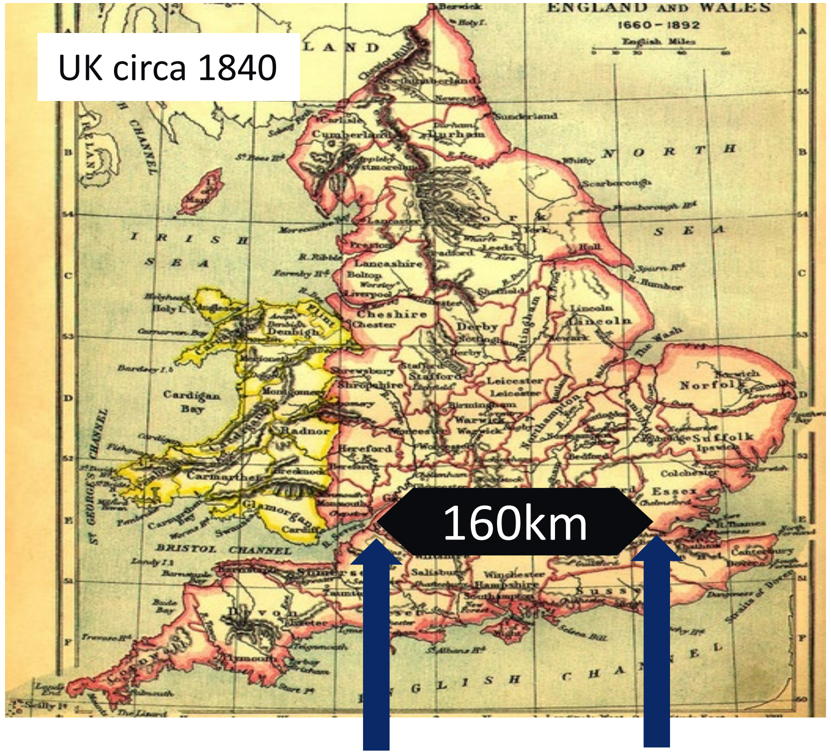
Navigation Safety Is Based On Precise Time: Understood Since the Mid 1800's



Bristol:10.50am London:11am
(relative to local midday sun)

In the early 1800s time keeping errors caused frequent train collisions.

A 10 minute time error at 60 kph equates to +/- 10 km location uncertainty for both trains.

Royal Commission investigation (1849):

Both trains should not have been in the same place at the same time.

In our words :

The cause was poor clock synchronization.

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Position Requirements & Awareness

Navigation Norm today: +/- 5 m fuzzy location / 10's of seconds
HAV requirement: +/-2 cm "continual absolute" location / < 100ms

Distance Travelled / Vehicle Speed more elastic (inaccurate) as vehicle speed increases

Speed Kph	Meters Per Second	Meters Per 100 ms	centimeters per 10 ms
50	15	1.5	15
100	30	3	30

Positional Awareness and Processing Times *(NHTSA)*

Autonomy Level	Longitude Accuracy	Lateral Accuracy	Max Processing Latency
1	+/- 200 - 500 cm	+/- 100 - 200 cm	100 millisec
3 - 5	+/- 2 - 5 cm	+/- 2 - 5 cm	10 millisec

