Location! Location! Location! An Examination of Ultra Precise Positioning

A 5G PNT Implementation for Smart Cities

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Frequency and Time Systems

Team FTS

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Ultra Precise Position, Navigation, & Time (PNT)

- **This presentation reviews three RF candidates for Ultra Precise Positioning :**
  - 3GPP FR1 "sub 6" (410MHz – 7.125GHz)
  - 3GPP FR2 mmWave (24.25GHz – 52.6GHz)
  - IEEE 802.15.4a UWB Ultra Wide Band (3.1GHz – 10.6GHz)

GNSS suffers from “Not Spots” which impacts PNT

- Urban Canyon
  - cities, tunnels, mountainous areas, heavily foliaged areas.

- Jamming / Spoofing

- It is assumed that PNT nodes will be deployed in Urban Canyon environments to complement GNSS

  - It is too early to assess the impact of LEO as against MEO

Mobile Networks & Positioning

Accuracy & Error by Radio Generation: 5G NR Changes the Game

No significant use before LTE because considered too inaccurate compared to GNSS

	2G	3G	4G	5G
Position error	> 100 m	> 50 m	> 5 < 50 m	< 0.1 m
Orientation error	N/A	N/A	N/A	< 1 degree
Latency	> 1 s	> 1 s	> 1 s	< 10 ms

5GNR Release 16 & Release 17:

Many New Features That Enable Exploit Precise Positioning

Radio Co-ordination

- Dynamic Spectrum Sharing,
- Dual Connectivity
- Carrier Aggregation
- Discontinuous Transmission (DTX)
- Ultra-Reliable Low Latency Communication (URLLC)
- UE Power Control
- MIMO & Beamforming

New Functions/Deployment Scenarios

- Unlicensed Spectrum
- Integrated Access & Backhaul (IAB)
- Industrial Internet of Things (IIoT)
- Device to Device Communications
- Intelligent Transportation Systems (ITS)
- C-V2X Vehicle-to-Anything Comms
  - Side-link (PC5) Evolution
- Ultra Precise Positioning

MICROCHIP

A Note about C-V2X Vehicle to Anything Comms

Can Be Deployed on FR1 or FR2

- **Support for time synchronization**
  - Allows C-V2X without continual visibility of GNSS (AI important here)
  - Enables uniform communications across varying RF both LoS & N-LoS

- **Distance as a PNT dimension at the physical layer**
  - Enables formation of "on-the-fly" multicast groups based on distance.
  - Platoons can use HARQ, or a distance configuration between Tx & Rx

NR V2X Requirements: Autonomous Driving*
(SA1 TS22.186 & 5GAA white paper*)

Use Cases	E2E latency (ms)	Reliability (%)	Data rate (Mbps)
Platooning	10	99.99	65
Advanced driving	3	99.999	53
Extended sensors	3	99.999	1000
Remote Driving	5	99.999	UL:25 DL:1

	Latitudinal (m)	Longitudinal (m)
Positional Accuracy	**0.1**	**0.5**

For reference only

*5GAA Maxime Flamant 3GPP TSG RAN Meeting #84 Newport Beach, USA, June 3-6, 2019

Radio Signal Properties & Positioning

FR1, FR2, UWB

FR1 & Positioning Signals - Baseline

- Lot of C-V2X development has been based on FR1
  - C-V2X has shown +/- 20cm accuracy on 40MHz using PC5 (Sidelink) in limited trials
  - For C-V2X FR1 is the most obviously available infrastructure
- “rich” signal with high number of positioning-usable multipath components
- RF Propagation model well understood
- FR1 based anchor Navigation nodes (base stations) are ubiquitous, already deployed by operators and relatively low cost to light up with new software
- Being steadily densified with Small cell Applications

FR-1 & Positioning Signals - Challenges

- Low frequencies makes it difficult to get consistent measurement of positioning signal arrival at the target UE
- FR1 antenna paucity limits angular resolution of positioning signal - FR1 network is not sufficient (today) to cover all "Not Spots
- Slow rising edge on low frequencies makes Positioning signals interference-sensitive
- Clutter in the channel impulse response weakens the signal & damages positional integrity
- Reflection
  - Specular multipath impacts accuracy of measurement of the signal start / stop
  - Reflection also causes the signal to reverse & partially cancel out original signal
- Interference
  - modifies direct signals, causes variations that change signal time at injection into the radio frame
  - makes it hard to determine the time the signal crosses the threshold used to measure Time of Flight
- FR1 at lower frequencies without significant assist (C-v2x / HARQ) is non-optimal for ultra precise positioning

