3GPP RAN#102
Edinburg/Scotland, 11-15 December 2023

RP-233126

SHARP

Be Original.

Exploring study in new spectrum 7–24 GHz

Sharp

RP-232617 Summary for 7-24 GHz

- 7-24 GHz frequency range is expected to be relevant for 6G.
- Awareness that the TR38.901 was not extensively validated by measurements at these frequencies.
- The areas of the model where it is most widely recognised that adaptations/extensions may be needed are:
  - Near-field propagation, where plane wave propagation and uniform array behaviour cannot be assumed;
  - Spatial non-stationarity;
  - Outdoor-to-indoor (O2I) penetration modelling.
- Study would be independent of any RAN-level study on ISAC, and could, in theory, therefore start in RAN WG1 in parallel.
- Continuity of the channel model in the frequency domain shall be ensured.
- Study of measurement results is likely to be able to start in Q3 2024.

Validation and extension of channel model below 100 GHz with a focus on FR3 Bands

Proposal 1: Accurately model the material penetration loss for various materials in the FR3 bands [1/3]

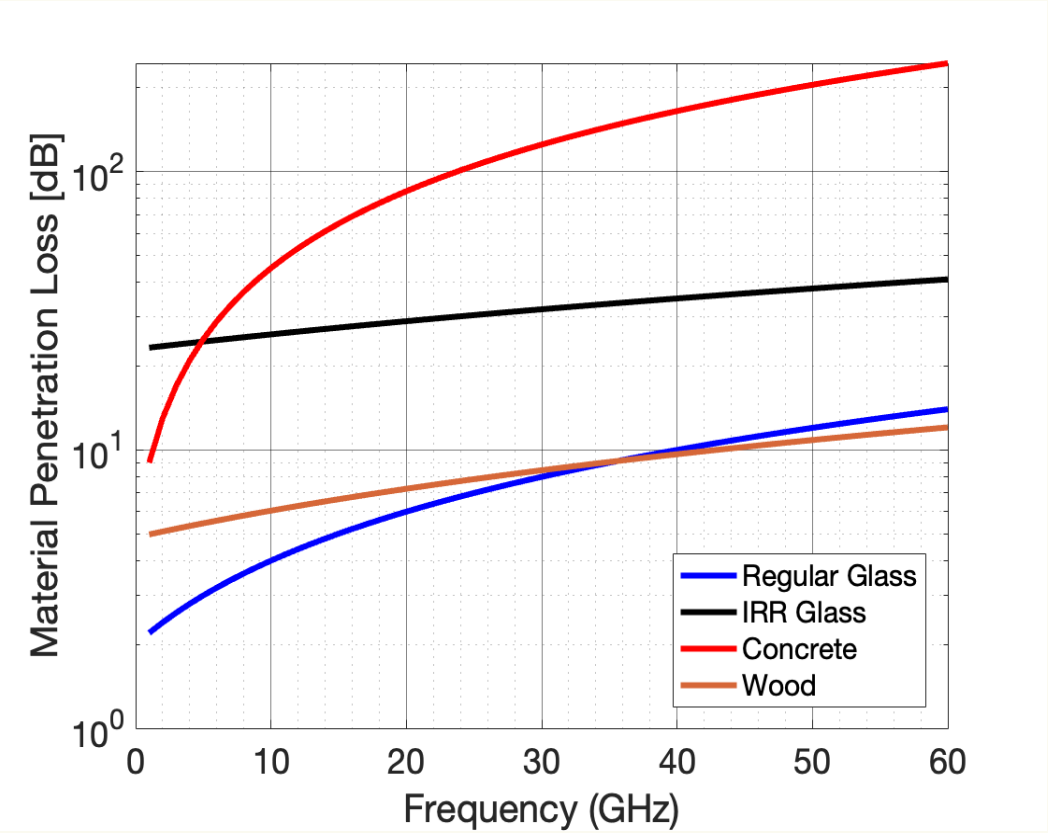


Figure 1. Material penetration loss for various materials at different frequencies (TR 38.901, Table 7.4.3-1) [1].

Material penetration losses for various materials at different frequencies (TR 38.901, Table 7.4.3-1 [1]) is shown in Figure 1.

Observations from Figure 1 are as follows [2]:

- Standard glass and wood are relatively permeable across the entire frequency FR3 range. The material penetration loss for these materials is < 8 dB.
- IRR glass is relatively permeable across the FR3 frequency range. The material penetration loss is > 20 dB.
- Concrete makes a sharp transition from relatively permeable to impenetrable in the FR3 frequency range. The material penetration loss is > 40 dB.
- Concrete is a widely used material in dense urban areas. Coverage for Indoor users can be severely affected due to high loss.

