

New 5ense

Improved Sensing and Positioning via 5G and mmWave radar for Airport Surveillance

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Outline

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- **3D Vector Antenna**
 - Principles of 3D VA
 - Preliminary results
- **Positioning and Sensing with in 5G Framework**
 - 5G Reference signals, the angle, delay estimation
 - Sensing (imaging) with 5G signal
 - Preliminary results
- **Sensing with mmWave Radar**
 - mmWave radar overview
 - Range and Doppler estimations
 - Usage of the Doppler for target/motion recognition
- **Conclusion and Future Work**

Background and Motivation

Socio-economic Factors

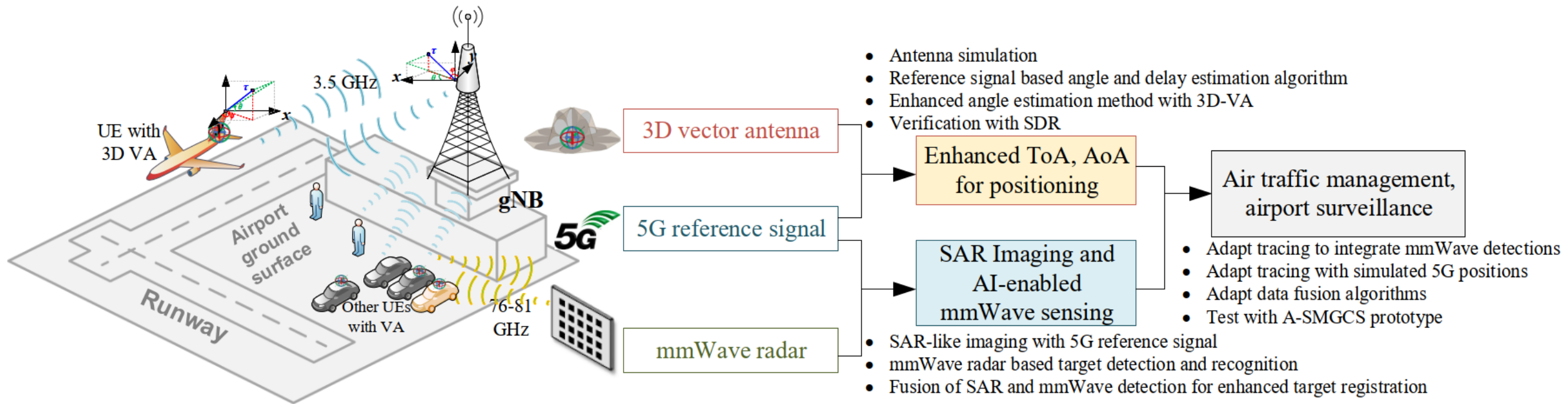
- Growth of the global air traffic
 - Low-cost carrier, regional airlines
 - Clogged primary airports
 - Streams to the secondary airports
 - lower landing fees, fuel costs, and shorter ground time
- Economic surveillance/monitoring solutions for the secondary airports

Technological Factors

- Advanced-Surface Movement Guidance and Control Systems (A-SMGCS) - **a platform consisting of different functionalities**
 - Surface movement radar (SMR), Multilateration (MLAT)
 - Large deployment, high cost, weather condition ...
 - Automatic Dependent Surveillance–Broadcast (ADS-B)
 - Cost efficient, low equipage rate
 - Camera, LiDAR
 - ...
- Rise of the private mobile (5G) network
 - Comparing with the virtual private network (VPN)
 - Dedicated spectrum and infrastructure, guaranteed service quality
 - Specialized services (e.g. positioning, low-latency)

Background and Motivation

NewSense Proposition



Before NewSense - SESAR ER3 ENVISION project (ADS-B, Video, LiDAR)

- Detection, tracking and recognizing all targets
- only identify cooperative targets (ADS-B)
- Enhanced tracking (ADS-B, LiDAR)
- Affordable (or not really)



