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Agenda Item: 10.5.1

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Title: Evaluation assumptions and performance evaluation for ISAC

Document for: Discussion and decision

1. Introduction

According to the SI for Release 20 ISAC [1], the objective of this SI is as follows:

Evaluate the performance of gNB-based mono-static sensing (i.e., single TRP with co-located sensing transmitter and receiver) for UAV use case [RAN1]

- Identify and study metrics, measurements, and relevant measurement quantization for UAV use case
- As baseline, existing DL NR waveform and DL NR reference signals are to be used for evaluations.
  - For other waveform and reference signals, companies are to share relevant information
  - No UE impacts
- Deployment scenario and assumptions for channel model calibration for UAV sensing targets in the Rel-19 ISAC channel model SI [*FS_Sensing_NR*] are used as starting point for evaluation assumptions.
  - FR1 frequency range is prioritized.

Study the procedures, signaling between RAN and CN to support ISAC [RAN3]

Study network architecture for gNB-based mono-static sensing for UAV sensing target use cases [RAN3]

- Applicability to gNB bistatic sensing may be considered as part of this network architecture without additional architecture impacts.
- No inter-gNB coordination will be studied.
- Coordination with SA2 as necessary.

The following agreements were made in Release 19 for UAV sensing scenarios:

Evaluation parameters for UAV sensing scenarios

Parameters		Value
Applicable communication scenarios		UMi, UMa, RMa, SMa UMi-AV, UMa-AV, RMa-AV
Sensing transmitters and receivers properties	Rx/Tx Locations	Rx/Tx locations are selected among the TRPs and UEs locations in the corresponding communication scenarios. Note1: This may include aerial UEs for UMi-AV, UMa-AV, RMa-AV communication scenarios. In this case, other Rx/Tx properties (e.g. mobility) are also taken from the corresponding communication scenario.
Sensing target	LOS/NLOS	LOS and NLOS
	Outdoor/indoor	Outdoor
	3D mobility	Horizontal velocity: uniform distribution between 0 and 180km/h, if horizontal velocity is not fixed to 0. Vertical velocity: 0km/h, optional {20, 40} km/h NOTE2: 3D mobility can be horizontal only or vertical only or a combination for each sensing target NOTE 3: time-varying velocity may be considered for future evaluations.
	3D distribution	Horizontal plane: Option A: *N* targets uniformly distributed within one cell. Option B: *N* targets uniformly distributed per cell. Option C: *N* targets uniformly distributed within an area not necessarily determined by cell boundaries. *N* = {1, 2, 3, 4, 5} NOTE4: *N*=0 may be considered for the evaluation of false alarm Vertical plane: Option A: Uniform between 1.5m and 300m. Option B: Fixed height value chosen from {25, 50, 100, 200, 300} m assuming vertical velocity is equal to 0.
	Orientation	Random in horizontal domain
	Physical characteristics (e.g., size)	Size: • Option 1: 1.6m x 1.5m x 0.7m • Option 2: 0.3m x 0.4m x 0.2m

Minimum 3D distances between pairs of Tx/Rx and sensing target	Min distances based on min. TRP/UE distances defined in TR36.777 as a starting point. NOTE5: the sensing target is assumed in the far field of sensing Tx/Rx
Minimum 3D distance between sensing targets	Option 1: At least larger than the physical size of a target Option 2: 10 meters
[Unintended/Environment objects, e.g., types, characteristics, mobility, distribution, etc.]	Can be considered in future evaluations

NOTE: A percentage of TRPs/UEs that have sensing capabilities may be considered for future evaluations.