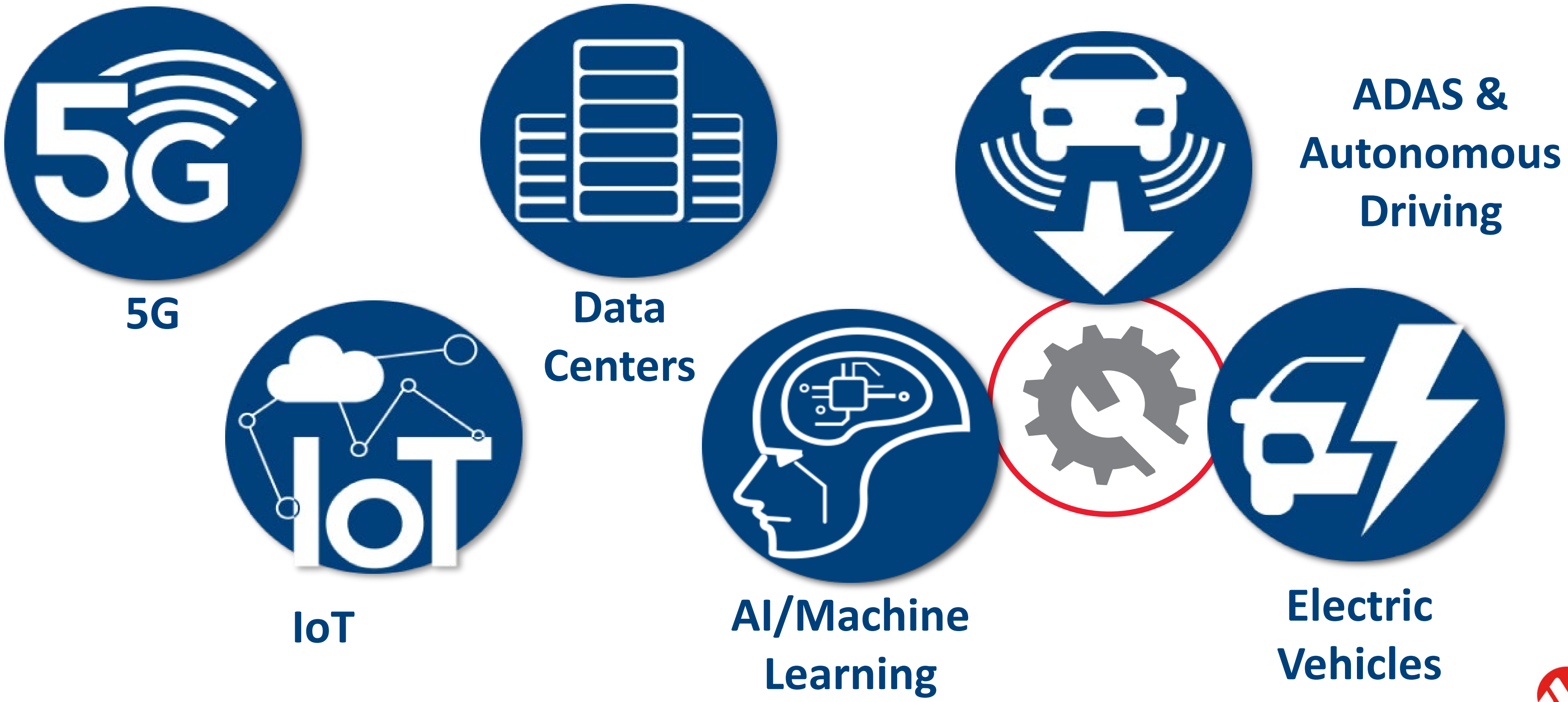
Note: Average driver reaction to hit brake = 2.3 seconds (IEA2000_ABS51. pdf)

Autonomous Driving in Smart Cities

How can we achieve 2-5cm accuracy, in real time, at normal driving speed?

In-vehicle intelligence & control with millions of powerful AI instances optimizing for trajectory and time!

This what we have now!



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Sophisticated Brains at Work……

Three Aspects to Vehicle Location and Timing

- **Timing and Clocks Inside Vehicles:**
  - Plethora of protocols/standards, many proprietary, TSN may eventually unify

- **On-Board Sensors: Position/Movement Relative to Neighbors**
  - To complement/replace GNSS information

- **Position, Navigation and Time (PNT) Relative to UTC**
  - Depends on satellite visibility and receiver integrity

These aspects are not yet well linked, In-Vehicle or Vehicle 2 Vehicle.
… and each takes significant computing effort