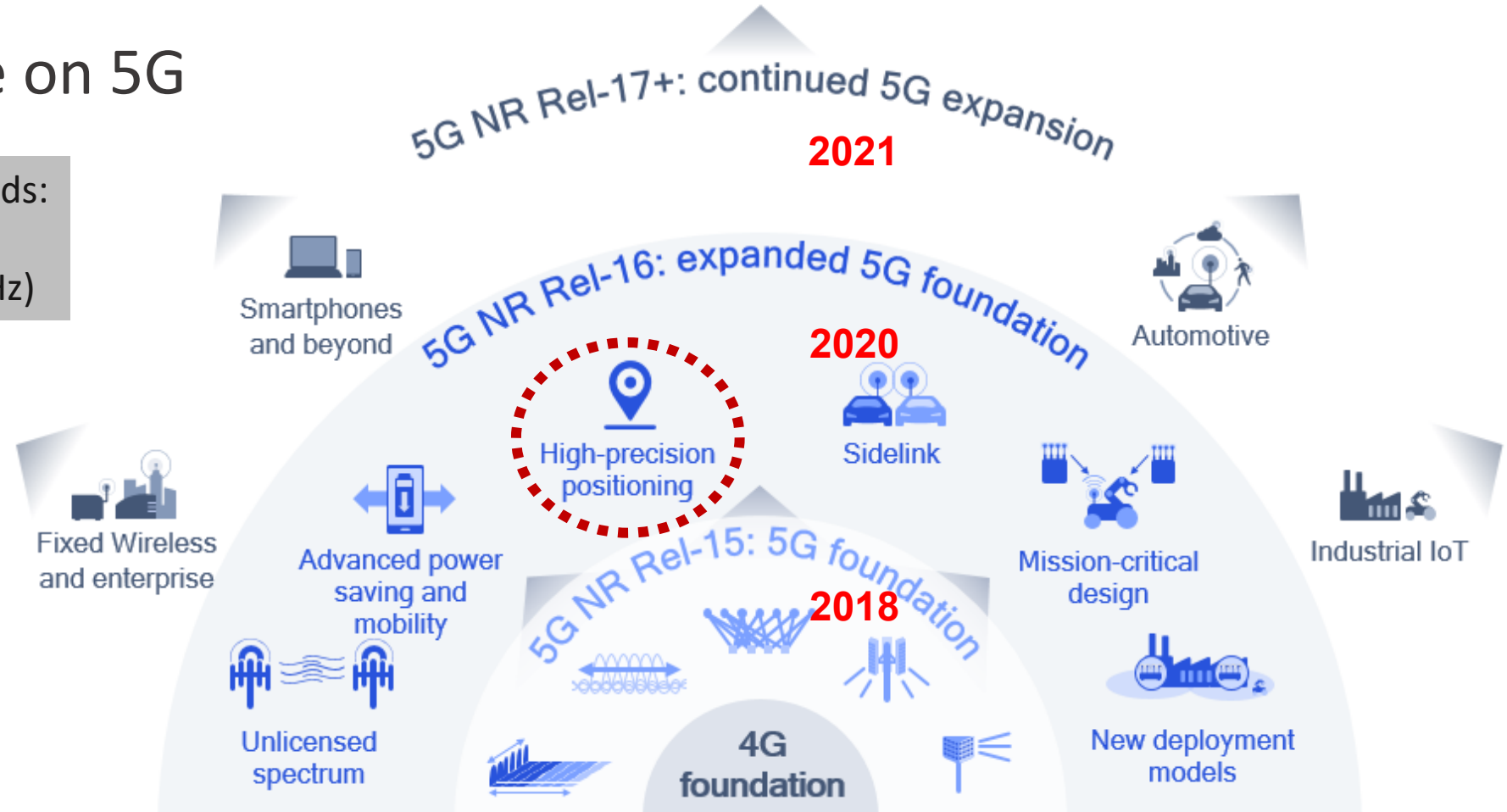
- Low visibility condition
- Non-ADS-B target tracking accuracy
- Non-cooperative target Identification
- Coverage
- Further cost reduction

Background and Motivation

A little bit more on 5G

Operates on different bands:

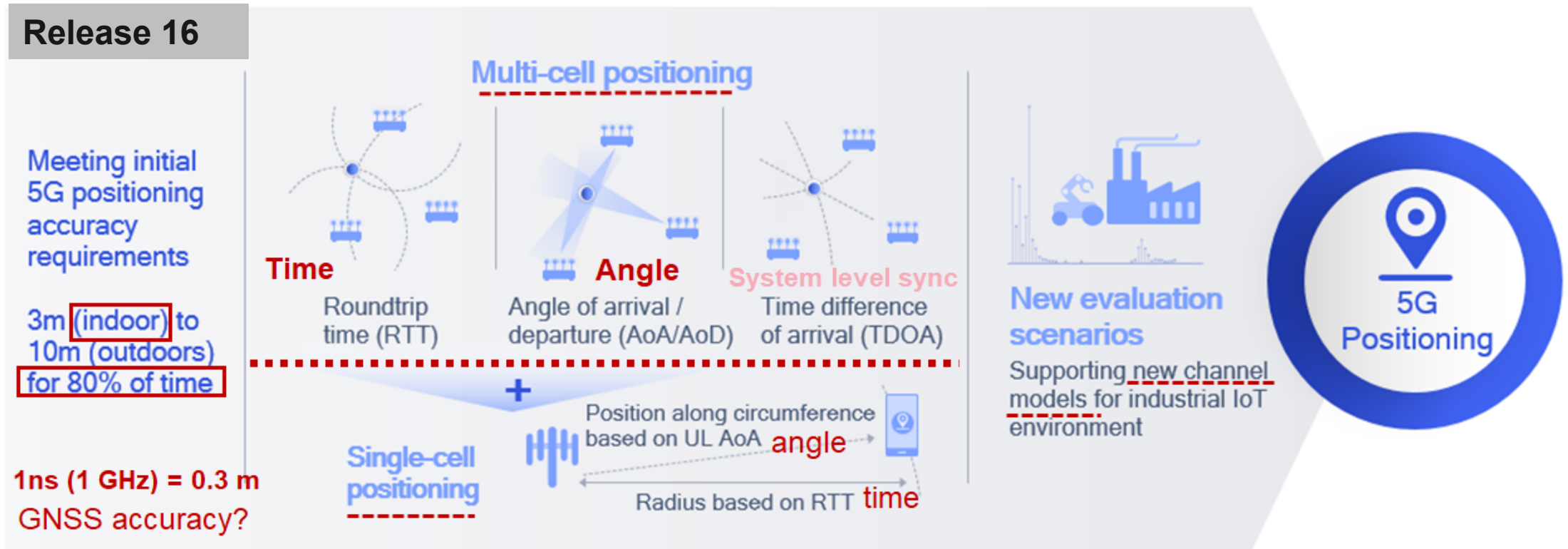
- FR1: Sub-6GHz
- FR2: mmWave (>28 GHz)



