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UAV Assisted 5G Het-Net: A Highly Supportive Technology for 5G NR Network Enhancement

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Abstract - Recently, unmanned aerial vehicles (UAVs) have grabbed impressive attention from industry and research network, because of the faster growth in a wide scope of applications. Especially, UAVs are being utilized to ensure a better solution to a dependable and cost-effective wireless communication network from the sky. The adoption of UAVs has been considered as an alternative supplement of existing cellular networks, to accomplish better transmission efficiency with enhanced coverage and network capacity. This article has represented some wireless communication scenarios where UAVs can be utilized to ensure better coverage, enhancement of efficiency and capacity. After that, to establish the effectiveness of UAVs in wireless communication the paper has included several performance scenarios (path loss, attenuation, and data rate) after utilizing UAVs in the wireless network. Finally concluded with discussing several challenges for UAV assisted wireless networks and the scopes of further enhancement of such kind of networks. This article might be informative to those who are engaged in research regarding UAV assisted wireless communication.

Keywords: 5G, Heterogeneous Network, Unmanned Aerial Vehicle, mmWave, Path Loss, Attenuation, Data Rate.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs), commonly known as drones, allude to a class of aerial vehicle that works without a human pilot on board. The light of UAVs can be acknowledged with different degrees of autonomy: either remotely controlled by an administrator or autonomously by the installed sensors and onboard computers or controllers programmed to perform dedicated tasks autonomously. Because of their capacity to hover, adequate adaptability, ease of deployment, high maneuverability, lower maintenance, and operating costs, UAVs have grabbed significant consideration recently for business applications. They are being utilized in an expansive scope of ways ranging from intelligent agriculture system, smart logistics support, law authorization, quick response to the disaster, pre-clinic emergency care, and mineral exploration, to private concerned commercial and non-commercial photography, video shooting, and drone racing [1], [2]. For example, Amazon prepared a business plan to own 450,000 business purpose drones in its product delivery system by 2020 under the proposed 'Amazon Prime Air' service, to extend the delivery of products worldwide [3].

Meanwhile, the innovation of highly capable UAVs has likewise prompted a lot of enthusiasm for the utilization of UAVs to ensure reliable and financially savvy solutions for wireless communications in many practical world scenarios. Specifically, by the support of wireless communication devices, UAVs can be quickly implemented as floating BSs (base stations) in 3D (three-dimensional) space. The UAVs for wireless communication have been viewed as a promising method to give universal access from the sky towards the ground UEs (user equipment) in specified regions for permanent support or temporary network support (e.g., hotspot zones). Contrasted with the ground static BSs, one unparalleled bit of leeway of utilizing UAV-based flying BSs is that their positions and heights can be progressively changed to provide on-the-fly A2G (air-to-ground) wireless communication links. The deployment of flying BSs has been regarded as an effective supplement of existing cellular frameworks to improve wireless network capacity and coverage expansion on the ground with higher traffic demands, to cope with the prerequisites of the 5G (fifth generation) and beyond cellular communications [4]. As an outcome of down to earth demands, a few UAV assisted wireless communication networks from different industrial communities have just been initiated, for example, AT&T's all-weather flying Cell on Wings (COW) to give the LTE (Long Term Evolution) coverage of the 4G (fourth-gen) cellular networks, Verizon's ALO (Airborne LTE Operations) to empower the access to remote connectivity, Nokia Bell Labs' F-Cell (flying-cell) to empower the 'drop and forget' small cell implementation anywhere, Facebook's Aquila utilizing the solar-power based UAVs to serve with Internet to under-served regions employing laser communications, and so on.

Moreover, UAVs can be deployed as relays to serve the ground UEs with wireless connectivity without any direct LOS (line-of-sight) communication links because of the blockage caused by the physical impediments like buildings or mountains. Accordingly, the load-carry and deliver forwarding technique is well fitted to the utilization of a single UAV to transfer data from one source UE to the destination UE, intending to achieve higher throughput [5]. From the point of view of aerodynamics attributes, the features of UAVs, for example, flying height, power source, payload, and perseverance time, will require the configuration of multi-tier engineering for future UAV aided cellular communication systems. It has been additionally featured that the collaboration, coordination, and self-organizing behavior of UAVs under this architecture can be utilized to form FANETs (flying ad hoc networks), IoD (Internet of Drones), and even UAV swarm like a group of birds which is beyond the

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capacity of a single UAV. The incorporation of intelligence into the UAV swarm will eventually bring heaps of advantages for 5G cellular networks, for example, higher spectral efficiency and better QoE (quality of experience) for ground UEs.

