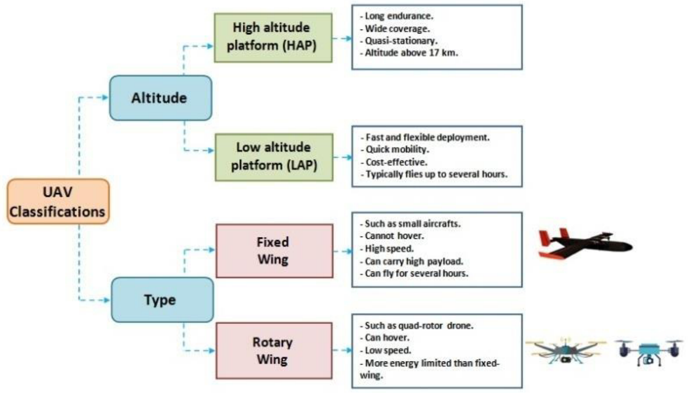
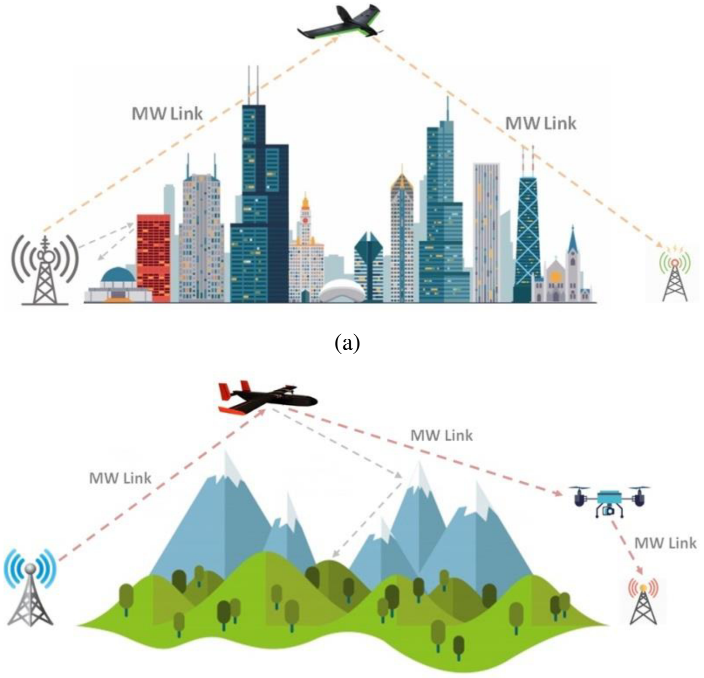


This article will emphasize fixed and rotary wing UAVs to assist the 5G network in different phenomena.

UAV Assisted NLOS Communication

Due to different infrastructures, objects and obstacles (buildings, trees, and mountains) presented in the ground, LOS (line of sight) of communication is quite difficult or sometimes impossible. As there is no LOS connectivity the propagated signal that is why degrades and sometimes totally lost due to the reflection, refraction, scattering, multipath fading effect, etc. To ensure communication between two ground transceiver stations preserving favorable signal strength, UAVs can be highly assistive to support this kind of NLOS (non-line of sight) communication ensuring a favorable data rate. The figure (fig. 6) will show UAV assisted NLOS communication.



(a)

(b)

Fig 6 (a) & (b). (a) UAV assisted NLOS communication in a city area,
(b) NLOS communication in an area with tall mountains

UAV Assisted Communication in Dense City

Communication UAVs or drones can be utilized to facilitate network communication in dense cities so as to ensure better communication and data rate. The UAVs can be utilized in dense cities to ensure communication between transceiver stations (Base Stations or gNBs) where LOS is not possible due to high-rise buildings or the in-between distance is much longer. UAV to UAV aerial communication can also be incorporated to establish longer distance length and extended coverage. The high altitude UAVs can be used to feed the lower altitude UAVs or drones or quad/hexa-copters to provide 5G mmWave communication to moving traffics or vehicles around the city and to provide connectivity in buildings where connectivity or communication via base stations is not possible. Furthermore, the UAVs can be utilized to provide coverage in street canyons where the transmitted signal level significantly degraded. Additionally UAVs can be used to feed base stations implemented above high-rise buildings where signals from ground base stations suffer significant degradation during communication. The figure (fig. 7) will illustrate the possible scenarios of a dense city where UAVs can be incorporated to enhance the 5G network.