Proposal 1: Accurately model the material penetration loss for various materials in the FR3 bands [2/3]

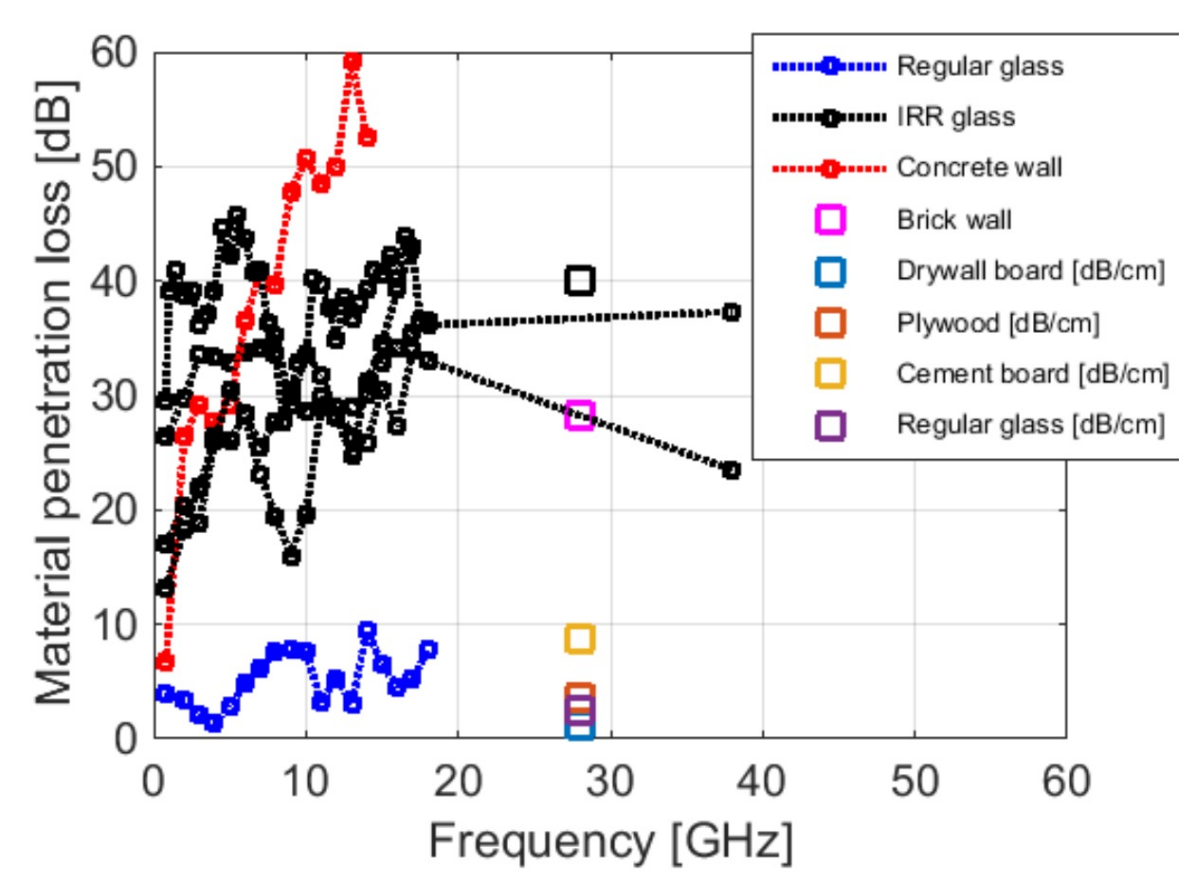


Figure 2. Measured material penetration loss for various materials at different frequencies [3].

- Verify the accuracy of the parameters in TR 38.901, Table 7.4.3-1 [1] for the material penetration loss of various materials in the FR3 range.

- Accuracy of the parameters for material penetration losses for various materials in the FR3 bands can be verified by:
  1. Conducting more measurements.
  2. Using already available measurements
  3. A mix of both 1 and 2.

- Some data points on material penetration loss measurements (shown in Figure 2) for common materials such as IRR glass, regular glass, concrete were conducted in the frequency range of 6-60 GHz [3].

Proposal 1: Accurately model the material penetration loss for various materials in the FR3 bands [3/3]

Table 1. Difference in material penetration loss between the current 3GPP material penetration loss model (Table 7.4.3-1 [1]) and past measurements conducted for penetration loss [3] in the FR3 band.

Frequency	Material Name	Material Penetration Loss [dB]		Difference [dB]
		Table 7.4.3-1 [1]	Measurements [3]	
7 GHz	Concrete	33	40	-7
	IRR glass	25	34	-9
	Regular glass	3.4	7	-3.6
10 GHz	Concrete	45	52	-7
	IRR glass	26	30	-4
	Regular glass	4	8	-4
12 GHz	Concrete	53	50	3
	IRR glass	26.6	33	-6.4
	Regular glass	4.4	4	0.4
15 GHz	Concrete	65	53	12
	IRR glass	27.5	35	-7.5
	Regular glass	5	10	-5

- 3GPP material penetration loss model (Table 7.4.3-1) [1] seems to underpredict the material penetration loss compared to the measurements conducted for material penetration loss in most of the FR3 frequency bands as shown in Table 1.
- Additionally, sampling data points are required to verify the validity of TR 38.901 Table 7.4.3-1 [1] in FR3 bands.
- Recalibration of parameters may be needed for material penetration loss models in TR 38.901 Table 7.4.3-1 [1].