Source: Qualcomm

Background and Motivation

A little bit more on 5G

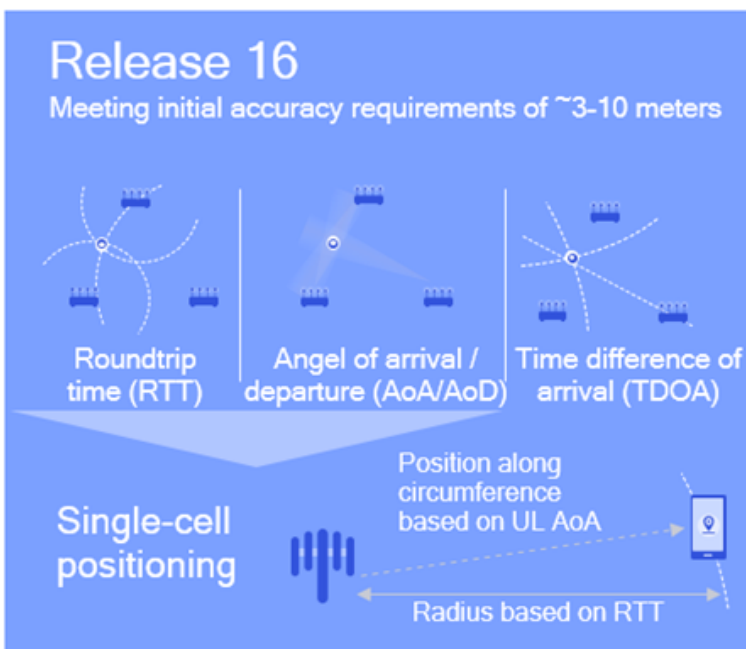


Source: Qualcomm

Background and Motivation

A little bit more on 5G

Release 16→17



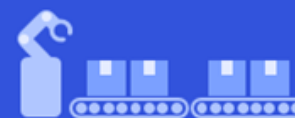
Release 17

Enhancing capability and performance for a wide range of use cases

Centimeter level accuracy
Meeting accuracy of down to **0.3m** [1]



Lower positioning latency
Reducing latency to as low as **10 ms**



New evaluation scenarios
Supporting IIoT channel models



Higher capacity
Scaling to millions of simultaneous devices
Sensor fusion, MEC support