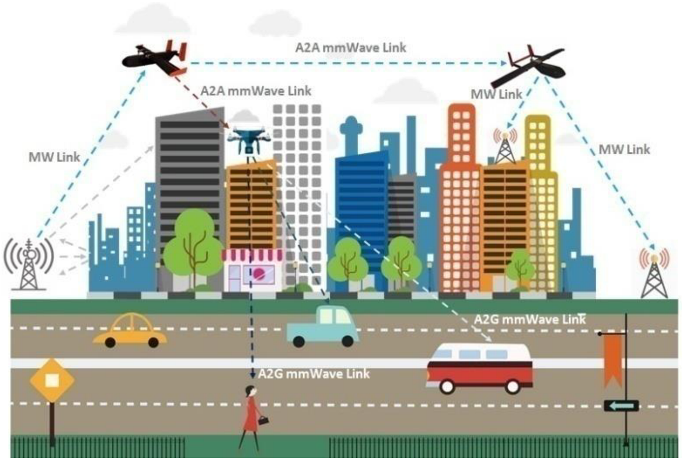


Fig 7. UAVs to assist the network in a dense city

UAV Assisted Macro to Small Cell Primary Link

The UAVs can be incorporated to extend coverage from a macro base station to a small base station. In this case, the UAV will work as a floating repeater or work as a coverage extender to provide a primary communication link between macro and small base stations of the 5G network. This type of network can be suitable where a direct LOS communication is not favorable or establishing a fiber optic link is not possible. Fig. 8 will show a macro to small cell UAV based communication network.

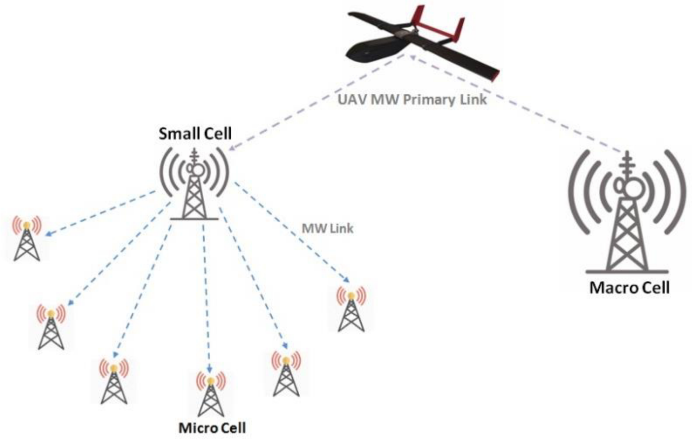


Fig 8. UAV supported macro to small cell primary link

UAV Assisted Macro to Small Cell Backhaul or Supportive Link

UAVs can be used to provide a backhaul or secondary link between 5G base stations (gNBs) as a supportive link with LOS MW (Micro Wave) link and/or optical fiber link. The figure (fig. 9) below will illustrate this type of network.

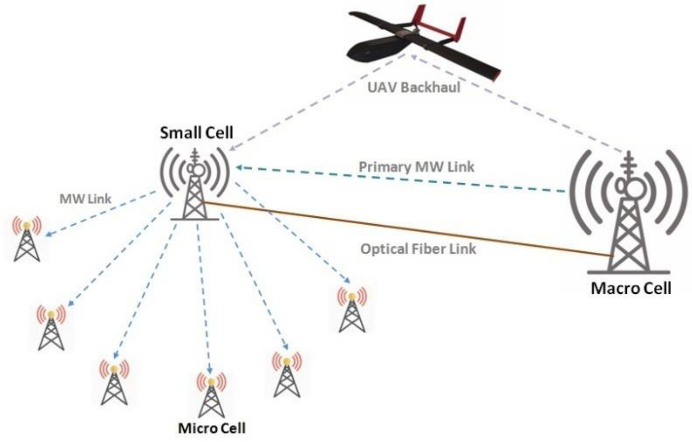


Fig 9. UAV backhaul link

UAV Assisted Coverage Extension

The UAVs can be incorporated to extend the network coverage. In this case, an extended link has been established from a base station (small cell) via UAV to support network connectivity with Pico cells (one of the 5G cell concepts to extend coverage) to extend the network coverage and capacity further. Fig. 10 will show the UAV assisted coverage extension scenario.

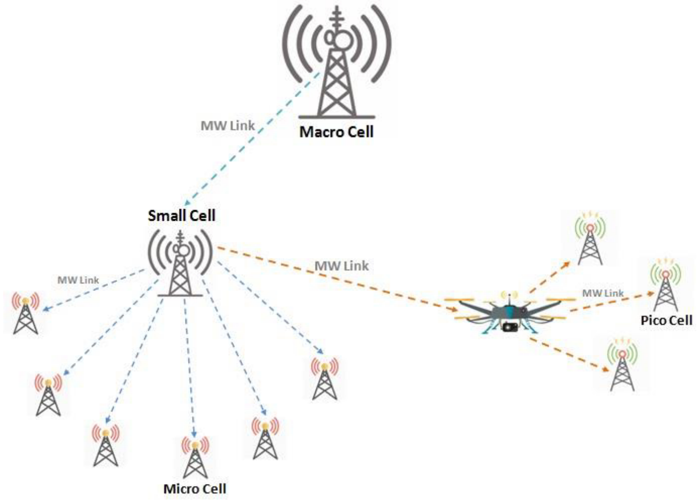


Fig 10. UAV assisted coverage extension

UAV Assisted Macro to Small Cell to UAV to UE

The UAVs can be used to provide mmWave communication link to the users directly when the users are in the nearby perimeter of the UAV's coverage and required a higher data rate. In this case, a macro cell will feed a small cell with network connectivity through an MW link then the small cell will feed the UAV over an MW link and finally the UAV will provide mmWave link to the user equipment within its coverage to ensure higher data rate communication. The fig. 11 will show an illustration of this network connectivity.