Navigation = Precise Location & Precise Time

Autonomous Driving will depend on precise time co-ordination to a common reference both between and inside vehicles

Critical Parameters

- **Relative Location:**
  - the location of a vehicle relative to adjacent vehicles
- **Relative time:**
  - the time used by a vehicle relative to the time used by adjacent vehicles

Simple Solutions

- **Easily solved with sensors…..**
- **Easily solved with GNSS……**

GNSS

- GNSS Problems
  - Weak signal / interference
  - Not always available
  - Tunnels
  - Parking garages
  - Urban canyons / skyscrapers
- Solutions
  - Even more sensors !
  - Real time maps & GPU/CPU intensive supplementary AI systems
  - Low Earth Orbit
  - Dedicated Short Range Comms (DSRC)
  - Signals Of Opportunity

In Vehicle Sensors

Sensor	Problems
RADAR	Lobe elasticity & strobing increases with speed, mutual interference
Map Matching + LIDAR	Database must be rapidly updated - requires precise location info from GNSS ! Heavily AI focused
Cameras	Inhibited by smoke, fog, precipitation
IMU	Rapidly inaccurate over short distances
SOP	***Comments***
LEO	*Generally same accessibility issues as GNSS*
DSRC	*Needs real time network access - (may have RF regulatory issues)*
Cellular, WiFi, TV	*May be useful for determining range or bearing.* *Coverage not ubiquitous, RF issues,*

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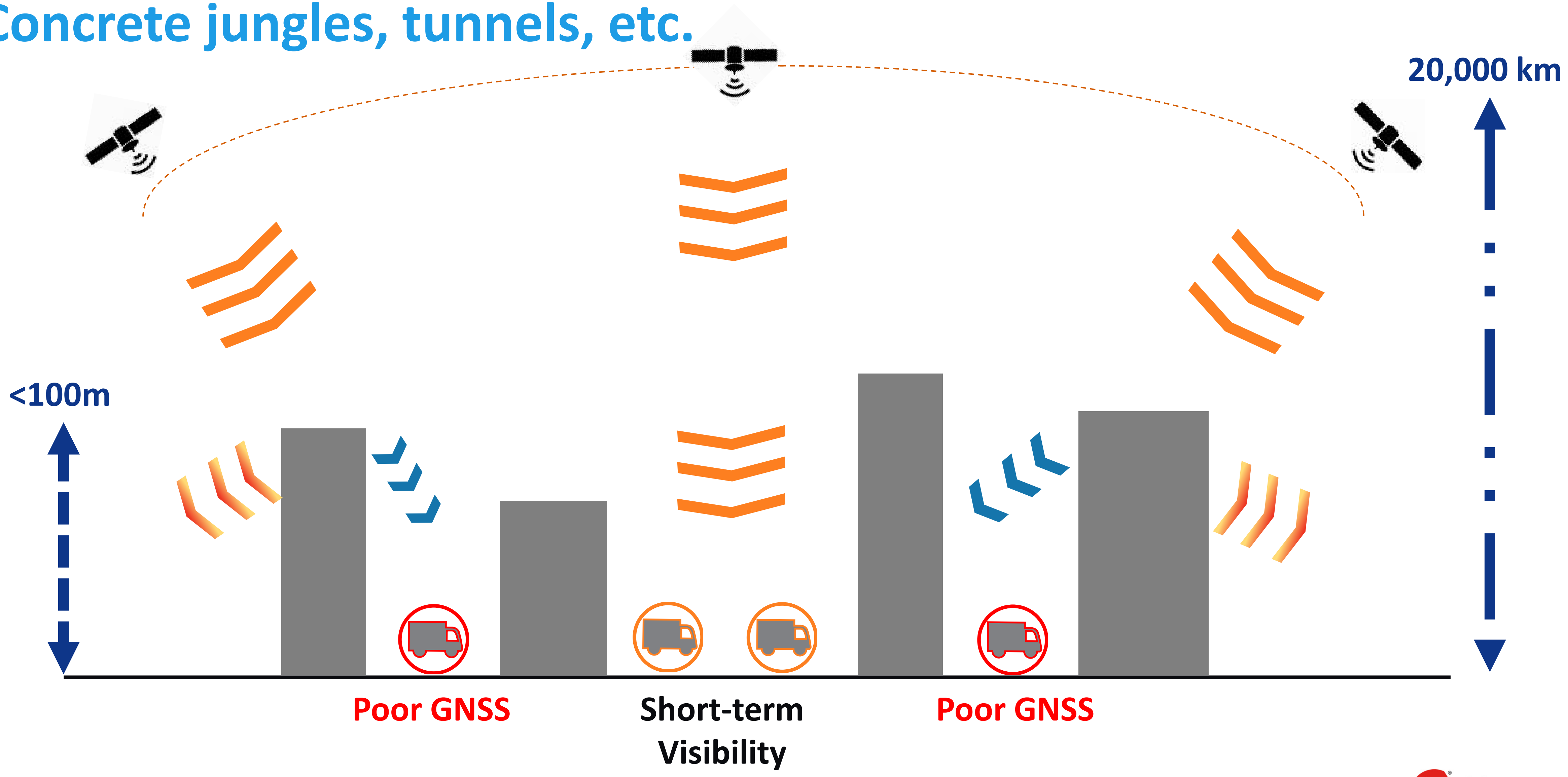
In-Vehicle Timing: Low Cost Oscillators