Proposal 2: Accurately model the O2I building penetration loss in the FR3 bands [1/2]

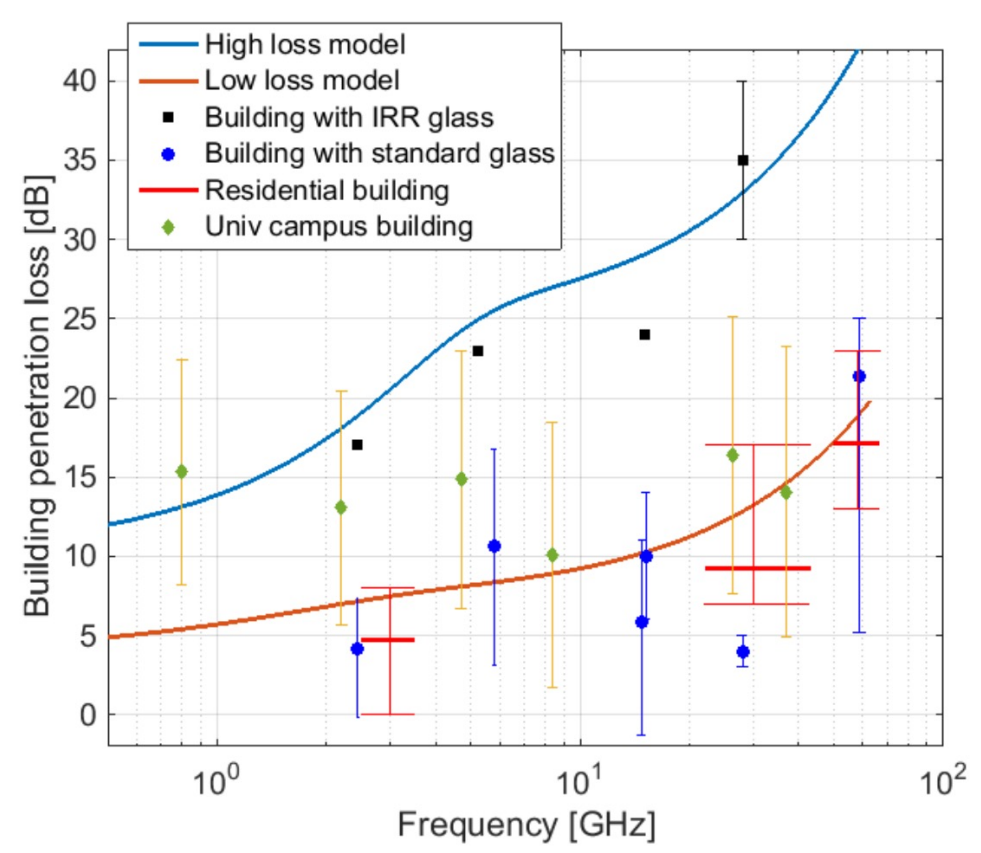


Figure 3. Effective building penetration loss measurements. The bars indicate variability for a given building. The solid curves represent two variants of the O2I building penetration loss model [3].

- Limited number of measurements are present for FR3 band. In fact, only 1 measurement is reported in O2I scenario in FR3 band [4] .
- Calibration is only made for 3.5 GHz and 28 GHz for O2I [4].
- TR 38.901 Table 7.4.3-2 [1] defines a low-loss and high-loss model for O2I building penetration loss.
- The low-loss and high-loss models defined in TR 38.901 Table 7.4.3-2 [1] incorporate the material penetration loss as well.
- Figure 3 shows a low-loss and high-loss model built based on curve fitting on measurement data collected from 6-60 GHz [3].
- The low-loss and high-loss model based on [3] are implemented in NYUSIM channel simulator [5].

Proposal 2: Accurately model the O2I building penetration loss in the FR3 bands [2/2]