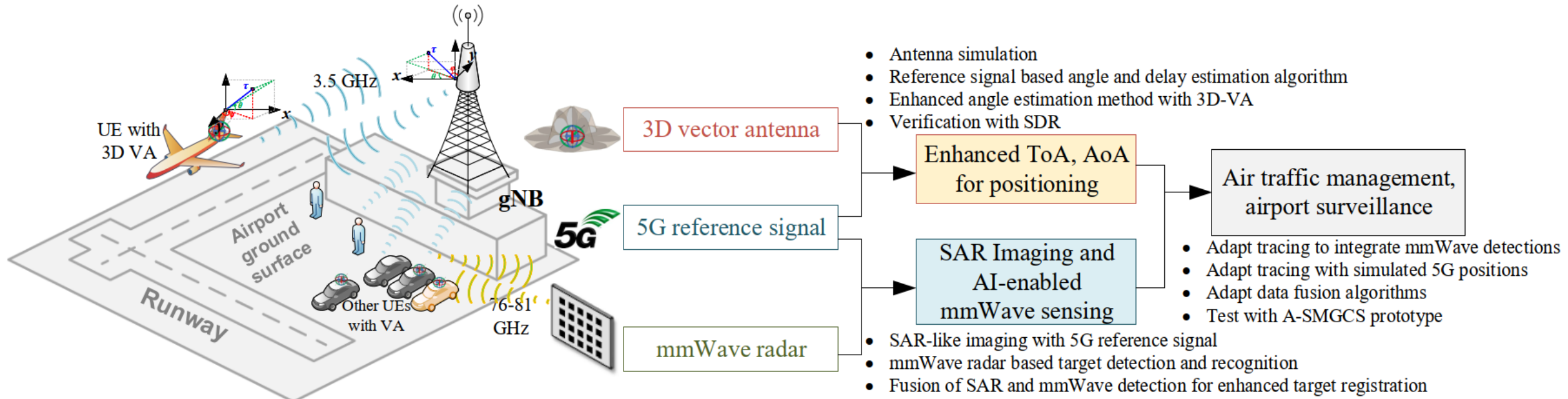


- Sensing has **NOT** been mentioned
- Exploit the mmWave signal

Source: Qualcomm

Background and Motivation

NewSense Proposition



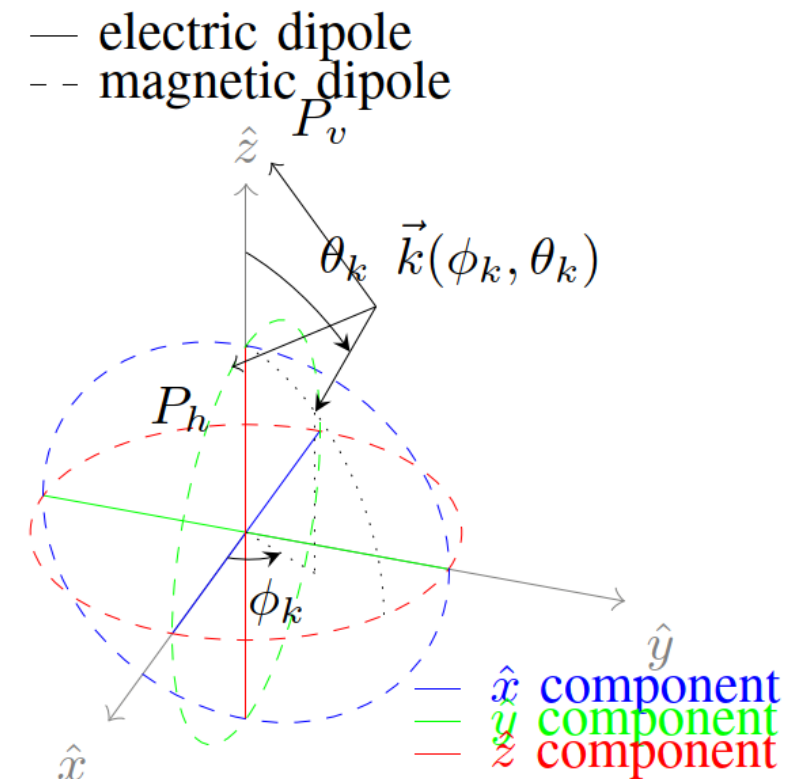
- **3D Vector Antenna**
 - An antenna naturally identify the spatial properties of radio signals
- **5G Reference Signals**
 - Naturally defined in 5G standard for time (distance), angle (direction) estimation
- **AI powered mmWave radar**
 - Next-level resolution and intelligence

3D Vector Antenna – Principle

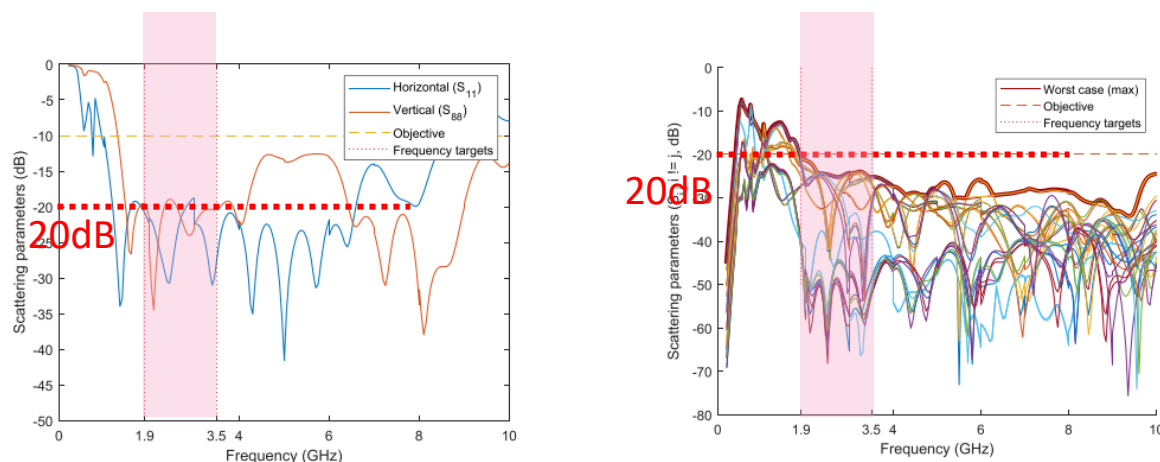
- A theoretical vector antenna (VA) is composed of six orthogonal and collocated antennas that combine **3 electric and 3 magnetic elementary dipoles**
- Signal model: $\mathbf{Y}(t) = \mathbf{F}_s(\varphi, \theta) \mathbf{p}(\eta, \gamma) \cdot \mathbf{s}(t) + \mathbf{N}(t)$

$$\mathbf{F}_s(\varphi, \theta) = \begin{bmatrix} \cos \varphi \cos \theta & -\sin \varphi \\ \sin \varphi \cos \theta & \cos \varphi \\ -\sin \theta & 0 \\ -\sin \varphi & -\cos \varphi \cos \theta \\ \cos \varphi & -\sin \varphi \cos \theta \\ 0 & -\sin \varphi \end{bmatrix} \varphi \in [0^\circ, 360^\circ], \theta \in [0^\circ, 180^\circ]$$