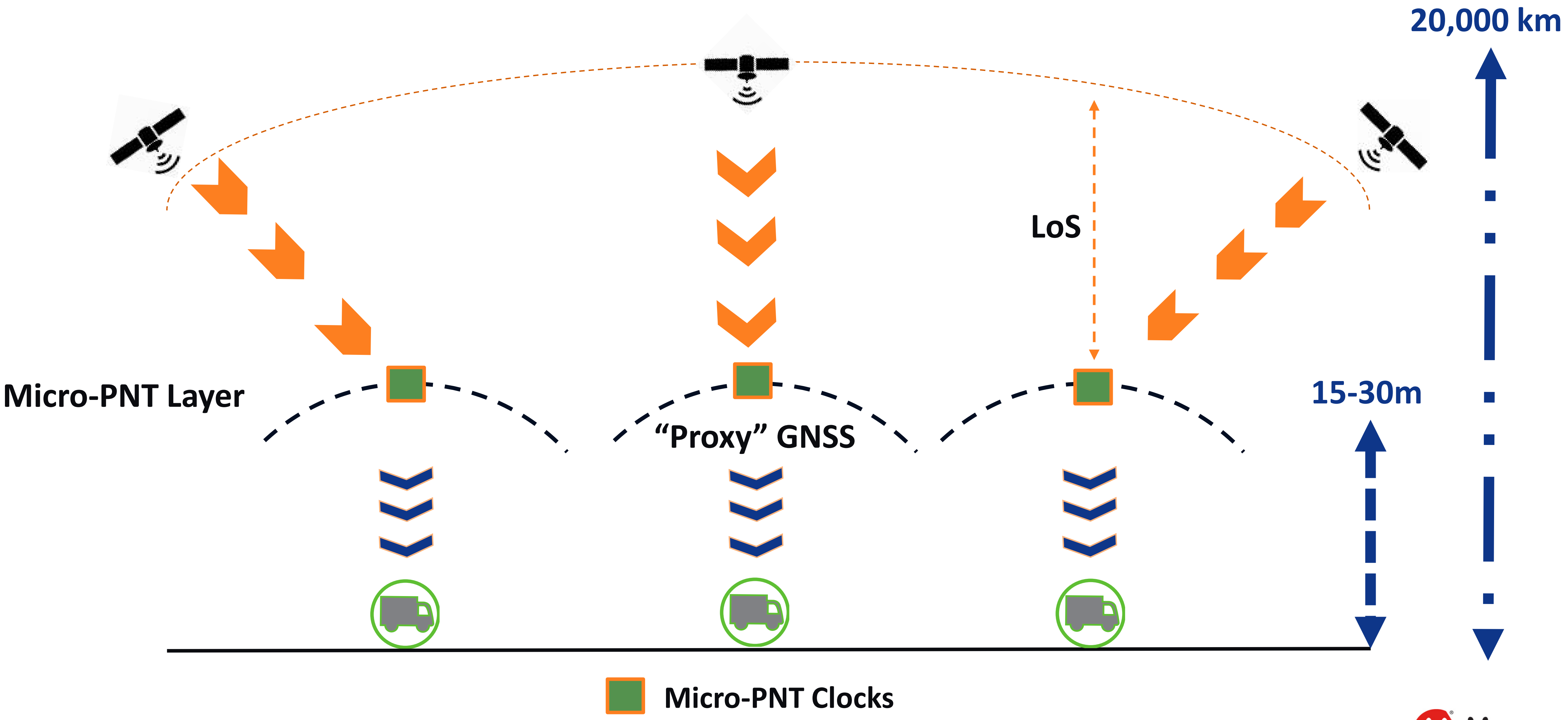
- **Many on-board timing requirements**
  - Critical: ECU, IMU, MCU, emergency braking
  - Non-Critical: Media
  - ***Navigation ?***
- **Many different In vehicle networks**
  - Linking control, sensors, mechanical systems, media etc.
- **Vehicles use low cost oscillators**
  - GNSS considered too unreliable
  - Clock quality depends on oscillator stability
  - GNSS considered too unreliable
- **Oscillators Drift**
  - Aging, short-term noise
  - Temperature variation
  - Supply voltage, shock, vibration…..
  - Initial frequency deviation - this will cause sharp drift in a short time on restart
  - ***No problem if vehicle timing is self contained***
- **Dilemma**
  - Problem for "situationally aware" systems
  - 1 autonomous vehicles cannot use on-board clocks that are drifting
  - 2 GNSS is not enough, convergence time, visibility