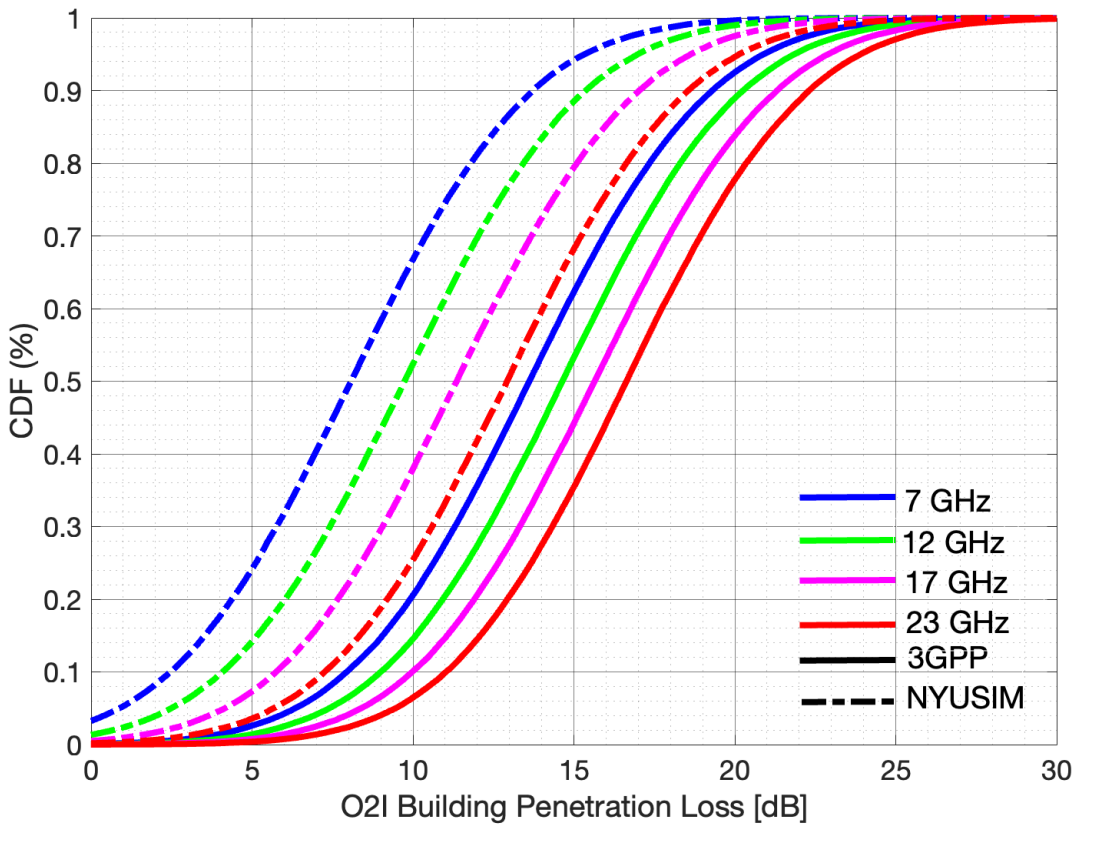


Figure 4. Comparison of 3GPP (Table 7.4.3-2 [1]) vs NYUSIM [5] O2I low-loss building penetration loss model.

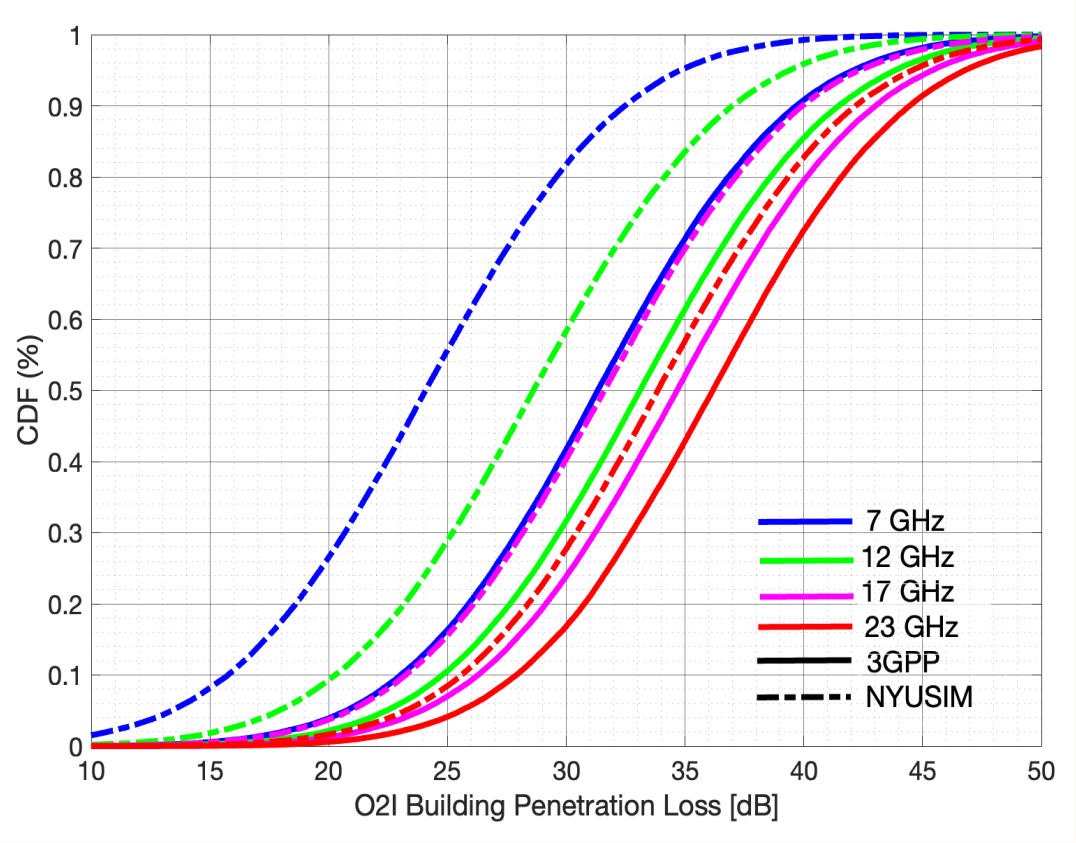


Figure 5. Comparison of 3GPP (Table 7.4.3-2 [1]) vs NYUSIM [5] O2I high-loss building penetration loss model.

From both Figure 4 and 5 we observe that 3GPP underpredicts the O2I building penetration loss compared to real-world measurement-based models implemented in NYUSIM.

Proposal 3: Validate and extend RMa Path Loss Models for FR3 and mmWave [1/2]

- Lack of measurements for RMa scenario in FR3 bands [4].

- RMa pathloss model is limited to use up to 30 GHz [1, 4]. Most measurements conducted are below 7 GHz and one measurement at 24 GHz is present [4].

- TR 38.901 7.4.1-1 defines the RMa LOS and NLOS path loss models [1].

- Observations for the RMa LOS path loss model [6]:
  - Lacks physical meaning – “min” correction factor terms are non-physical curve fitting adjustments.
  - Use of h (average building height) is not justified considering that RMa scenario doesn’t have tall buildings.
  - LOS breakpoint distance is not appropriate for mmWave bands in RMa scenario.