- $\mathbf{p}(\eta, \gamma)$ is the polarization vector



3D Vector Antenna – Preliminary Measurement

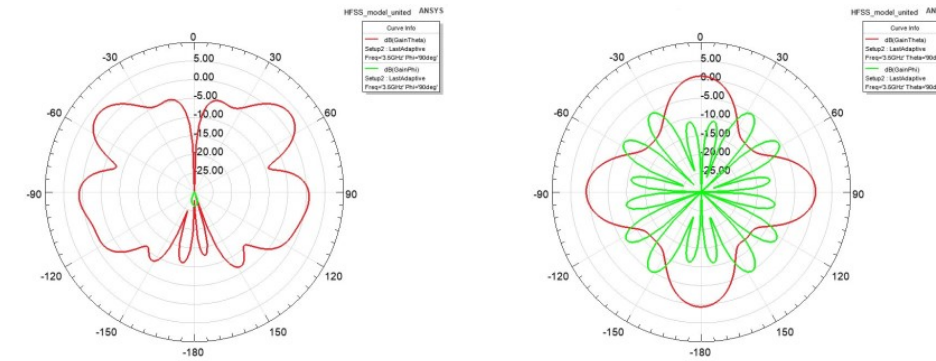


Left side: reflection coefficient S_{11} (horizontal element) S_{88} (vertical element);

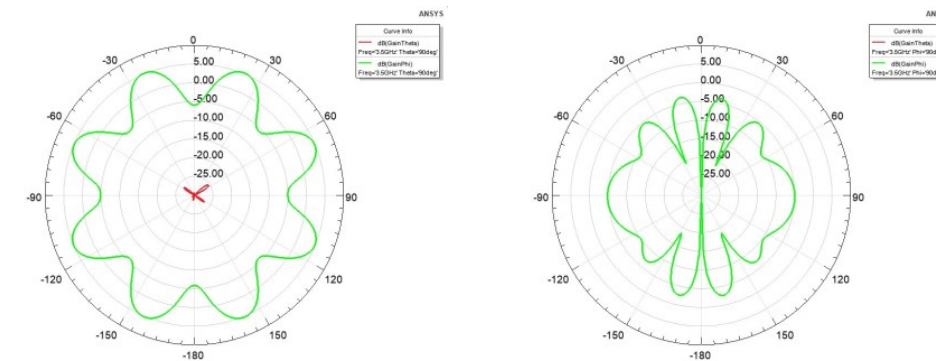
Right side: Isolation coefficient between S_{ij} ports

1.3~9 GHz reflection coefficient $S_{ii} < -10\text{dB}$ and specifically $S_{ii} < -20\text{dB}$ in the optimized bandwidth from 1.9 to 3.5GHz (sub-6GHz of 5G FR1 spectrum).

A mutual coupling reduction of -20dB is obtained for each port allowing a good orthogonality properties between ports.



Gain(dB) in Co (red) and Cross (green) polarization for the equivalent electric dipole in E (left) and H (right) planes

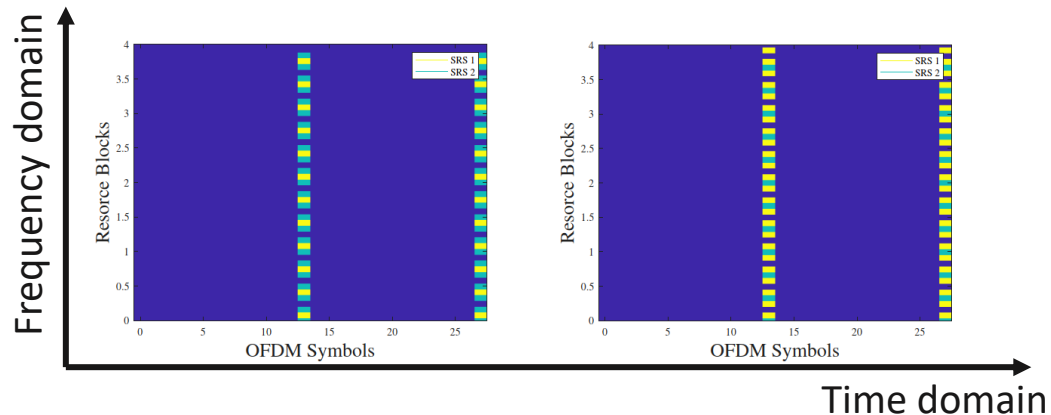


Gain(dB) in Co (green) and Cross (red) polarization for the equivalent magnetic dipole in the E (left) and H (right) planes

5G Positioning

Reference signal

- Sounding reference signal (**SRS**, uplink)
- Channel status information reference signal (**CSI-RS**, downlink)
- Positioning reference signal (**PRS**, downlink)



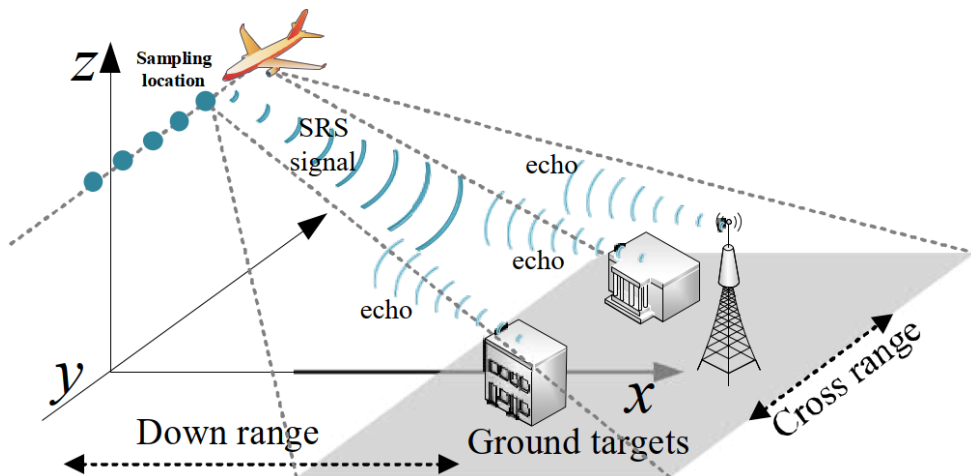
Example of the multiple SRS from different users:
orthogonal on time frequency domains