mmWave (FR2) Baseline

- Well defined fast rising edge & stop/start improves signal measurement
- High bandwidth, high frequency, fast signaling, low latency improves time-delay estimation with finer resolution enabling more accurate ToF / ToA measurements & lower absolute positional error (cm)
- Sparse channel with few multipath components making it easier to track and use for positioning
- Dense phase arrays with higher number of antennas enhances bandwidth effects
  - allows higher antenna gain & enables narrow beamforming with better SINR
  - improves accuracy of bearing / AoA, & positioning estimates
  - reduces interference,
- Orders of magnitude improvement in time-delay accuracy estimates compared to FR1

* Signal-to-Interference-plus-Noise Ratio

mmWave (FR2) Challenges

- Visibility highly dependent on propagation environment – humidity etc
- Beam Alignment / Beam Management can present challenges at mmWave frequencies as well as significant advantages
- Less multipath means signal is received from fewer directions - SNR may be insufficient to establish a link - losing beamforming benefits
- Limited RF reach requires high node density
- Deployment today is limited – economies of scale yet to be realized
- Not currently being deployed as UC complement for FR1
    - operators hoping that C-V2X on FR1 will be sufficient

* Signal-to-Interference-plus-Noise Ratio

Ultra Wide Band & Positioning Baseline

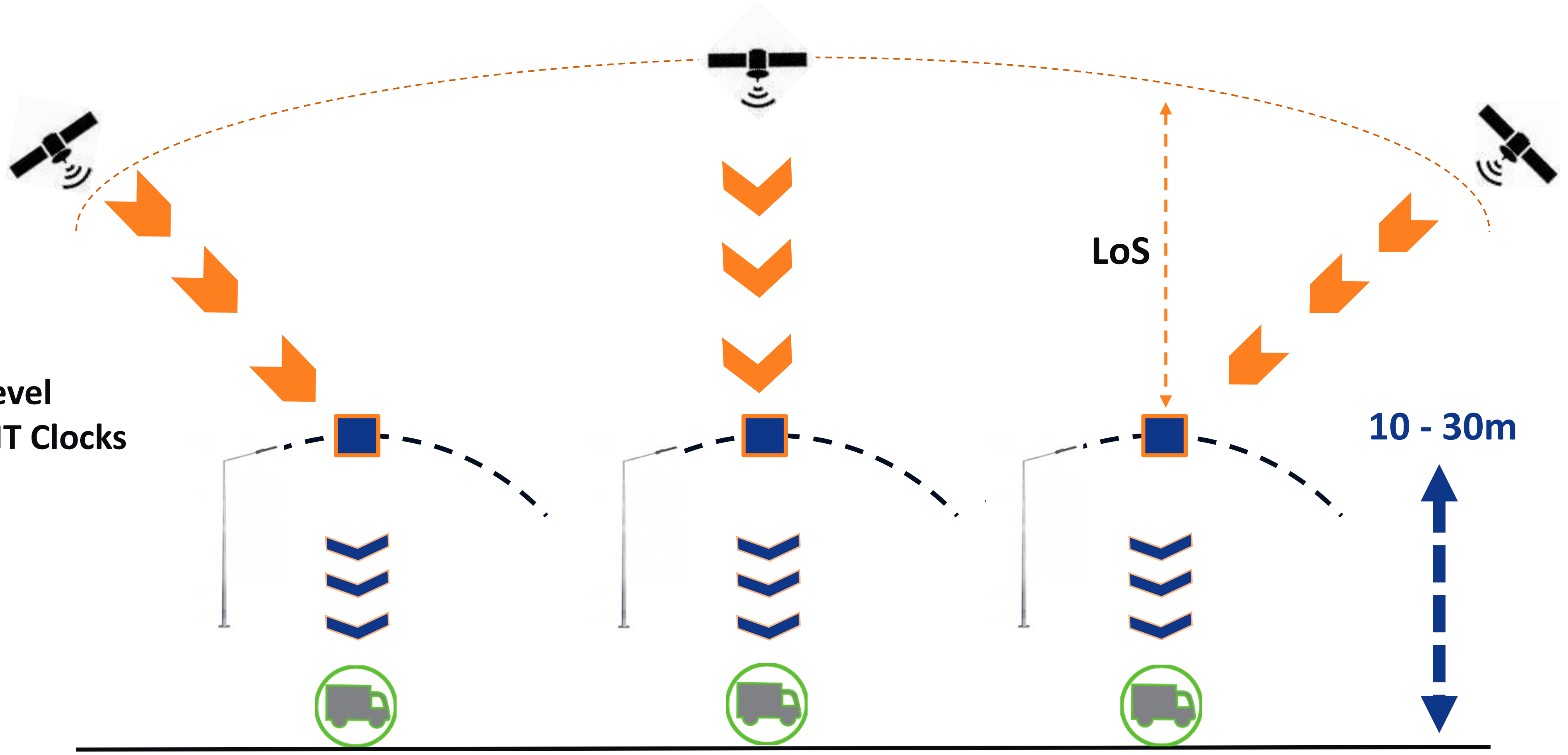
- Pulsed RF (2ns intervals) at C-Band frequencies
- Maintains integrity /structure in the presence of noise
  - Immune to multi-path effects and reflection
- Short bursts with sharp rises/drops, makes the signal start/stop inherently easier to measure.
- Can easily determine the threshold used to measure the ToF
- Distance between UWB devices can reach 5cm - 10cm accuracy as with FR2
- Short RF reach (as FR2) requires dense node deployment
- Not a 5G data plane – must be dedicated to PNT But because of this it can be treated as a clocking application directly combined with GNSS to allow correction of the anchor node coordinates and engineering of collaborative clock clusters
- Business model TBD – funded by Smart City ?