- Observations for the RMa NLOS path loss model [6]:
  - Based on measurements conducted in dense urban environment (Tokyo) and at ultra high frequencies (UHF) up to 1433 MHz, so many parameters do not apply.
  - No logical explanation exists for having correction factors for street width and building height in rural environments.

Proposal 3: Validate and extend RMa Path Loss Models for FR3 and mmWave [2/2]

- Small measurement campaign at 24 GHz was conducted based on which RMa path loss models are extended up to 30 GHz.
  - Limited 2D Tx-Rx separation distance was used 200 to 500 m in 24 GHz measurements.
  - RMa LOS model valid up to 10 Km and RMa NLOS model valid up to 5 km. But the measurement distances is only 500m.

- Very limited empirical evidence exists to support RMa LOS and NLOS path loss models above 6 GHz.

- Work in [6] conducted measurement in RMa scenario at 73 GHz and developed a CIH Path loss model for RMa scenario.

- The authors in [6] also provide a comparison of TR 38.901 models with the empirical model derived from measurements and underscore the limitations/inaccuracy of TR 38.901 RMa path loss models.

- Validate the accuracy of the RMa path loss models by conducting more measurements in mmWave bands/considering measurements data collected in work like [6].

- No measurement data exists to validate the RMa path loss models in FR3 frequency range. Thus, additional measurements are needed in FR3 bands.

Proposal 4: Consider Base Station (BS) height dependency for Pathloss Models

- Pathloss model only with the fixed BS height measurement [4].

- For the UMi and UMa scenarios the LOS and NLOS pathloss models may not be impacted by BS height. The height of buildings in UMi and UMa scenario usually range from 20 to 150 m and BS height is 10 m and 25 m in UMi and UMa scenarios, respectively. Hence, reducing or increasing the BS height will still lead to a very similar propagation environment.

- RMa scenario has a dependency on height of BS [6].

- InH scenario may have a dependency on height of BS. However, these might not be large because the BS height is limited to 1 to 5 m (typical height of the ceiling in an indoor environment).

- InF scenario may have a dependency on height of BS. However, these may be large depending on the factory environment because the BS height can range from 1 to 15 m (typical height of the ceiling in a large indoor factory).

Proposal 5: Study the effect of near-field (NF) and non-stationarity in spatial domain for FR3 channel model

- NF and non-stationarity become prominent at FR3 bands [9].
- Near field is characterized by spherical waves instead of planar waves.
- Channel gain scales differently with distance in the NF, thus it is critical to have accurate knowledge of the NF regions to apply the corresponding power scaling laws. Path loss reduction based on distance^2 may not be applicable in the near-field region.
- Need to verify the accuracy of path loss models in TR 38.901 Table 7.4.1-1 [1] in the near-field region.
- Impact of small-scale channel parameters in near-field. May need to update the parameters in TR 38.901 Table 7.5-6 [1].
- Measurements are required in FR3 band to study and include the effect of NF in channel modeling (if required).

Proposal 6: Verification of frequency dependent parameters

- Validate whether linear interpolation of channel parameters listed in TR 38.901 Table 7.5-6 [1] holds true for FR3 bands [4].
- Verify the Delay Spread (DS) and Angular Spread (AS) dependence on frequency.
- No clear dependence of DS on frequency [4].
- Work in [7] based on real-world measurements conducted in 28 and 73 GHz shows a clear decrease in DS as the frequency increases in indoor scenarios for LOS and NLOS (Table 2).
- Further investigation is needed to study the dependance of DS on frequency for different frequency bands (including FR3), scenarios (indoor and outdoor) and channel conditions (LOS and NLOS).

Table 2. Omnidirectional DS for indoor LOS and NLOS scenarios at 28 and 73 GHz [7].

Omnidirectional RMS Delay Spread	InH LOS				InH NLOS			
	NYU WIRELESS		3GPP		NYU WIRELESS		3GPP	
	28 GHz	73 GHz	28 GHz	73 GHz	28 GHz	73 GHz	28 GHz	73 GHz
min DS	0.7 ns	0.6 ns	N/A	N/A	0.6 ns	0.5 ns	N/A	N/A
max DS	134.4 ns	101.9 ns	N/A	N/A	198.5 ns	142 ns	N/A	N/A
mean DS	10.8 ns	6.24 ns	20.4 ns	20.21 ns	17.1 ns	12.3 ns	27.4 ns	21.52 ns

Proposal 7: Further investigation on ways to mitigate interreference between TN and NTN