From the above mentioned practical application scenarios, it can be said that the widespread utilization of UAVs has asserted a significant influence on wireless communication. The wireless communication network incorporating one or multiple UAVs to support wireless networks has attracted considerably more consideration from both the academic community and industry. Beyond that, several other typical applications about UAV-assisted wireless networks include Internet of Things (IoT) [6], wireless sensor networks (WSNs) [7], vehicle-to-everything (V2X) communications [8], flyMesh [9], [10], wireless powered networks [11], mobile edge computing (MEC) [12], [13], caching aided wireless networks [14], cloud radio access networks (CRANs) [15], device-to-device (D2D) communications [16], emergency networks [17], cognitive radio (CR) networks [18], etc. In addition to the role of classic aerial BS, the part played by UAVs in these application scenarios has covered various networking entities such as an aerial relay, aerial data collector, aerial caching, aerial MEC server, aerial power source, and so on. Figure (fig. 1) will show an illustration of integrating UAV in the 5G cellular network.

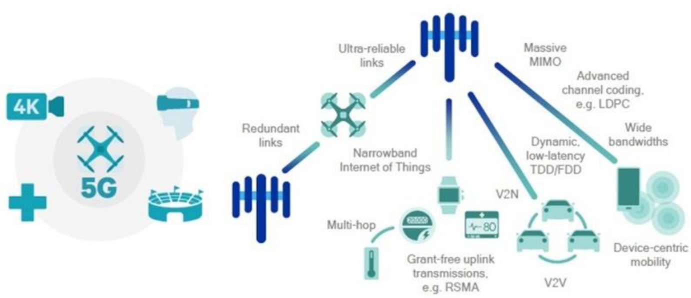


Fig 1. UAV in 5G network

II. LITERATURE REVIEW

A. 5G NR

Features of 5G NR (New Radio)

The 5G NR is based upon and intended to facilitate:

- eMBB (enhanced Mobile Broadband)
- URLLC (Ultra-Reliable Low Latency Communications)
- mMTC (massive Machine Type Communications)

eMBB -
The following features are supported by the 5G eMBB use case.
• Peak data rate: 10 to 20 Gbps
• 100 Mbps whenever needed
• 10000 times greater traffic
• Macro and small cells support
• High mobility up to 500 Kmph
• Network energy savings by 100 times [19].

mMTC –
The following features are supported by the 5G mMTC use case.
• A high density of devices (about 2 x 10^5 - 10^6/Km^2)
• Supports a long-range
• A lower data rate (about 1 to 100 Kbps)
• Leverages the benefits of the ultra-low-cost of M2M
• It offers 10 years of battery life
• Provides asynchronous access [20].

URLLC -
The following features are supported by the 5G URLLC use case.
• Provides ultra-responsive connections.
• 1 ms air interface latency.
• 5 ms end-to-end latency between UE (i.e. mobile) and 5G gNB (i.e. base station).
• Ultra-reliable and available 99.9999% of the time.
• Ensures low to medium data rates (about 50 kbps to 10 Mbps).
• High-speed mobility [21].

Fig. 2 will show the features of eMBB, mMTC, and URLLC.

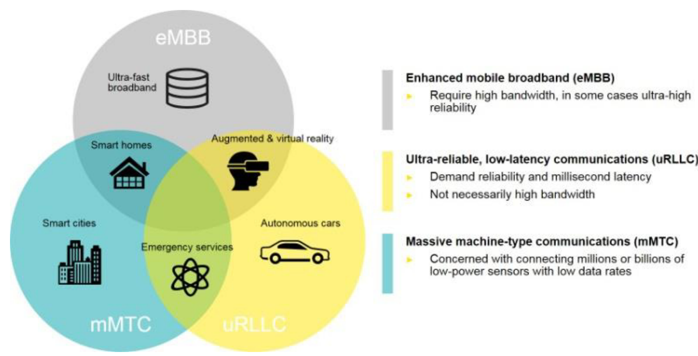


Fig 2. Features of eMBB, mMTC, and URLLC

Technologies Behind 5G

There are numerous new 5G technologies that are being researched and analyzed for incorporation in the 5G standards. These new techniques and advancements will enable 5G to ensure progressively adaptable and dynamic assistance. The innovations being developed for 5G includes:

Millimeter-Wave communications: Utilizing frequencies of higher frequency spectrum opens up a wide spectral range and ensures the probability of having wider channel bandwidth. However, most of the frequency bands of around 2 GHz and bandwidths of 10 - 20 MHz are at present being used. For 5G, frequency bands beyond 30 GHz are in consideration and this will exhibit some difficulties in the case of circuit design, the technology, and the manner in which the system is utilized, these frequencies can't propagate far and are assimilated totally by surrounding obstacles. Different nations are utilizing different frequency spectrum for 5G [22].