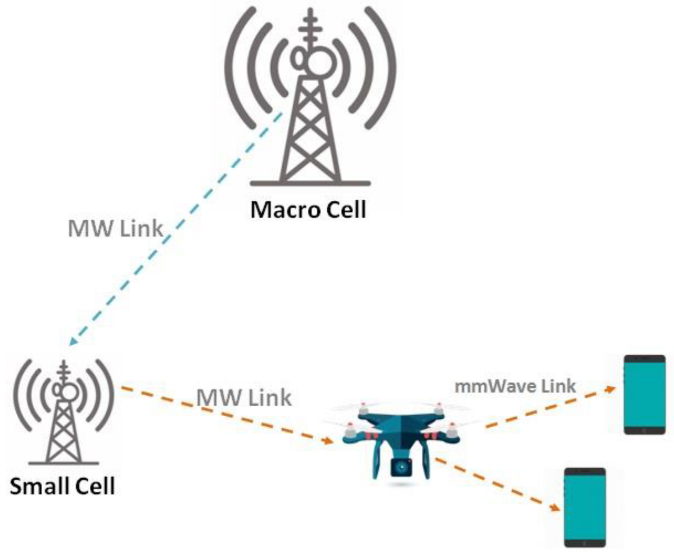


Fig 11. UAV Assisted Macro to Small Cell to UAV to UE connectivity

UAV Assisted Macro Cell to UAV to Micro Cell

Unmanned Aerial Vehicles (UAV) can be incorporated to establish a link and extend coverage from a macro cell to a micro cell. If the establishment of a direct link from the macro cell to micro cell is not possible than UAVs can be used between them as a floating or flying network extender. In this kind of network, the macro cell (5G base station) will feed the UAV with a radio link (microwave link) then the UAV will ensure support to the micro cells to extend the network coverage. Fig. 12 will show the network.

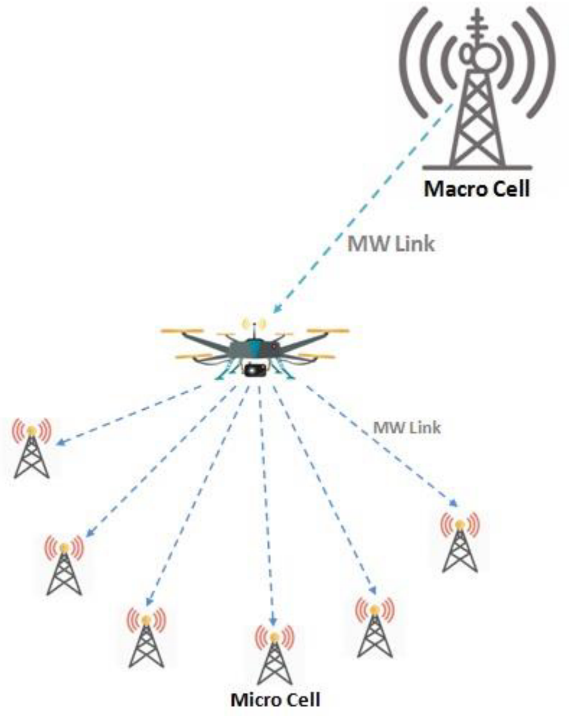


Fig 12. Macro cell to UAV to micro cell connectivity

UAV Assisted Macro Cell to UE via UAV

UAVs can provide a direct communication link to the user equipment (UE). In an area where ensuring network to the user equipment via a base station (macro or small or micro) is not possible in such case UAVs can be used to provide the communication link to the user equipment where the UAVs are fed by the macro cells over a microwave link. Fig. 13 will illustrate the network.

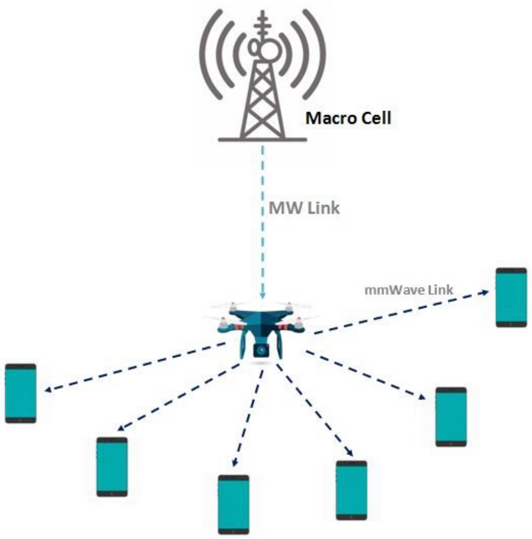


Fig 13. Macro cell to UE via UAV

UAV Assisted Vehicular Communication

UAVs can be utilized to establish a favorable communication link with the vehicles. For high-speed vehicles direct data communications through base stations sometimes unable to ensure a favorable communication link because of different environmental conditions, losses and Doppler Effect hence reduces the data rate as well. To combat such cased UAVs can be used to establish a favorable link with vehicles. Fig. 14 will illustrate the application of UAVs to assist in vehicular communication.