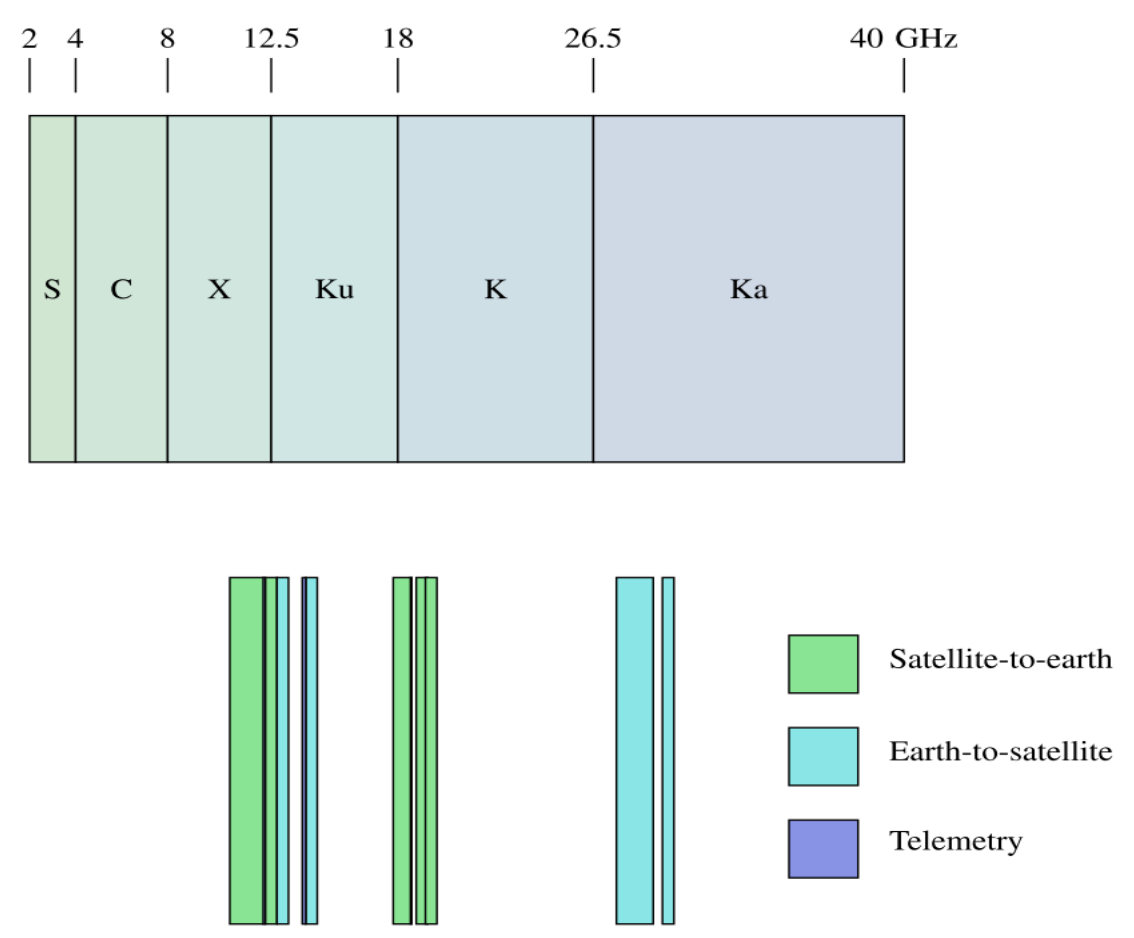


Figure 6. Top: Satellite bands. Bottom- Request made by Starlink to FCC for satellite additional bands which are in the FR3 range [1].

- Currently as per 3GPP has focus on S and Ka bands for satellite services, which is outside FR3 band.
- Some Satellite operators are requesting access to FR3 bands for operation.
- This can cause interference between Terrestrial and Non-terrestrial networks.
- Further studies are needed to analyze interference between TN and NTN networks and ways to mitigate interference.

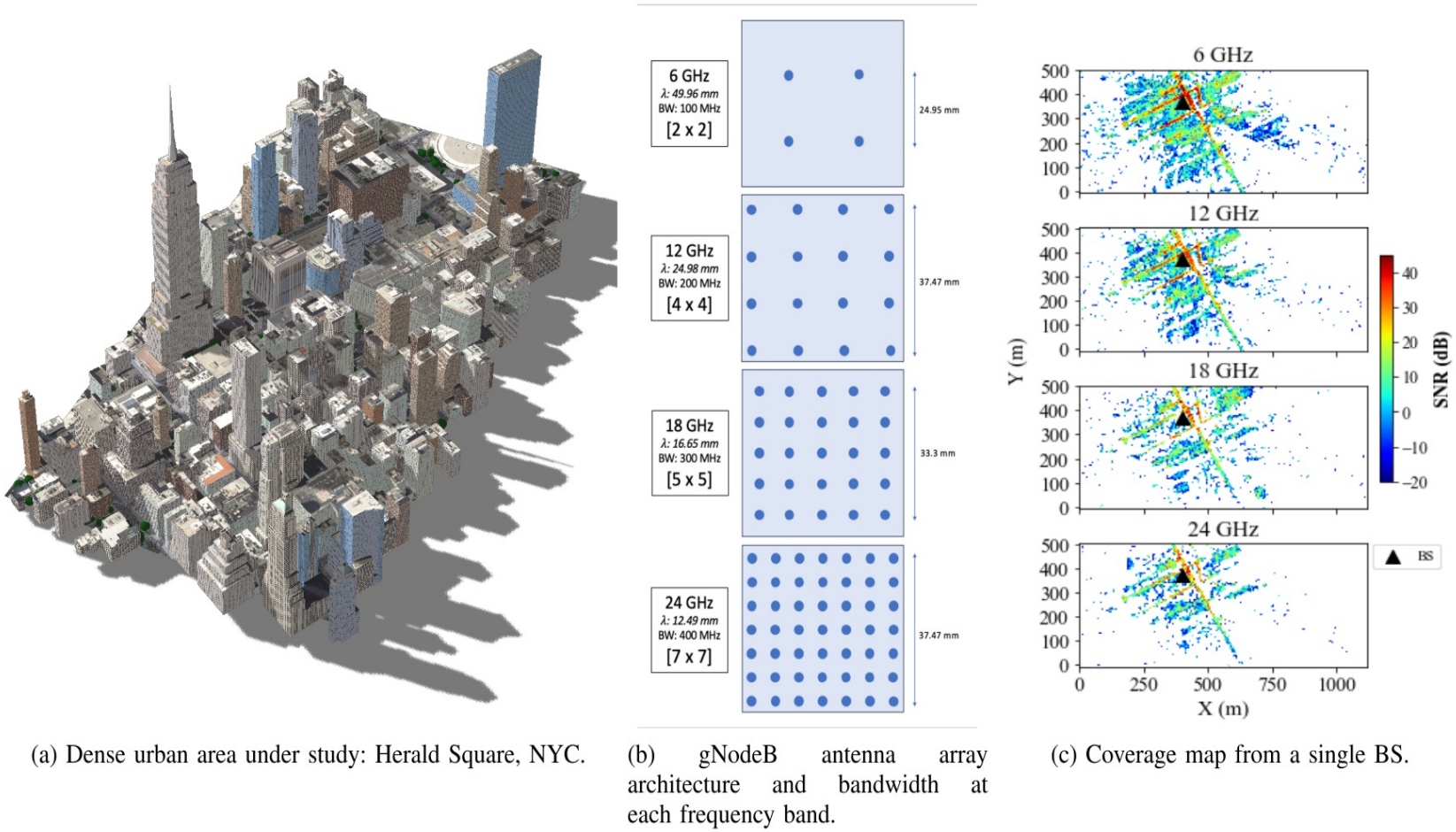
Proposal 8: Investigate the effect of blockage across the FR3 band [1/2]