Deployment Scenarios for Urban Canyon

Dense Radio Deployment Complements GNSS

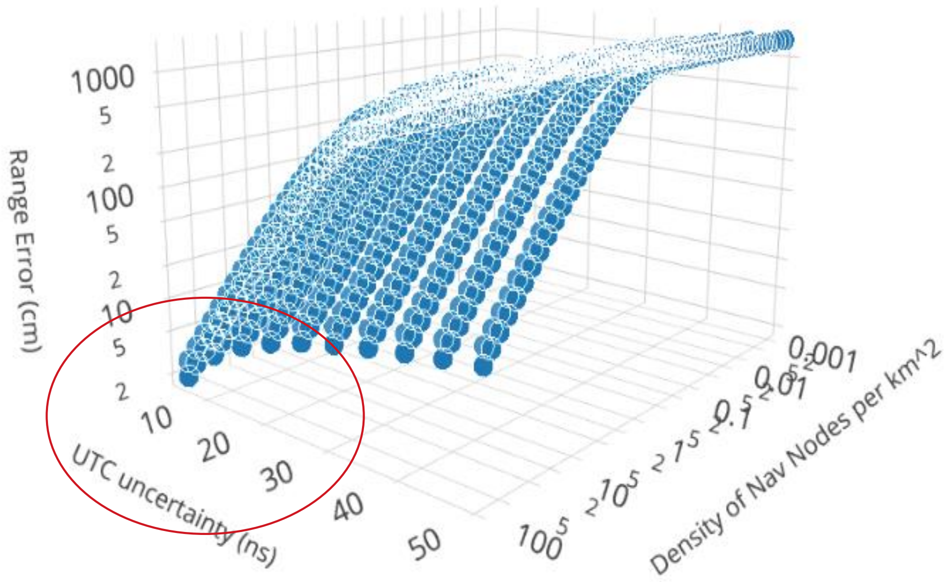
Micro PNT Can Be Deployed in GNSS “not spots” (Urban Canyon)