GNSS: The Urban Canyon Challenge

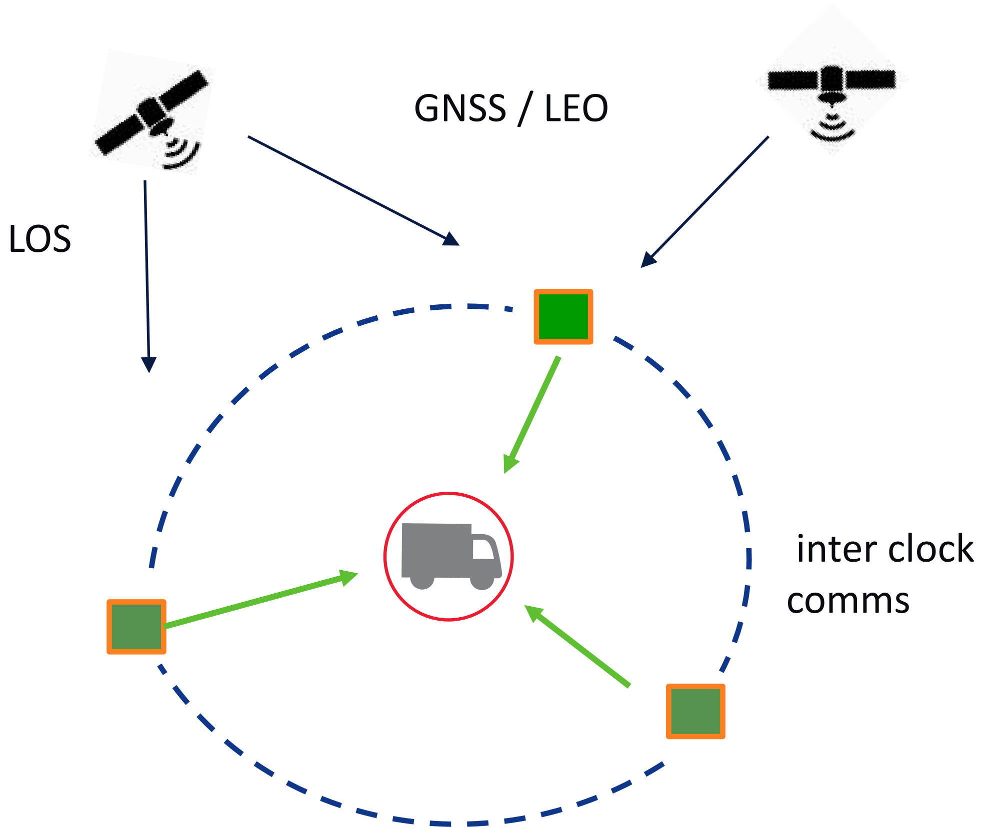
Concrete jungles, tunnels, etc.