Simulation assumptions for large scale calibration for UAV sensing targets

Parameters	Values
Scenario	UMa-AV
Sensing mode	TRP monostatic, TRP-TRP bistatic, TRP-UE bistatic, UE-UE bistatic
Target type	UAV of small size (0.3m x 0.4m x 0.2m)
Sectorization	Single 360-degree sector can be assumed
Carrier Frequency	FR1: 6 GHz FR2: 30 GHz
BS antenna configurations	Single dual-pol isotropic antenna
BS Tx power	FR1: 56dBm FR2: 41dBm
Bandwidth	FR1: 100MHz FR2: 400MHz
BS noise figure	FR1: 5dB

	FR2: 7dB
UT antenna configurations	Single dual-pol isotropic antenna; (M,N,P,Mg,Ng;Mp,Np) = (1,1,2,1,1;1,1)
UT noise figure	FR1: 9dB FR2: 10dB
UT height	1.5m for terrestrial UTs,
UT Tx power	23dBm
UT Distribution	• The overall number of UTs is 30 uniformly distributed in the center cell. • All of the UTs are either terrestrial UTs or aerial UTs, all outdoors. • Vertical distribution of aerial UE: Fixed height value of 200 m. • FR1 is assumed for aerial UE.
Sensing target distribution	1 target uniformly distributed (across multiple drops) within the center cell. Vertical distribution: Fixed height value of 200 m.
Component A of the RCS for each scattering point	-12.81 dBsm
Minimum 3D distances between pairs of Tx/Rx and sensing target	10 m
Wrapping Method	No wrapping method is used if interference is not modelled, otherwise geographical distance based wrapping
Coupling loss for target channel	power scaling factor (pathloss, shadow fading, and RCS component A included): $L_{TX-SPST-RX} = PL_{dB}(d_1) + PL_{dB}(d_2) + 10lg\left(\frac{c^2}{4\pi f^2}\right) - 10lg(\sigma_{RCS,A}) + SF_{dB,1} + SF_{dB,2}$

Sensing Tx/Rx selection	Best N = 4 Tx-Rx pairs to be selected for the target. NOTE1: Based on the Tx-Rx pairs with the smallest power scaling factor of the target channel.
Metrics	Coupling loss for target channel Coupling loss for background channel (in case of monostatic sensing, this is the coupling loss between Tx and one reference point) Note: CDFs can be separately generated for target channel, background channel

Simulation assumptions for full calibration for UAV sensing targets

Parameters	**Values**
Scenario	UMa-AV
Sensing mode	TRP monostatic, TRP-TRP bistatic, TRP-UE bistatic, UE-UE bistatic
Target type	UAV of small size (0.3m x 0.4m x 0.2m)
Sectorization	Single 360-degree sector can be assumed
Carrier Frequency	FR1: 6 GHz FR2: 30 GHz
BS antenna configurations	Single dual-pol isotropic antenna
BS Tx power	FR1: 56dBm FR2: 41dBm
Bandwidth	FR1: 100MHz FR2: 400MHz
BS noise figure	FR1: 5dB

	FR2: 7dB
UT antenna configurations	Single dual-pol isotropic antenna; (M,N,P,Mg,Ng;Mp,Np) = (1,1,2,1,1;1,1)
UT noise figure	FR1: 9dB FR2: 10dB
UT height	1.5m for terrestrial UTs
UT Tx power	23dBm
UT Distribution	• The overall number of UTs is 30 uniformly distributed in the center cell. • All of the UTs are either terrestrial UTs or aerial UTs, all outdoors. • Vertical distribution of aerial UE: Fixed height value of 200 m. • FR1 is assumed for aerial UE.
Sensing target distribution	1 target uniformly distributed (across multiple drops) within the center cell. Vertical distribution: Fixed height value of 200 m.
RCS for each scattering point	Component A: -12.81 dBsm Component B1: 0 dB Component B2: 3.74 dB for standard deviation The same values are used for monostatic RCS and bistatic RCS
Minimum 3D distances between pairs of Tx/Rx and sensing target	10 m
Wrapping Method	No wrapping method is used if interference is not modelled, otherwise geographical distance based wrapping
Fast fading model	TR 36.777 Annex B.1.3
(u, std) for XPR of target	Mean 13.75 dB, deviation 7.07 dB