Street Level
microPNT Clocks

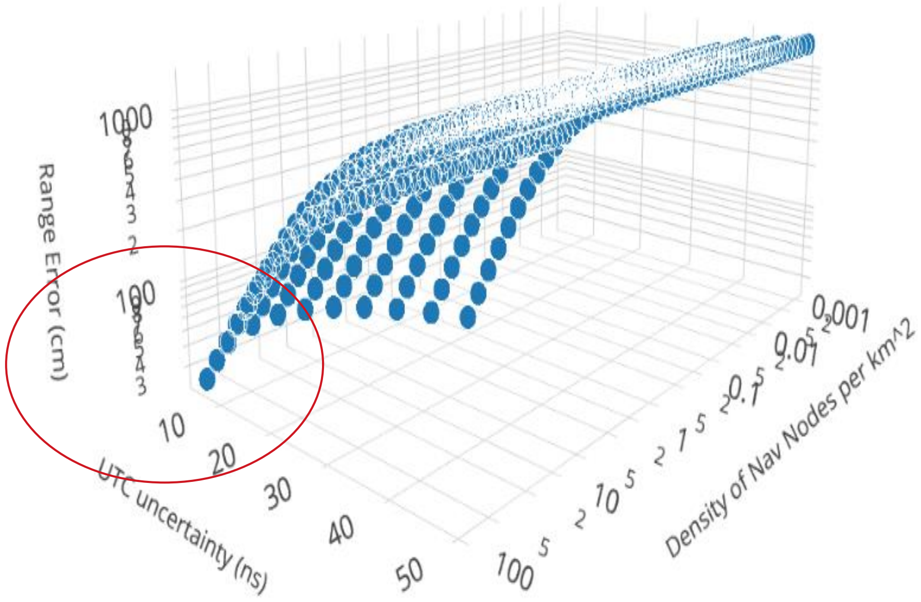


Navigation Node Density & Spatial Decorrelation

Simple model confirms that higher Navigation Node density = less ranging error relative to UTC and therefore less positional uncertainty