Street-level Micro-PNT – a Smart City Solution



Micro-PNT Clock Mesh Creates MicroTimescales



mPNT Clock

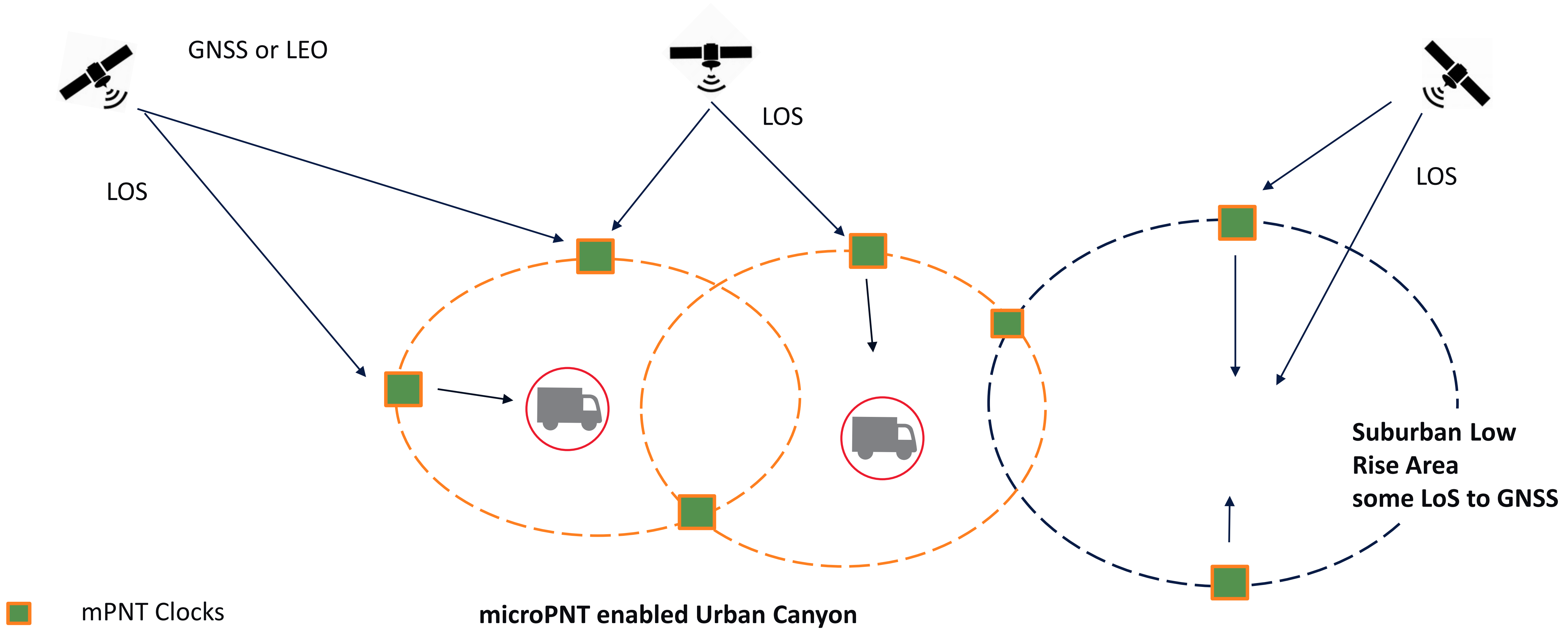
- GNSS Receiver
- Ultra-stable clock using Chip Scale Atomic Clock or HP OCXO
- Generic RF to vehicle (e.g. UWB)