Waveforms: One of the prime areas of interest in 5G NR (5G New Radio) is that of the new waveforms that might be seen. OFDM has been utilized effectively in 4G LTE and also in various other higher data rate frameworks (networks), yet it has a few confinements in certain conditions. Other waveform techniques that are being analyzed include GFDM (Generalized Frequency Division Multiplexing), FBMC (Filter Bank Multi-Carrier), and UFMC (Universal Filtered Multi-Carrier). There is no perfectly ideal waveform, and it is conceivable that OFDM with its multiple access scheme OFDMA, is utilized as which exhibits better performance without being the excessively complex level of processing technique required [23].

Multiple Access: A variety of new multiple access schemes are being researched and analyzed for 5G NR. Techniques including OFDMA, SCMA, NOMA, PDMA, MUSA, and IDMA have been in consideration. As mentioned earlier, during research it seems that the most likely scheme would be OFDMA [24].

Massive MIMO with beam-steering: In spite of the fact that MIMO is being utilized in numerous applications from LTE to Wi-Fi, and so on, the numbers of antennas are limited. Utilizing microwave frequencies opens up the plausibility of utilizing a huge number of antennas on single equipment, becomes a possibility because of the antenna sizes and spacing relevant to wavelength. This would empower beams to be steered to ensure enhanced 5G NR performance.

Dense networks: Diminishing the cell area ensures overall effective utilization of the spectrum available. Technologies to facilitate that small cells in the macro-network and implemented as femtocells can work satisfactorily as per requirement. It is very challenging to add large numbers of additional cells to a network, and technologies are being introduced to empower this. These are a couple of primary techniques being developed and examined for 5G NR.

5G mmWave Communications

This section of the article has focused on papers that have been dedicated to mmWave communications for 5G wireless communication networks. The section observed papers regarding different characteristics of mmWave and utilization of mmWave to serve the purposes of 5G including the of Rangan *et al.* [25], Xiao *et al.* [26], Niu *et al.* [27], Rappaport *et al*. [28], Hemadeh *et al*. [29], Rappaport *et al*. [30], Zhou *et al*. [31], and Jameel *et al*. [32] briefly discussed on topics relevant to the 5G mmWave communications. Table I has described those papers in brief.

TABLE I: PAPERS RELEVANT TO 5G MMWAVE COMMUNICATION

Paper	Topic	Elaborated and addressed issue
Rangan *et al.*	mmWave cellular wireless networks	Channel measurement, adaptive beamforming, multi-hop relaying, heterogeneous network architecture, and carrier aggregation
Xiao *et al.*	mmWave communications for 5G and beyond 5G networks	mmWave channel measurements campaigns and modeling, mmWave MIMO systems, multiple-access technologies, and mmWave bands for backhauling
Niu *et al.*	mmWave communications for 5G networks	Characteristics, research challenges, and potential applications of mmWave communications.
Rappaport *et al.*	mmWave communications for 5G and beyond 5G networks	mmWave propagation measurements campaigns
Hemadeh *et al.*	mmWave communications for 5G and beyond 5G networks	mmWave propagation characteristics, channel modeling, and design guideline
Rappaport *et al.*	mmWave communications for 5G and beyond 5G networks	mmWave propagation models
Zhou *et al.*	IEEE 802.11ay based mmWave WLANs	Channel bonding and aggregation, channel access and allocation, beamforming training and beam tracking, SU-MIMO and MU-MIMO beamforming
Jameel *et al.*	Propagation channel modeling for mmWave vehicular communication	mmWave channel modeling approaches, channel attributes, and channel models based on three measurement scenarios including V2I, inter-vehicular, and intra-vehicular

B. UAV Assisted Wireless Networks and Communications

A couple of papers relevant to UAV communications have been published over the past couple of years, including the characteristics and requirements of UAV networks, main communication issues, cyber-security, wireless charging techniques, and channel modeling for UAV communications, etc.

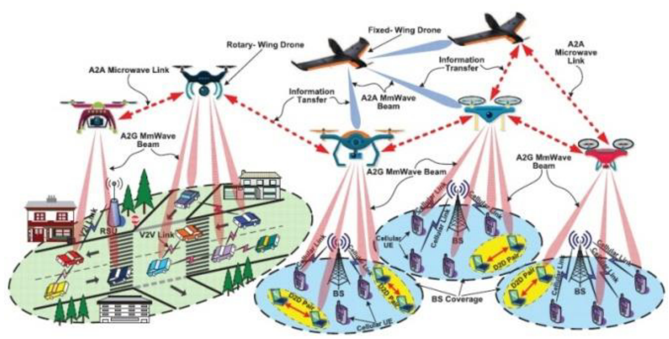
More specifically, Hayat *et al.* [33], Gupta *et al.* [34], Motlagh *et al.* [35], Krishna *et al.* [36], Khawaja *et al.* [37], Khuwaja *et al.* [38], Cao *et al.* [39], Bekmezci *et al.* [40], Xiao *et al.* [41], Mozaffari *et al.* [42], Fotouhi *et al.* [43], Li *et al.* [44], Sekander *et al.* [45] have focused on research topics relevant to UAV assisted wireless communications for 5G, beyond 5G and other types of wireless networks. Table II has enlisted those paper and their research topics in brief.