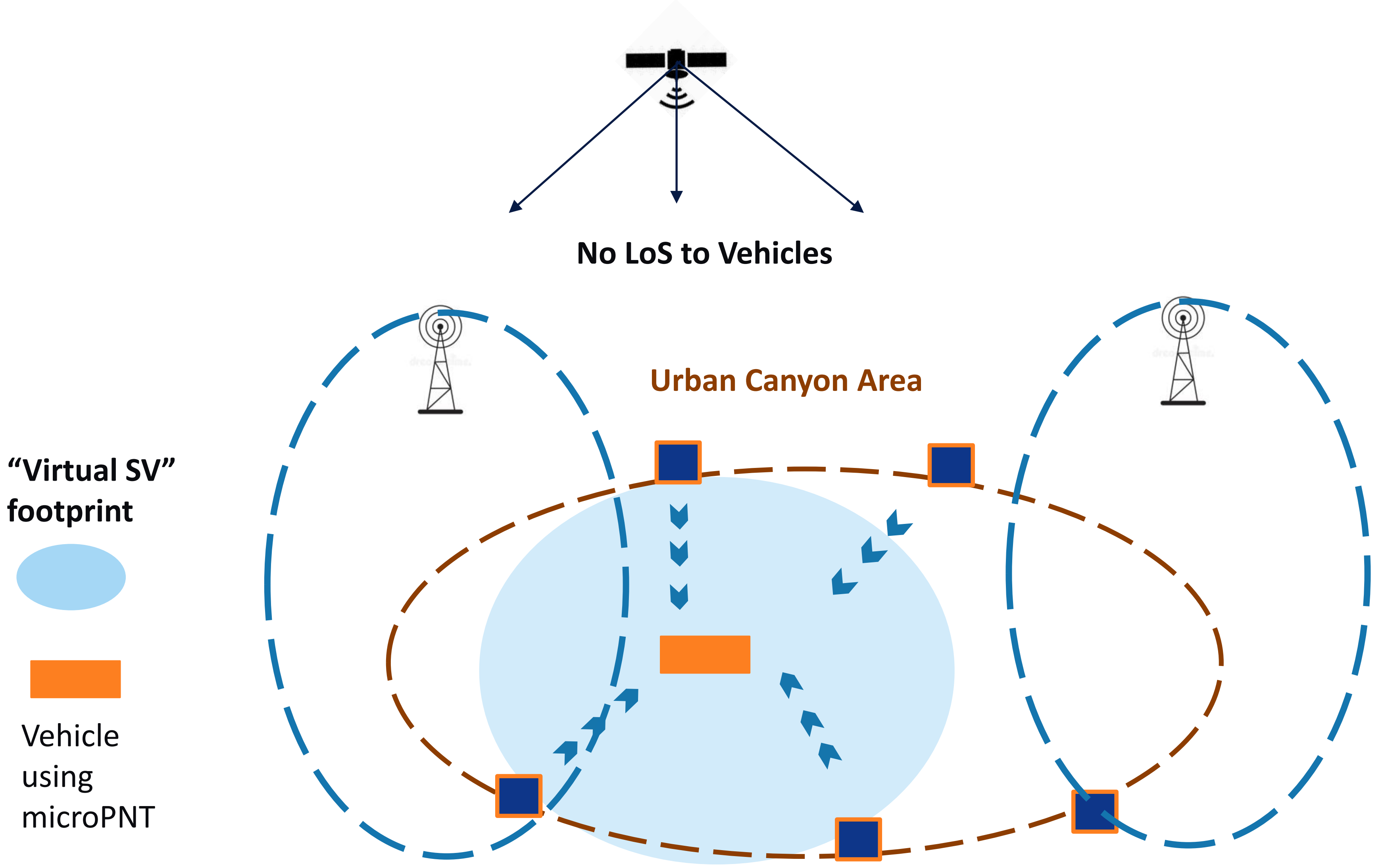
Ranging Performance: Open Sky GNSS



Ranging Performance: Degraded GNSS

FR1 & GNSS with microPNT Navigation Node Footprints

Complementary Navigation Nodes Are FR2 or UWB

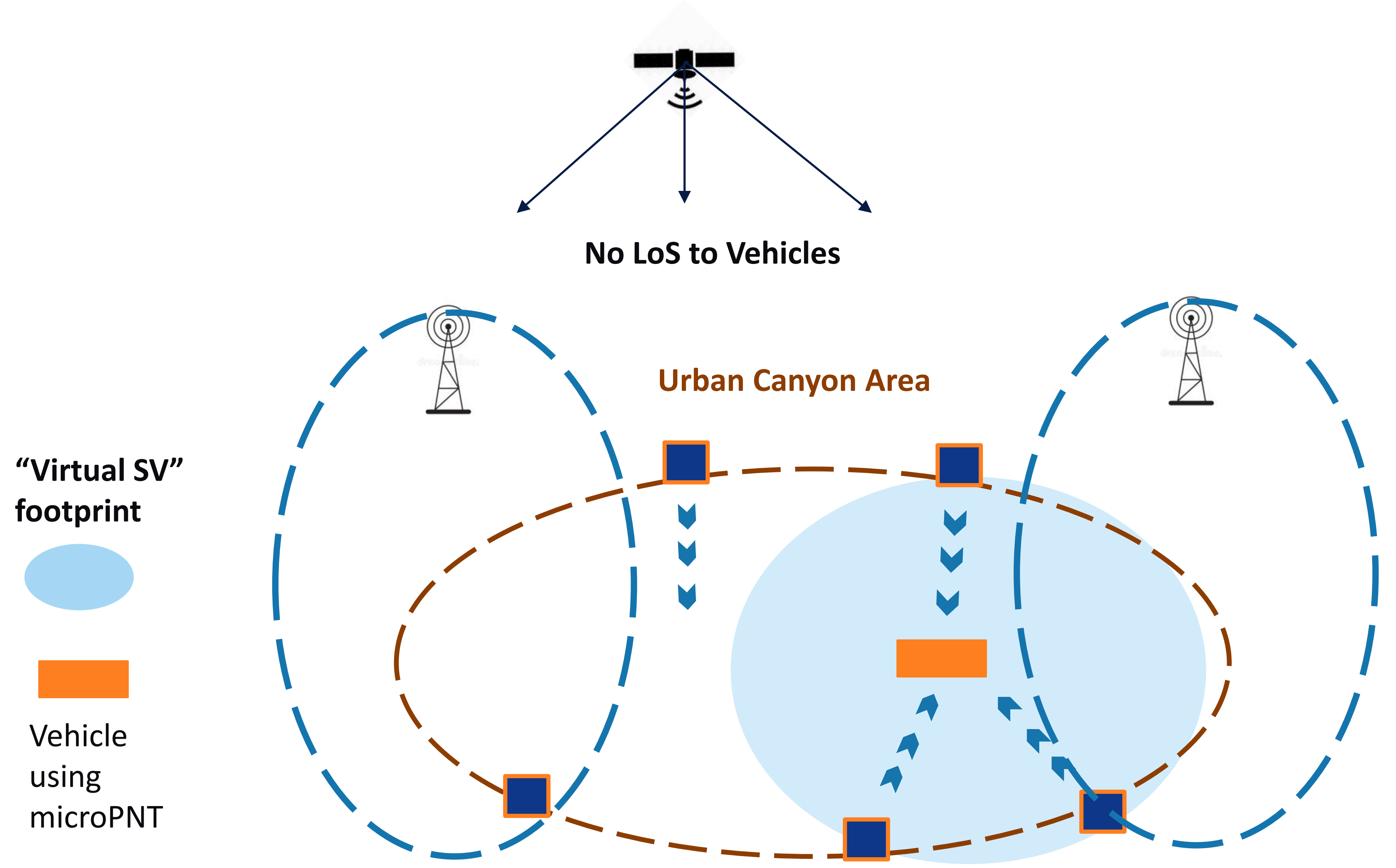


Mitigation of Time Error as AV traverses PNT cluster boundary. Signal precision is critical in determination of ToF, TDoA, AoA etc