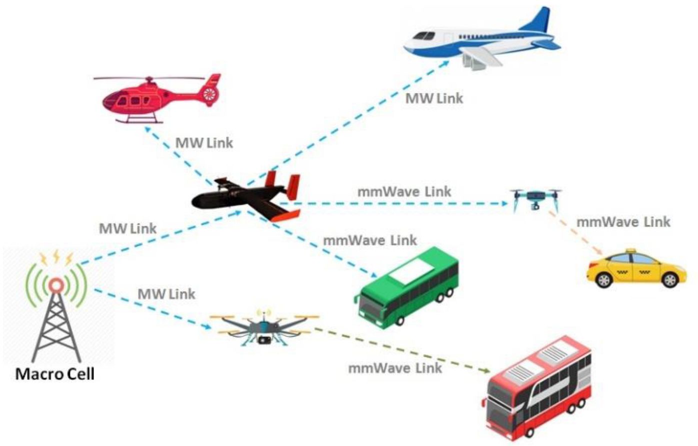


Fig 14. UAV Assisted Vehicular Communication

Offshore Communication with UAVs

UAVs can be highly useful and supportive to establish a communication link with a ship in deep sea which is far away from the shore and establishing a link through the base station is impossible. The following figure (fig. 15) will show the scenario of offshore communication via UAVs.

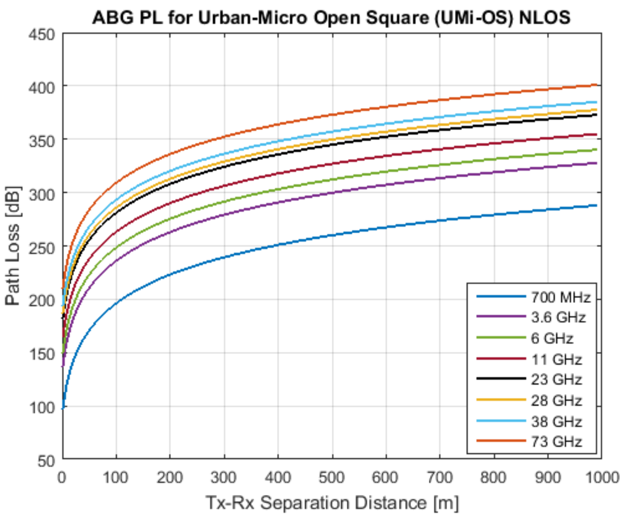


Fig 23. ABG UMi-OS (1000 m)

C. FI (Floating Intercept) Path Loss Model

The equation for the single-frequency FI model [60] is given by (4):

$$PL^{FI}(d)\ [dB] = \alpha + 10\beta log_{10}(d) + X_\sigma^{FI} \quad (4)$$

where $PL^{FI}(d)$ denotes the path loss in dB as a function of the 3D TX-RX separation distance d, α is a coefficient characterizing the dependence of path loss on distance, β is a floating intercept in dB, and X_σ^{FI} is the shadow fading (SF) standard deviation describing large-scale signal fluctuations about the mean path loss over distance [61].

The figure (fig. 24) will show path loss for the FI model UMi street canyon scenario for a Tx-Rx separation distance of 300 meters.

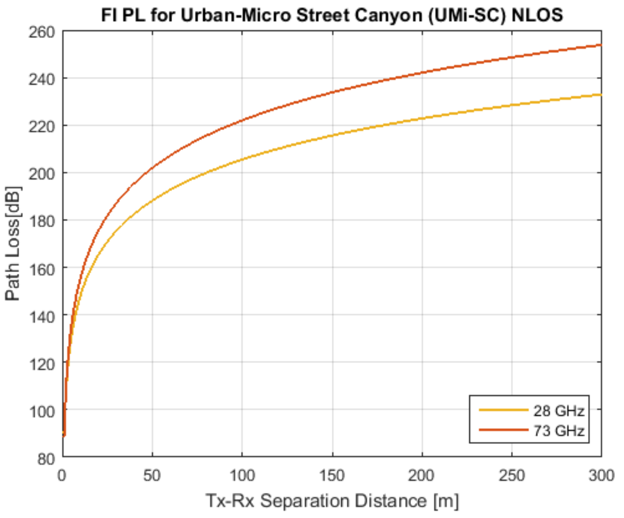


Fig 24. FI UMi-SC (300 m)