Table 3. Simulation parameters for Coverage Analysis in FR3 bands [2].

Parameters	Values			
Area (m^2)	1120×510			
Inter-site distance between BSs (m)	200			
Transmission power of users (dBm)	23			
Number of sectors for BSs	3			
Down-tilted antenna angle of BSs	$-12°$			
UE Noise figure	7 dB			
Field pattern of antenna element	3GPP TR 37.840 [47]			
Frequency-dependent parameters				
Frequency [GHz]	6	12	18	24
Bandwidth [MHz]	100	200	300	400
UE URA dimensions	2×2	4×4	5×5	7×7

- Simulation parameters to study Coverage in FR3 band.
- 18 gNB locations are selected manually and the gNB is located on rooftops (20 m–160 m).
- SNR computed at each UE location from each base station.
- UE is height is fixed at 1.6 m.

Proposal 8: Investigate the effect of blockage across the FR3 band [2/2]



(a) Dense urban area under study: Herald Square, NYC.

(b) gNodeB antenna array architecture and bandwidth at each frequency band.

(c) Coverage map from a single BS.

Figure 7. Simulation results obtained via ray tracing a dense urban area of NYC at four frequencies in the upper mid-band for one example base station site [2].

- Coverage map for a single BS deployment is shown in Figure 7 using ray-tracing.
- Rooftop deployments causes coverage problem in NLOS street, coverage reduces as the frequency increases in the FR3 band.
- Lower gNB deployments may cause coverage to decrease further due higher chances of link being blocked.

Extension of channel model above 100 GHz with a focus on sub-THz Bands

Proposal 9: Include Atmospheric Attenuation Models for frequencies above 100 GHz

- Current 3GPP TR 38.901 channel model limited to 100 GHz [1] and captures far-field radio propagation only.

- Atmospheric attenuation models/molecular absorption models not required for frequencies less than 100 GHz as attenuation due to atmosphere is insignificant (less than 1 dB/Km or 0.1 dB/100 m as shown in Figure 8).