The power threshold for path dropping after concatenation for target channel	FFS
The power threshold for removing clusters in step 6 in section 7.5, TR 38.901 for background channel	FFS
Coupling loss for target channel	By definition, need to consider all direct and indirect paths. The following parameters are included in the calculation: • power scaling factor (pathloss, shadow fading, and RCS component A included) • for small scale RCS B1/B2 and power of rays in Tx-target/target-Rx links ($P_{n',m',n,m}^{k,p}$), Tx/Rx antenna pattern, 3 polarization matrixes, i.e., $$\sqrt{P_{n',m',n,m}^{k,p}}\begin{bmatrix}F_{rx,u,\theta}\left(\theta_{rx,n',m',ZOA}^{k,p},\phi_{rx,n',m',AOA}^{k,p}\right)\\F_{rx,u,\phi}\left(\theta_{rx,n',m',ZOA}^{k,p},\phi_{rx,n',m',AOA}^{k,p}\right)\end{bmatrix}^T CPM_{rx,n',m'}^{k,p}CPM_{n',m',n,m}^{k,p}CPM_{tx,n,m}^{k,p}$$ $$\cdot\begin{bmatrix}F_{tx,s,\theta}\left(\theta_{tx,n,m,ZOD}^{k,p},\phi_{tx,n,m,AOD}^{k,p}\right)\\F_{tx,s,\phi}\left(\theta_{tx,n,m,ZOD}^{k,p},\phi_{tx,n,m,AOD}^{k,p}\right)\end{bmatrix}$$
Sensing Tx/Rx selection	Best N = 4 Tx-Rx pairs to be selected for the target. NOTE1: Based on the Tx-Rx pairs with the smallest power scaling factor of the target channel.
Absolute delay	The model of UMa scenario defined in TR 38.901 7-24GHz channel modeling [ref] is reused for UMa-AV for all sensing modes.

Metrics	Coupling loss for target channel Coupling loss for background channel (in case of monostatic sensing, this is the linear sum of coupling losses between Tx/Rx and all reference points) Note: CDFs can be separately generated for target channel, background channel CDF of Delay Spread and Angle Spread (ASD, ZSD, ASA, ZSA) For monostatic sensing mode: delay spread and angle spread of the background channel is calculated separately for each reference point Definition of Delay Spread is similar to the definition of angle spread in Annex A of TR 25.996, Definition of Angle Spread can ref to Annex A of TR 25.996.

2. Discussion

2.2.1 Sensing metrics

a. Sensing range

The range that the gNB in UAV monostatic sensing scenarios can sense a target UAV is expressed in the following equation:

$$P_r=\frac{P_t G_t G_r \lambda^2 \sigma F^4}{(4\pi)^3 R^4}$$

where P_t: signal transmission power

P_r: signal reception power

G_t: transmitting antenna gain

G_r: receiving antenna gain

σ: radar cross section of the target UAV

F: pattern propagation factor

R: distance between the gNB and the target UAV

Given P_t, G_t, G_r, σ and F, the signal reception power Pr depends on the range between the gNB and the target UAV. When the reception power is lower than the detection threshold of the gNB, it cannot detect the UAV. Sensing range is considered based on the sensing requirement to ensure that the gNB can detect the target as required by the applications.

For the UAV scenarios, sensing range is set to 200 m for evaluation.

b. Range resolution

Range resolution shows the minimum distance between two targets that the gNB can distinguish. This metric is important to evaluate sensing accuracy of a sensing operation in measuring the range between the gNB and the target UAV. Range resolution depends on bandwidth used for sensing signal. Based on Option 2 of the minimum distance between two sensing targets in the agreement in Release 19, both horizontal and vertical range resolutions are set to 10 m for evaluation.

c. Velocity resolution

Velocity resolution is a metric to evaluate sensing accuracy of a sensing operation in measuring the target's velocity. Velocity resolution depends on pulse width and carrier frequency. For the UAV scenarios, velocity resolution is set to 5 m/s for evaluation.