D. CI (Close-In Reference) Path Loss Model

The equation for the CI model [62] is given by (5),

$$PL^{CI}(f,d)[dB] = FSPL(f,1\,m)[dB] + 10n log_{10}(d) + X_\sigma^{CI},$$

(5), where d ≥ 1 m

where f is the frequency in Hz, n is the PLE (Path Loss Exponent), d is the distance in meters, X_σ^{CI} is the shadow fading (SF) with σ in dB, and the free space path loss (FSPL) at 1 m, with frequency f, is given as:

$$FSPL(f,1\,m) = 20log_{10}\left(\frac{4\pi f}{c}\right) \quad (6)$$

Note that the CI model has an intrinsic frequency dependence of path loss embedded within the 1 m FSPL value, and it has only one parameter, PLE, to be optimized. Furthermore, the CI model is applicable to both single and multi-frequency cases. Free space path loss in the first meter of propagation ranges between 32 and 72 dB from 1 to 100 GHz, where a substantial amount of path loss in a practical mmWave communication system occurs. This first meter of loss is captured in the FSPL term and is treated separately from the PLE which characterizes loss at distances greater than 1 m [63], [64].

The fig. 25 will show path loss for CI UMa LOS scenario for 1000 meters distance.

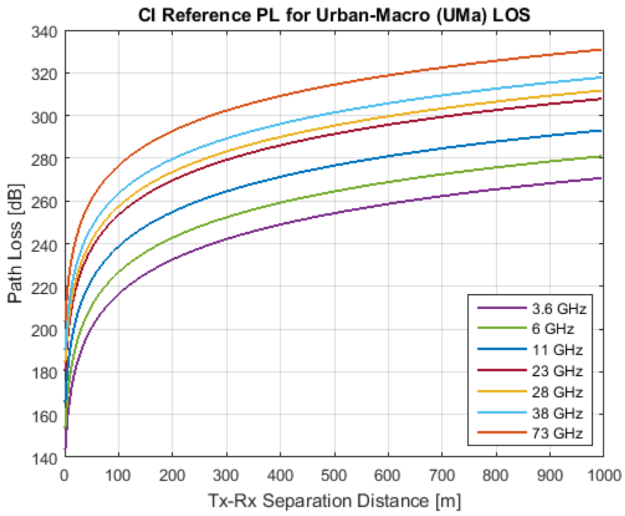


Fig 25. CI UMa LOS (1000 m)

The fig. 26 will show the path loss for CI UMa NLOS scenario for 2000 meters distance.

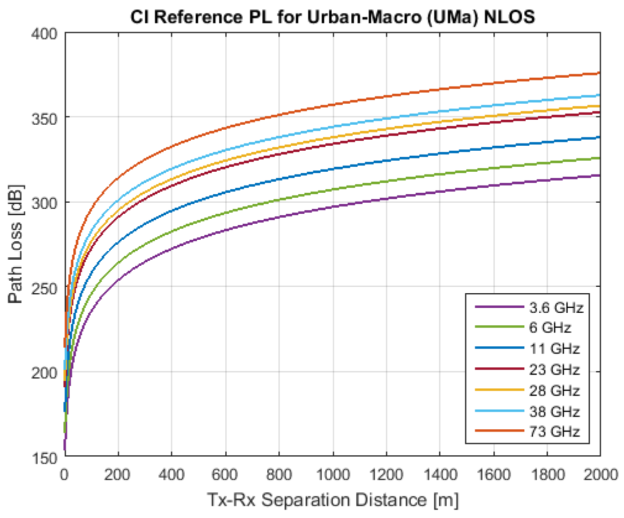


Fig 26. CI UMa NLOS (2000 m)

The fig. 27 will show path loss for CI UMi street canyon LOS scenario for 250 meters distance.

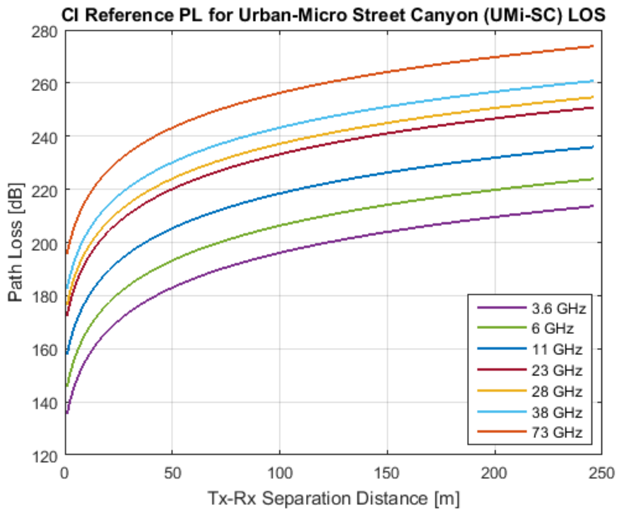


Fig 27. CI UMi-SC LOS (250 m)

The fig. 28 will show the path loss for CI UMi street canyon NLOS scenario for a distance of 600 meters.