In-Vehicle

- Generic low cost, low power transceiver to request/receive GNSS info from micro-PNT mesh

- Urban Canyon miniature timescale (meshed clocks) tied to UTC
- Extremely fast delivery of loc/time data to receiving vehicles

City Block “microTimescales” can mesh.



GNSS Enhancement & mPNT Compared

Method	Convergence	Receiver	Requires	Precision
microPNT	**Milliseconds**	**LoS to mPNT nodes**	**Dense mPNT network**	**< 5cm up to 200km/h**
RTK: Real Time Kinematics	> 30 mn	limited range **Needs LoS** to reference nodes	Calibrated reference nodes	1 cm – static 10cm @100kph
PPP: Precise Point Positioning	10 - 30 mn	**Needs LoS** to GNSS	Multi band receivers	10cm static 5m @ 100kph
SBAS Space Based Augmentation System	> 30 mn	**Needs LoS** to reference nodes & GNSS	Heavily calibrated reference nodes	20cm static 2m @100kph

What infrastructure is most suitable?

Scalable, fixed infrastructure, powered, new or retrofittable and close to vehicles …

Source: Signify

Smart City Micro-PNT

- **Bring GNSS closer to the vehicle**
  - Provides ubiquitous ultra precise location and traceable precise time with reference to UTC
  - Provide security and protection for existing GNSS/LEO signals

- **Creates highly distributed miniature "Timescales" that are difficult to disrupt**
  - Peer-to-peer exchange of timing info between City and Vehicle sensors in a localized system tied to UTC

- **Leverages Well Established Timing models**
  - Leverages high performance clocking systems e.g. Chip Scale Atomic Clocks & powerful compensation techniques and clocking algorithms derived from decades of experience - no need to reinvent the mapping or location wheel

- **Simple and low cost**
  - Easy to deploy at different densities by campuses towns, cities, freeways
  - Cheap enough to implement with any vehicle – cars, bikes, scooters, trains, trucks ...

Summary

- **Quasi or Fully Autonmous Vehicles of all kinds need smart timing solutions**
  - Mitigate GNSS Denial of Service from malicious activity and Urban Canyon that is increasingly complex and difficult to navigate
- **GNSS & Sensor solutions do not address the problem adequately**
  - too expensive, too complex, too slow, too unwieldy, too vehicle centric…
- **Vehicles, & people, need much tighter location data, much faster, at low cost,**
  - RARR "Rapid Access/Rapid Return" model, more nimble, more assured, more reliable,
- **Just as we engineered the Global Timescale using Satellite Systems, we now need to engineer the Smart City for the *Internet of Moving Things***
  - miniature Timescales based on scalable, economically viable micro-positioning technologies

Notions Discussed In This Presentation

- **Bringing reliable fast precise secure PNT into Urban Canyons**
  - Offloading cost of PNT from vehicle to Smart City
- **Tying autonomous vehicles to a global reference time (UTC)**
  - Unifying relative and absolute vehicle time/location
- **Ensembling micro-clocks to create miniature Timescales**
  - Flexible, localized, and tied to UTC
- **Complementing on board sensors with high availability PNT**
  - Offloading high intensity compute required by AI map matching

- ***Precise Timing enables "The Internet of Moving Things"***

Frequency and Time Systems

Thank You

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