d. Positioning accuracy

Positioning accuracy represents the accuracy of a sensing operation in measuring the range from a transmitter to a target. In the applications to track the UAV to avoid the collision of the UAVs or the UAVs with the manned aircraft, the requirement is to avoid the near-miss accidents where the definition of a near-miss accident is when the distance between a UAV and a manned aircraft is smaller than 10m. For this reason, positioning accuracy is smaller than 10 m. For the UAV scenarios, the positioning accuracy (both horizontal and vertical) is set to 5 m for evaluation.

e. Velocity accuracy

Velocity accuracy represents the accuracy of a sensing operation in measuring the velocity from the of a target. For the UAV scenarios, the velocity accuracy is set to 2 m/s for evaluation.

f. Maximum unambiguous range

The maximum unambiguous range is the maximum range that a target can be sensed so that when the reflected signal from the target to the gNB is associated to the most recent transmitted pulse, it is associated to the right transmitted pulse. This metric affects sensing range and needs to be taken into account. For the UAV scenarios, maximum unambiguous range is set to 200 m for evaluation.

g. Maximum unambiguous velocity

Maximum unambiguous velocity is the highest velocity that the gNB can measure without ambiguity in Doppler shift. Frequency spectrum of the received signal can only be used for unambiguous velocity measurements when the displacement of the received spectrum is smaller than the line spacing in the spectrum. A smaller frequency of pulse repetition equivalent to a higher period of pulse repetition results in a smaller maximum unambiguous velocity. A balance between maximum unambiguous range and maximum unambiguous velocity must be taken into account based on the sensing requirements of the applications. For the UAV scenarios, maximum unambiguous velocity is set to 50 m/s (180 km/h) for evaluation to guarantee the sensing of the UAV with maximum speed of 180 km/h as in the Release-20 agreement.

h. Update rate

Update rate is the frequency that the gNB has data about the target's range and velocity. Update rate depends on the period that the gNB transmits the sensing signal. A high update rate is important in dynamic environment where the UAV moves with high speed. For the UAV scenarios, update rate is set to 1s for evaluation.

i. Sensing latency

Sensing latency is the time from the transmission of the sensing signal to the acquisition of the measurement reports at the intended receiver. It is critical for the time-sensitive applications. For the UAV scenarios, sensing latency is set to 1s for evaluation.

j. Detection rate

Detection rate is the rate that the gNB detects the targets given the presence of the targets. This metric is important to evaluate the reliability of the sensing operation. For the UAV scenarios, the detection rate is set to 95% for evaluation as in 22.837. Detection rate can be higher for the critical service such as detecting the intruding UAV near to the aiports.

k. False alarm rate

False alarm rate is the rate that the gNB falsely detects an object when there is no object in that position. This metric is important to evaluate the reliability of the sensing operation. For the UAV scenarios, the false alarm rate is set to 5% for evaluation as in 22.837.

Proposal 1: Sensing range: 200 m

Range resolution (both horizontal and vertical): 10 m

Velocity resolution (horizontal): 5 m/s

Positioning accuracy (both horizontal and vertical): 5 m

Velocity accuracy (horizontal): 2 m/s

Maximum unambiguous range: 200 m

Maximum unambiguous velocity: 50 m/s

Update rate: 1s

Sensing latency: 1s

Detection rate: 95%

False alarm rate: 5%

Proposal 2: For the UE distribution, the height of the UAVS is below 200m

2.2.2 Communication metrics

The communication metrics for ISAC are the same as the communication metrics in 5G: error rate for reliability, latency, throughput, power consumption, spectral efficiency.

3. Conclusion

Proposal 3: Sensing range: 200 m

Range resolution (both horizontal and vertical): 10 m

Velocity resolution (horizontal): 5 m/s

Positioning accuracy (both horizontal and vertical): 5 m

Velocity accuracy (horizontal): 2 m/s

Maximum unambiguous range: 200 m

Maximum unambiguous velocity: 50 m/s

Update rate: 1s

Sensing latency: 1s

Detection rate: 95%

False alarm rate: 5%

Proposal 4: For the UE distribution, the height of the UAVS is below 200m