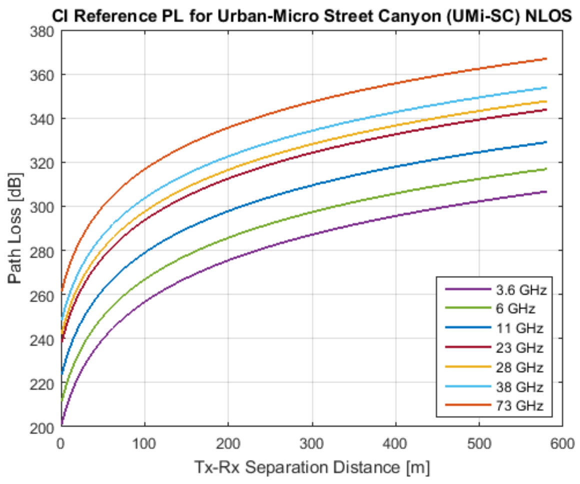


Fig 28. CI UMi-SC NLOS (600 m)

All those simulations shows the path loss in terms of frequency and distance and those are performed in Matlab to show that if the UAVs can be incorporated in a communication channel or link as a signal booster or repeater the path loss gets reduced (Lets consider the utilization of a UAV at half of the total distance between transmitter and receiver separation distance, the path loss decreases significantly which can be realized by the previously mentioned figures (fig. 20-28)).

Also, an important thing to be noted that low-frequency carrier signals suffer less path loss compared to the high-frequency carriers (by observing the figures above). The path loss is significant for high-frequency carrier signals when the transmitter-receiver separation distance is large. That is why according to the observance it can be said that low-frequency carriers are more suitable when the base station to UAV or UAV to base station link is longer and when the link is shorter high frequencies can be utilized.

Fig. 29 will define the 3D separation distance.

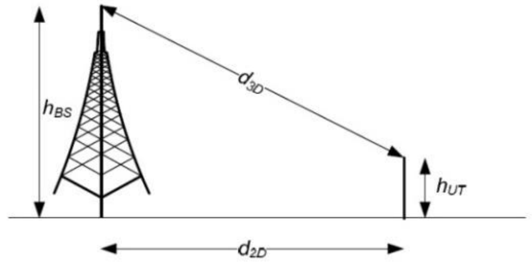


Fig 29. The definition of 3D separation distance

TABLE III: PARAMETERS USED FOR DETERMINING PATH LOSS

Model	Scenario	Frequency	Distance	Parameters
FSPL	LOS	700 MHz, 3.6, 6, 11, 23, 28, 38, 73 GHz	6 km	Not required

ABG	UMa-NLOS	700 MHz, 3.6, 6, 11, 23, 28, 38, 73 GHz	2000 m	α = 3.4, β = 19.2, γ = 2.3, SF = 6.5 dB
	UMi-SC-NLOS		1000 m	α = 3.48, β = 21.02, γ = 2.34, SF = 7.8 dB
	UMi-OS-NLOS		1000 m	α = 4.14, β = 3.66, γ = 2.43, SF = 7.0 dB
FI	UMi-SC-NLOS	28 GHz	300m	α = 80.6, β = 2.5, SF = 9.7 dB
		73 GHz		α = 80.6, β = 2.9, SF = 7.8 dB
CI	UMa-LOS	3.6, 6, 11, 23, 28, 38, 73 GHz	1000m	n = 2.0, σ = 4.6
	UMa-NLOS		2000 m	n = 2.7, σ = 10.0
	UMi-SC-LOS		250 m	n = 2.0, σ = 2.9
	UMi-SC-NLOS		600 m	n = 3.1, σ = 8.1

E. Atmospheric Attenuation

The strength of a propagated signal possibly can suffer atmospheric attenuation because of several atmospheric conditions. Rainfall is one of the most dominant reasons behind the atmospheric attenuation of the propagated signal. The 5G signals can be absorbed, scattered, depolarized, and diffracted by rainfall. This can restrict their propagation, causing high signal attenuation loss through the effective propagation path length. And the attenuation caused by the rain is significant in a long-distance wireless propagation channel or link. The figure (fig. 30) will illustrate the effects of rainfall on the propagating signal.