Angle and delay estimation algorithms

- Spatial steering vector: $\mathbf{F}_s(\varphi, \theta) = \begin{bmatrix} \cos \varphi \cos \theta & -\sin \varphi \\ \sin \varphi \cos \theta & \cos \varphi \\ -\sin \theta & 0 \\ -\sin \varphi & -\cos \varphi \cos \theta \\ \cos \varphi & -\sin \varphi \cos \theta \\ 0 & -\sin \varphi \end{bmatrix}$
- Time steering vector: $\mathbf{g}(t) = [1, e^{-2j\pi t f_1}, e^{-2j\pi t f_2}, \dots, e^{-2j\pi t f_{N-1}}]$
- Joint steering vector: $\mathbf{A}(\varphi, \theta, t) = \mathbf{F}_s(\varphi, \theta) \otimes \mathbf{g}(t)$
- $\mathbf{P}(\varphi, \theta, t) = \frac{\mathbf{A}^*(\varphi, \theta, t) \mathbf{A}(\varphi, \theta, t)}{\mathbf{A}^*(\varphi, \theta, t) \mathbf{E}_n \mathbf{E}_n^* \mathbf{A}(\varphi, \theta, t)}$
- $\mathbf{E}_n$ is the noise space of the receiving signal covariance matrix $\mathbf{R}_{YY}$
- $\mathbf{R}_{YY} = \mathbb{E}[\mathbf{Y}(\varphi, \theta, t) \mathbf{Y}^*(\varphi, \theta, t)]$
 - Eigen values: $\lambda = [\lambda_0, \lambda_1, \dots, \lambda_{N \times M}]$
 - Eigen vectors: $\mathbf{E} = [e_0, e_1, \dots, e_{N \times M}] = [\mathbf{E}_s, \mathbf{E}_n]$

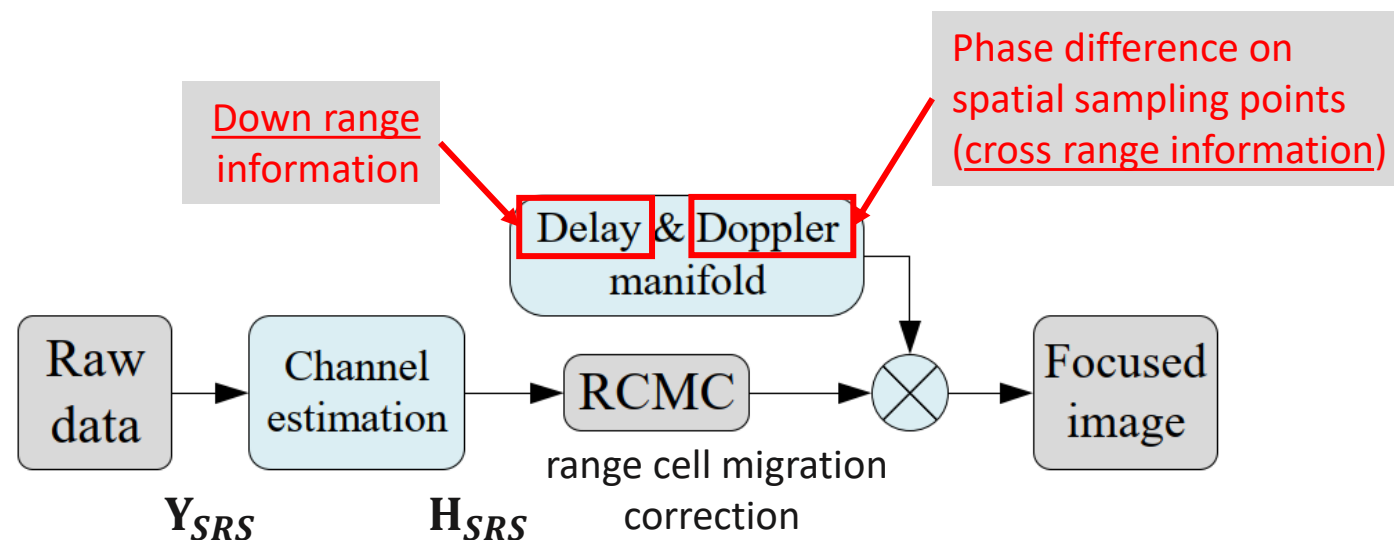
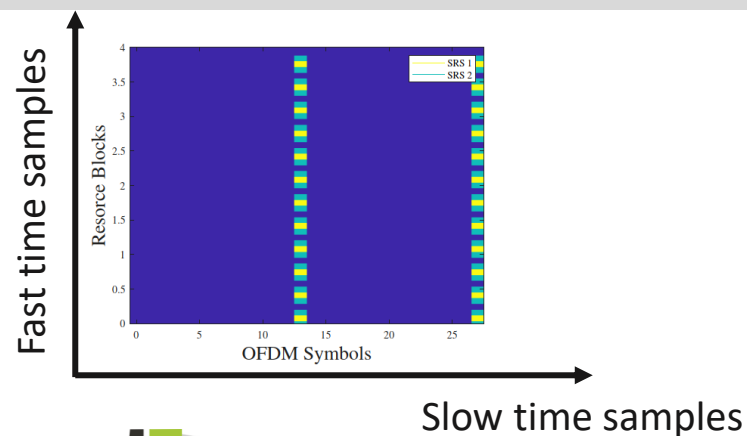
Also, method based on the [Expectation–Maximization](#) (EM) algorithm