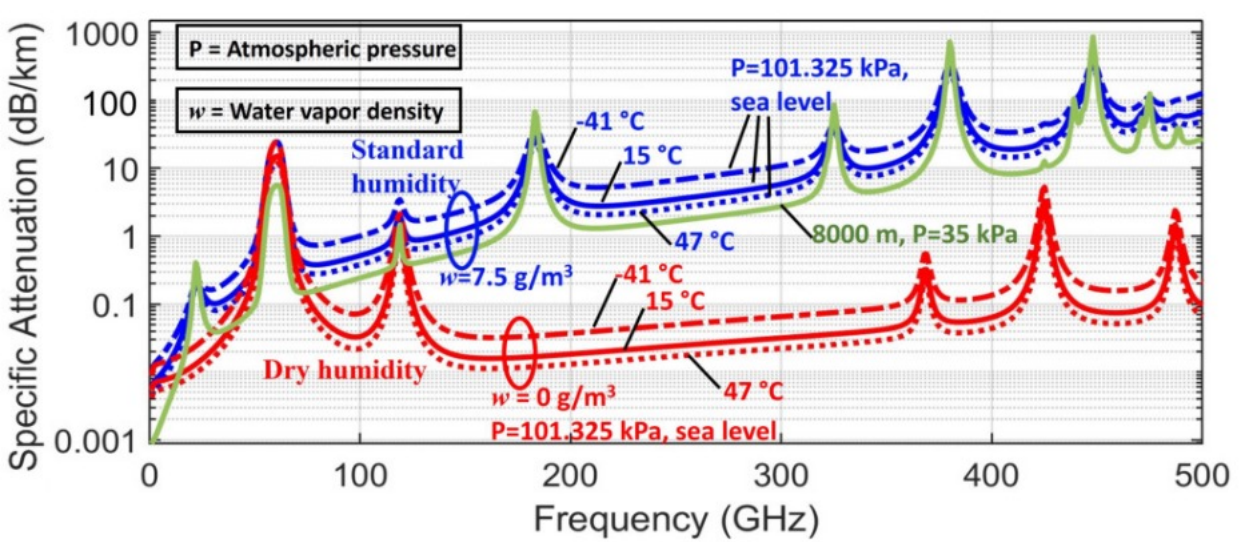


Figure 8. Atmospheric attenuation of electromagnetic waves for temperatures at 15 ◦C, extreme heat (47 ◦C, Kuwait), and cold (-41 ◦C, Russia), 101.3 kPa sea level and 35 kPa (8848 m above sea level, Nepal) atmospheric pressure, and water vapor density (w) of zero and 7.5 g/m3 [10].

- However, in the sub-THz bands (100–300 GHz) the atmospheric attenuation is within ~100 db/Km or 10db/100 m and beyond 300 GHz it can go higher than 10 db/100 m (Figure 8). Thus, in addition to the large-scale path loss loss one must include the effect of atmospheric attenuation for frequencies above 100 GHz.

Proposal 10: Additional Modeling Components above 100 GHz

- LOS probability models in TR 38.901 Table 7.4.2-1 [1] are frequency independent and thus may not require any change.
- Validate and extend the path loss models in TR 38.901 Table 7.4.1-1 [1].
- Validate and extend the material penetration loss models in TR 38.901 Table Table 7.4.3-1 [1].
- Validate and extend the O2I building penetration loss models in TR 38.901 Table Table 7.4.3-2 [1].
- Validate and extend the channel model parameters in TR 38.901 Table 7.5-6 [1] in all scenarios.
- Near-field propagation and spatial non-stationarity (due to large antenna arrays) are important for frequencies above 100 GHz and are not modeled in the current 3GPP TR 38.901 channel model [1,9].
- Beam squinting effect.
- Doppler effect above 100 GHz.
- Accurate modeling of blockage.

Conclusion

- Conduct measurements, validate and refine (if needed) the 3GPP TR 38.901 channel model for different scenarios accordingly for frequencies less than 100 GHz especially FR3.
    - Proposal 1: Accurately model the material penetration loss for various materials in the FR3 bands.
    - Proposal 2: Accurately model the O2I building penetration loss in the FR3 bands.
    - Proposal 3: Validate and extend RMa Path Loss Models for FR3 and mmWave.
    - Proposal 4: Consider Base Station height dependency for Pathloss Models.
    - Proposal 5: Study the effect of near-field and non-stationarity in spatial domain for FR3 channel model.
    - Proposal 6: Verification of frequency dependent parameters.
    - Proposal 7: Further investigation on ways to mitigate interreference between TN and NTN.
    - Proposal 8: Investigate the effect of blockage across the FR3 band.
- Channel model extension above 100 GHz.
    - Proposal 9: Include Atmospheric Attenuation Models for frequencies above 100 GHz.
    - Proposal 10: Additional Modeling Components above 100 GHz.

References

[1] 3GPP, “Study on channel model for frequency spectrum from 0.5 to 100 GHz,” TR 38.901.
[2] Kang, S., Mezzavilla, M., Rangan, S., Madanayake, A., Venkatakrishnan, S.B., Hellbourg, G., Ghosh, M., Rahmani, H. and Dhananjay, A., 2023. Cellular Wireless Networks in the Upper Mid-Band. *arXiv preprint arXiv:2309.03038*. (https://arxiv.org/abs/2309.03038).
[3] Haneda, Katsuyuki, et al. "5G 3GPP-like channel models for outdoor urban microcellular and macrocellular environments." *2016 IEEE 83rd vehicular technology conference (VTC spring)*. IEEE, 2016 (https://arxiv.org/pdf/1602.07533.pdf).
[4] RWS-230212 Rel-19 Workshop “Motivation and Proposal for FR3 channel model study in Rel-19”.
[5] Ju, S., Kanhere, O., Xing, Y., & Rappaport, T. S. (2019, December). A millimeter-wave channel simulator NYUSIM with spatial consistency and human blockage. In *2019 IEEE global communications conference (GLOBECOM)* (pp. 1-6). IEEE (https://arxiv.org/pdf/1908.09762.pdf).
[6] MacCartney, George R., and Theodore S. Rappaport. "Rural macrocell path loss models for millimeter wave wireless communications." *IEEE Journal on selected areas in communications* 35.7 (2017): 1663-1677 (https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7914696).
[7] Xing, Yunchou, Theodore S. Rappaport, and Amitava Ghosh. "Millimeter wave and sub-THz indoor radio propagation channel measurements, models, and comparisons in an office environment." *IEEE Communications Letters* 25.10 (2021): 3151-3155. (https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9450830)
[8] Ju, Shihao, et al. “142 GHz Sub-Terahertz Radio Propagation Measurements and Channel Characterization in Factory Buildings”, Accepted in 2023 Transactions on Wireless Communications.
[9] RP-231760 RAN Plenary 101 “Views on Channel modeling and ISAC studies in Rel-19”.
[10] D, Shakya, et al. “Radio Propagation Measurements and Statistical Channel Models for Outdoor Urban Microcells in Open Squares and Streets at 142, 73, and 28 GHz”, Submitted in 2023 Transactions on Antennas and Propagation.