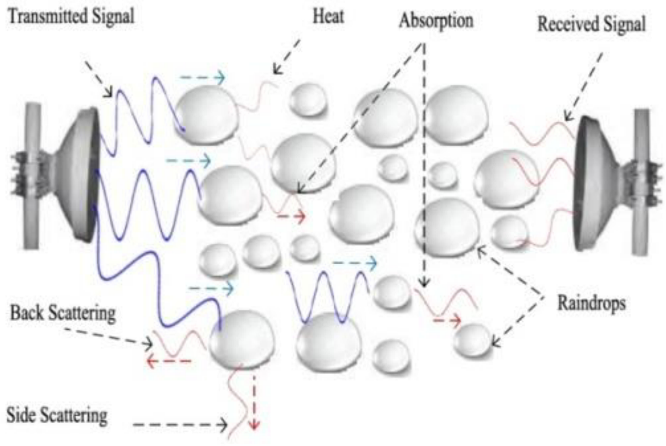


Fig 30. Effects of rainfall

The amount of signal attenuation per unit distance is characterized as SRA (Specific Rain Attenuation) estimated in [dB/km] [65]. The measurement of specific rain attenuation primarily relies upon the rain rate with the attributes of rainfall and the incident EM (electromagnetic) waves in that particular area. The rainfall characteristics incorporate the rain temperature, rainfall direction, shape of the drops, and raindrop size distribution; on the other hand, the characteristics of the EM waves incorporate the polarization, frequency band, and the direction of the propagated signal at that point. The specific rain attenuation additionally relies upon the forward scattering of the propagated EM wave. Its effect varies relying upon the water refractive index, temperature, and the frequency spectrum. In this way, some portion of the EM wave energy is absorbed by the raindrops and squandered as warmth, while the rest is scattered in different directions [66], as illustrated in Fig. 40. Accordingly, the specific rain attenuation is mathematically represented in Eq. 7 [67]:

$$\gamma = kR^{\alpha} \qquad (7)$$

where k and α denote the regression factors that are subject to several factors such as drop size distributions (DSD), temperature, operating frequency, and radio-wave polarization. The specific attenuation is also subject to the polarization type of EM radiations due to the non-spherical nature of the raindrops. The attenuation level that results from vertical polarization waves is less than what can result from horizontal polarization [33]-[38]. The values of parameters k and α can be obtained from ITU Rec. P.838-3 [99].

$$log_{10}\, k = \sum_{j=1}^{4}\left(a_j \exp\left[-\left(\frac{log_{10}f-b_j}{c_j}\right)^2\right]\right) + m_k log_{10}f + c_k, \qquad (8)$$

$$\alpha = \sum_{j=1}^{5}\left(a_j \exp\left[-\left(\frac{log_{10}f-b_j}{c_j}\right)^2\right]\right) + m_{\alpha} log_{10}f + c_{\alpha}, \qquad (9)$$

The specific rain attenuation denoted by Eq. 7 shows the rain attenuation per kilometer; while, the rain attenuation for the overall length between the transmitter and receiver ought to be determined by multiplying the specific rain attenuation, with the actual transmission path length, L, in case of uniformly distributed rainfall. Actually, the rainfall isn't typically uniformly distributed along the propagation path length of a radio wave; therefore measuring rain attenuation depending on the actual path length will produce incorrect results. That is why; the horizontal homogeneity of rainfall is required to be considered. This phenomenon was distinguished as the effective path length of the wireless link between the transmitter and receiver, which ought to be shorter than the actual propagation path. Thus, the effective path length can be mathematically calculated in Eq. 10 [68]:

$$L_{eff} = rL, (km) \qquad (10)$$

where L_{eff} denotes the effective path length, r denotes the path reduction factor or distance factor as introduced by ITU [69], and L represents the actual path length of a link between the transmitter and receiver. Several prediction models were suggested by different research groups to evaluate the rainfall variations [70]. The most preferred and famous model applied in such regions would be the distance factor proposed by ITU [69]. The model is evaluated as a function of frequency, with rain rate at 0.01% percentage of time, exponent in the specific attenuation model, and actual path length.

ITU-R Model

The most confident and famous model employed for calculating the path reduction factor is the ITU-R Model [69], which is mathematically provided in Eq. 11:

$$r = \frac{1}{0.477L^{0.633}R_{0.01}^{0.073\alpha}f^{0.123} - 10.579\left(1-\exp(-0.024L)\right)}, \quad (11)$$

where f denotes the frequency in GHz, $R0{:}01$ is the rain rate at 0.01% percentage of time, α is the exponent in the specific attenuation model, and L is the actual path length between the transmitter and receiver. The maximum recommended value by ITU for ‘r’ was 2.5; Eq. 3 was not used for small values for the denominator, providing larger values.

In all these models, the Complementary Cumulative Distribution Function (CCDF) of the rainfall rate and rain attenuation at a one-minute rainfall rate is required. From the specific rain attenuation and the effective path length, the total rain attenuation overall effective path lengths exceeded for 0.01% of the time calculated, as introduced by ITU-R [71]. Thus, from Eq. 7 and Eq. 10, the total rain attenuation overall effective path lengths that exceeded for 0.01% of the time is given in Eq. 12 [72], [73]:

$$A_{0.01} = kR^{\alpha}rL \quad (12)$$

$$\text{or, } A_{0.01} = kR^{\alpha}L_{eff} \quad (13)$$

The figure (fig. 31) will show the specific rain attenuation (SRA) for horizontal polarization.