5G Sensing

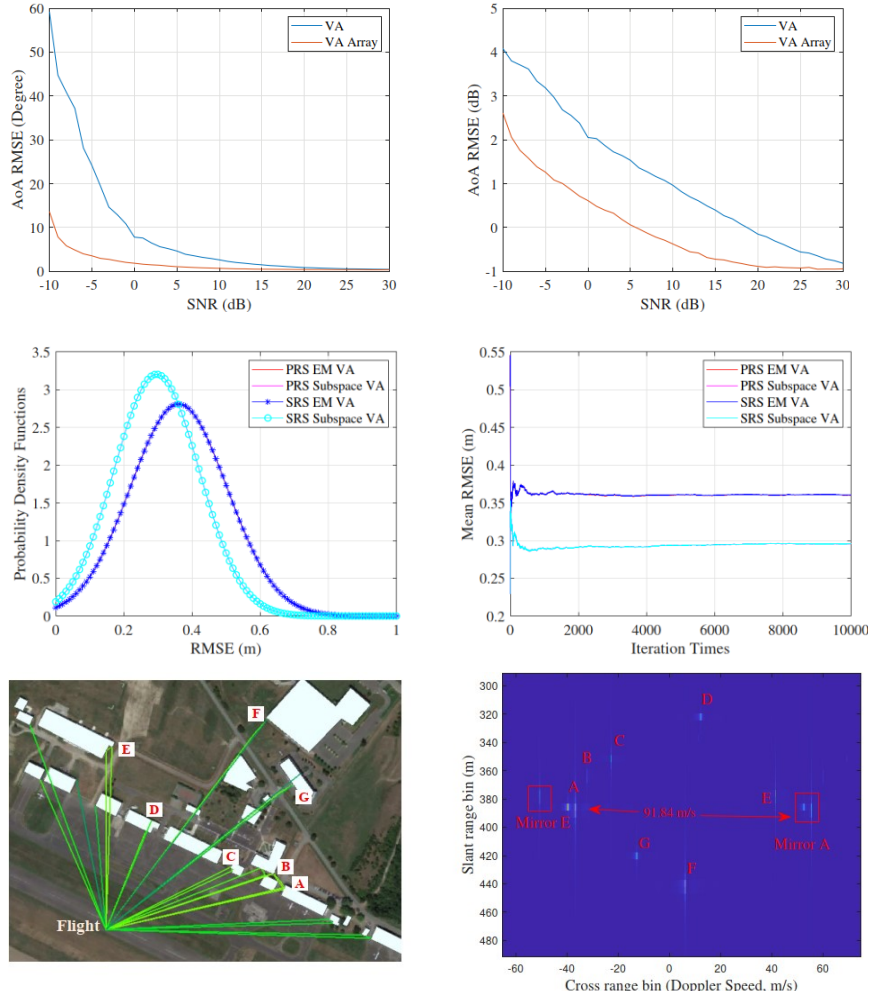


- Assume the aircraft with a 5G UE
- The uplink SRS (UE $\rightarrow$ base station) can be reflected by ground targets
- With proper self-interference cancellation

Viewing the SRS from radar processing perspective



5G Positioning & Sensing – Preliminary simulation



3.5GHz, 300MHz, 15kHz interval, 20 reference signals, single target, static position, Downlink PRS and Uplink SRS signals

- AoA Estimation comparison (upper) : RMSE of angle estimation with VA and VA array
- Positioning comparison (middle) : RMSE of positioning result with joint and angle and distance estimations (subspace V.S. EM)

Channel Ray Tracing of Muret Airport (**bottom left**, with Wireless InSite®).