Best as a system of "Collaborative Clocks" that present a "virtual SV" footprint in the Urban Canyon

Dynamic “virtual SV” Footprint Improves Availability

Enhances Signal Presence for Precise Positioning Functionality



“virtual SV” Moves with the target vehicle as it converges PNT information from the nodes in the clock cluster

Low spatial de-correlation radically improves Positional Awareness and Signal precision

Navigation Node Diversity: FR2, UWB

Dense PNT Required in Urban Canyon Ultra Precise Positioning

- **Navigation Node is improved by**
  - Anchor Node RF Diversity and Intersection of different RF signals
  - High-speed backhaul (e.g FR2) from UE to PNT Node
- **Time Error Mitigation**
  - Time Error is maximally constrained as UE crosses Cluster boundaries
  - Density minimizes Time Error and thus Positional Error
  - Fast accurate cleanly defined signal is better than a sloppy signal
- **UTC Traceability (GNSS) Absolute positional reference**
  - Ensures that TE between Nodes is closely correlated in time to maximize the common mode collaborate clock components between nodes in the Virtual SV

FR1 vs FR2 vs UWB

Comparisons With Respect to Positioning Applications

Given here for reference and not discussed in detail

NR RAT-Dependent Positioning (UWB added)

Based on TS 38.855 6.1 Scenarios for Positioning Evaluations

Scenario	FR1	FR2	UWB
Deployment	Sparse / macro	Dense Small Cell	Dense Small Cell
Indoor	Some	Open office (LoS)	Open office (LoS)
Urban Canyon UMi ISD 200m	Poor today C-V2X may improve	V Good (LoS)	V Good (LoS)
Outdoor UMa ISD 500m	Poor today C-V2X may improve	density required for Geofencing	density required for Geofencing
Owner	MSP / Operator	MSP / Operator	Smart City

Applications Mapped to RF Type

Application	Accuracy (cm)	GNSS	FR1	FR2	UWB
Indoor closed no LoS RU to UE	≤ 10	N	Possible (freq)	N	N
Indoor LoS RU to UE	≤ 5	N	Unusual	Y	Y
Geofenced campus / port / warehouse LoS RU to UE	≤ 5	N	Possible	Y	Y
Geofenced Urban Canyon bike/scooter lanes @ 25kmh	≤ 10	N	C-V2X	C-V2X	Y
Geofenced Open Freeway @ any speed	≤ 50 - 100	Y	C-V2X	C-V2X	Y

5GPPP applications require positioning accuracies from 1m to 5 cm.

Disturbance Impact & Feature Enhancement

Disturbance	FR1 “sub 6”	FR2 mwave	UWB
Interference	High impact	Low impact	Very low impact
Reflection	High impact	Low impact	Very low impact
Multipath	High impact	Low impact	Very low impact

Feature	FR1 “sub 6”	FR2 mwave	UWB
Dense antenna array	Minimal effect	Very high	No
Beamforming	Some effect	Very high	No
Density Required	Sparse	High	High

Optimal Radios – No Obvious “winner”

Functions	Optimum Radio
Positioning communication at very short timescales.	FR2 / UWB
Dedicated waveforms & accurate BA / beamforming	FR2 / UWB
Large angular separation between reference nodes.	FR1
Tracking multipath components	FR2
Radical Reduction of multipath component lifetime	FR2 /UWB
Positional component lifetime > 50m *(negative)*	FR1

Conclusion

All 3 Radios have advantages. Deployment models are key

- **FR1: operator owned / UE subscription model**
  - ubiquitous, well understood, sparse distribution but in the ground
  - inherent propagation challenges - C-V2X needed in target UE

- **FR2: operator owned / UE subscription model**
  - Much tighter positioning functions with or without C-V2X,
  - Requires high density deployment – not dedicated to PNT
  - Operator owned

- **UWB: Funding model undetermined - Smart City ownership**
  - Most resilient - Immune to spoofing/jamming, interference,
  - Requires high density deployment , can be a clocking infrastructure

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