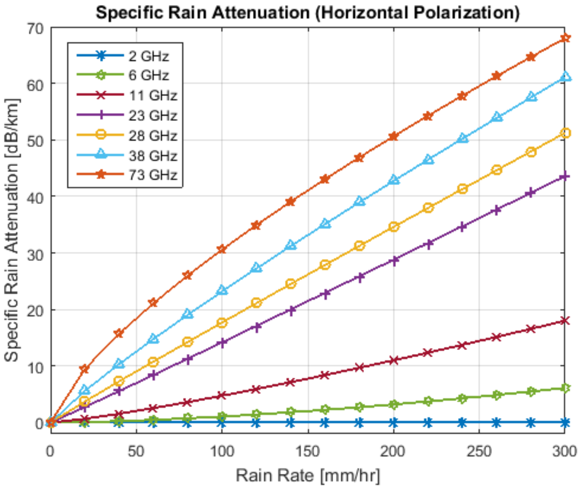


Fig 31. Specific Rain Attenuation (Horizontal Polarization)

Fig. 32 illustrates the specific rain attenuation (SRA) for vertical polarization.

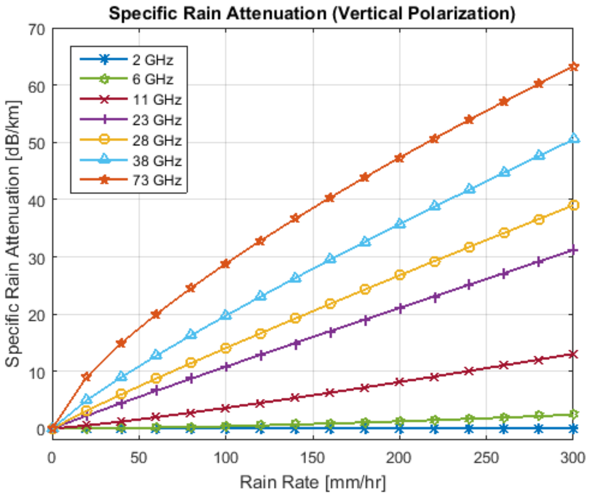


Fig 32. Specific Rain Attenuation (Vertical Polarization)

Comparing those figures a declaration can be given that if vertically polarized antennas are utilized in UAV assisted communications there will be less SRA (specific rain attenuation) compared to the horizontal polarization.

The fig. 33 will show the effect of rainfall for a 3 kilometers wireless communication link or channel for a carrier frequency of 38 GHz.

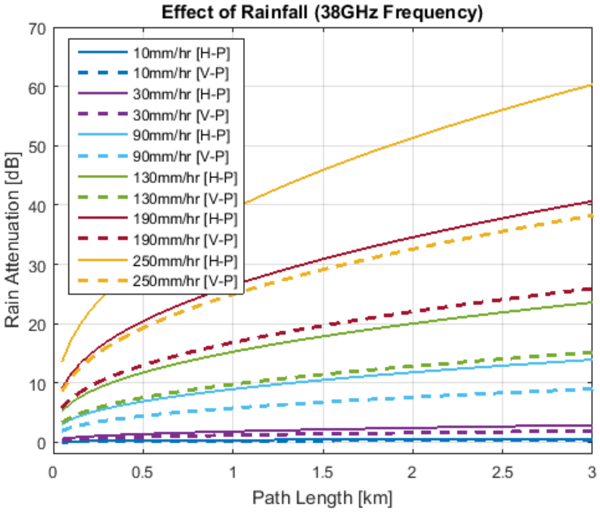


Fig 33. Effect of rainfall (3 km, 38 GHz)

Figure (fig. 34) will show the effect of rainfall and the amount of rain attenuation on different carrier frequencies for a path length of 3 kilometers with a rain rate of 100 mm/hr.

coverage during a crisis where UAVs can act as a flying wireless BS (base station) when the ground base station is down. They can likewise be utilized to enhance the capacity of ground base stations to ensure better coverage and higher data rate. Incorporating UAVs in wireless communication requires sophisticated research, where network topology, coordination among UAVs in a multiple UAV based network, energy consumption, and mobility balancing are few challenges confronting UAVs in wireless communication systems. This research article has represented UAV uses cases to assist the 5G NR focusing on the minimization of path loss, atmospheric attenuation, and enhancement of data rate. The article includes literature reviews of research and survey papers relevant to UAV assisted wireless communication, propositions to include UAVs in wireless communication scenarios, analyze network performance incorporating UAVs, challenges against UAV based wireless network and research scopes. The utilization of UAVs in wireless communication networks seemed to be highly assistive if properly investigated and researched. Sophisticated researches are required to make the usage of UAVs in wireless communication link in an effective manner. This article seems to be highly supportive of its audience and researchers to know about the UAV assisted wireless communication and perform further researches and enhancements.

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