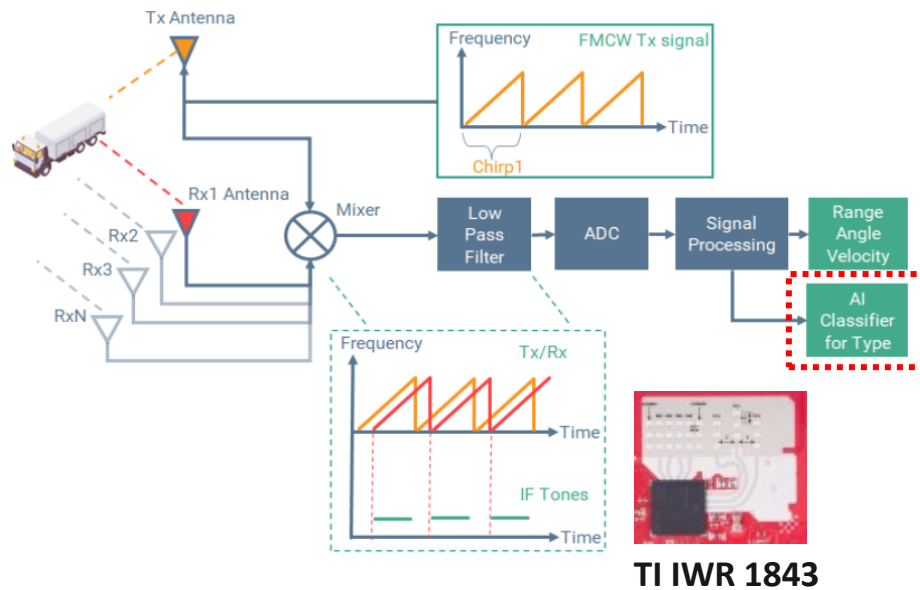
Flight transmitting SRS to base station and objects illuminated by SRS signal are reflecting signal back to the flight.

- 24dBm TX power and 17.1dBi antenna gain.
- The received signal strength from every path is higher than the flight RX sensitivity -90dBm;

Imaging result (**bottom right**)

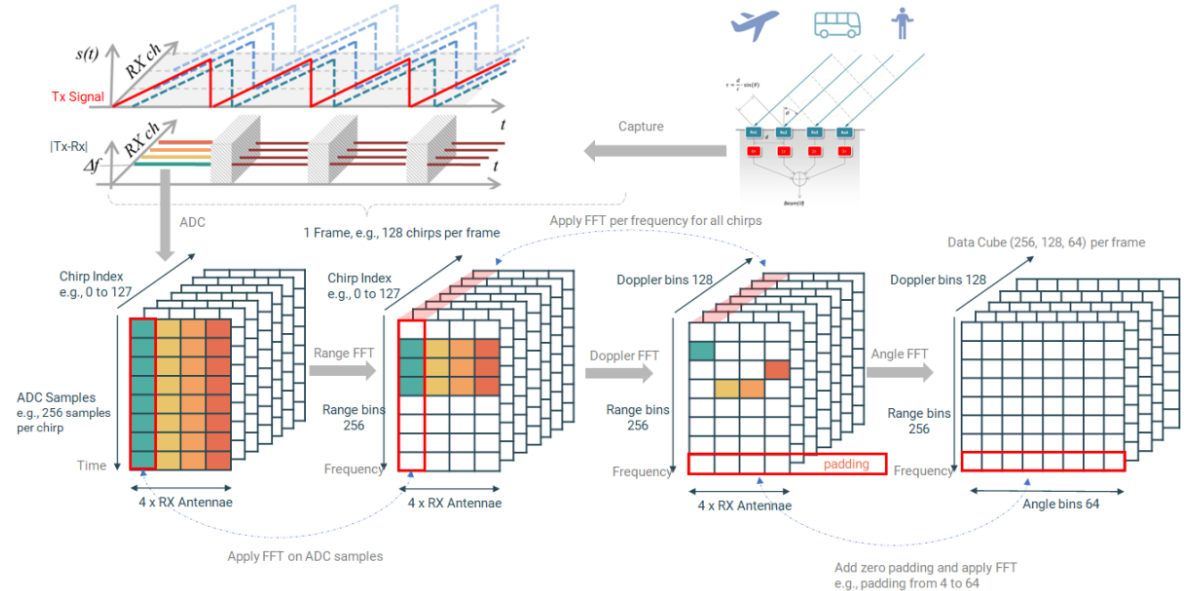
- It contains seven reflection points (Marked as A to G) and two mirrors of A and E

Sensing with mmWave Radar



Concept Schematic of the mmWave radar

- Phase coherent system FMCW
- Multiple receiver – angle capability
- Range-velocity information
- Data interpretation with AI



Radar Signal Processing

- Sample the signal after the ADC → digitized beat frequency (one chirp)
- Arrange multiple chirps as “information cube”: one chirp → one column
- **Spatial FFT (horizontal)**: FFT over spatial samples → angle
- **Range FFT (vertical)**: take FFT of one chirp → distant
- **Doppler FFT (depth)**: **(then)** take FFT of a slice multiple “chirps” → velocity of the target

Conclusion and Future Work

- The **NewSense** is proposed to look for economic surveillance solutions that can be used in secondary airport
- Private 5G network may be a system which can work together/in A-SMGCS
 - Enhance the positioning and sensing
 - Sub-6GHz, mmWave bands
- Preliminary results of 3D vector antenna measurement, 5G reference signal for positioning and sensing, mmWave radar sensing
- The scattered results need to be integrated

Future work

- Experimental 3D-VA angle estimation performance evaluation;
- Verification of the angle-delay algorithms and imaging capability with practical 5G radio samples;
- Intelligent target recognition with Doppler signature of mmWave radar;
- Joint target registration based on sub-6GHz SAR image and mmWave radar detection.

Thank you!
Q & A