In addition to those papers on UAV networks, UAV cellular networks, UAV-enabled wireless networks, FANETs, and multi-tier drone networks, several other papers have also been published on different topics with regard to UAV-related networks and communications, such as channel modeling, civil applications [46], UAV-assisted vehicular networks, wireless charging techniques [47], game-theoretic optimization approach [48], CR-based UAV [18], etc.

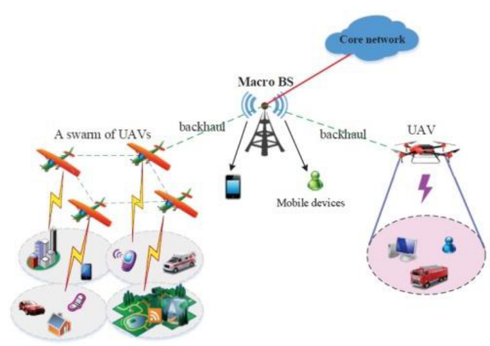
TABLE II: PAPERS ON UAV ASSISTED WIRELESS COMMUNICATIONS

Paper	Topic	Research issues
Hayat *et al.*	UAVs applications in communication	Civil applications of UAVs from a communication network perspective also with its characteristics, included experimental results from several UAV communication projects
Gupta *et al.*	Data transmission using UAV	Issues encountered in UAV communication to ensure reliable wireless transmission
Motlagh *et al.*	UAV based IoT services	Potentials of low altitude UAV-based IoT application and services
Khawaja *et al.*	UAV communication channel modeling	Air-to-ground propagation channel measurement and modeling
Krishna *et al.*	UAV network security	Cybersecurity issues for UAV assisted communication network
Khuwaja *et al.*	Measurement methods for UAV channel modeling	Extensive channel measurement and modeling methods for UAV communication channel based on the LAPs and described several characteristics of the channel
Cao *et al.*	UAV communication protocols	Protocols for the LAP and the HAP-based communication networks, and the integrated communication networks
Bekmezci *et al.*	Flying ad hoc network	FANET application scenarios, design characteristics, communication protocols, test-beds, and simulators
Xiao *et al.*	UAV cellular networks with mmWave communication	mmWave channel propagation characteristics, fast beamforming training and tracking, mmWave SDMA, and blockage problems
Mozaffari *et al.*	UAV assisted wireless communication and networks	Application scenarios, key research directions, challenges and problems, and summary of analytical frameworks
Fotouhi *et al.*	UAV cellular communication	Standardizations, implementation of aerial base stations, UAV communication prototypes, regulations, and security
Sekander *et al.*	Multi-tier drone network	Potential challenges, performance optimization of UAV aided cellular, and feasibility study of multi-tier UAV assisted network architecture
Li *et al.*	UAV communications for 5G and beyond 5G networks	Physical layer, network layer, joint communication, computing and caching, and mmWave communications for UAV networks

Fig. 3 (a) & (b) will illustrate UAV assisted communication scenario.



(a)



(b)

Fig 3 (a) (b). UAV assisted communication

C. 5G Het-Net

According to the paper of Sun *et al.* [49] the mainstream adoption of wireless networks and smart gadgets have contributed to the exponential growth of network traffic over the last couple of years and will be continued to be one principal source of the network traffic growth. In addition to the requirements generated for the traditional human-to-content and human-to-human communications, the emerging IoT (internet of things) and tactile internet will be the significant drivers to wireless networks and will lead for higher capacity of the networks. The worldwide CAGR (compound annual growth rate) has been anticipated to be 57%, by a ten times increment from 2014 to 2019. The newly emerged application scenarios from tactile internet require the 5G cellular system to assist mission-critical MTC (machine-type communications) with ultra-low latency; on the other hand, IoT demands the 5G system to assist massive MTC with billions of gadgets.

Inspired by the above-mentioned scenarios, significant endeavors have initiated from both the academic sector and industry on the 5G (fifth generation) cellular communications research. Compared with the initial four ages of cellular communication, which have concentrated primarily on human-to-content and human-to-human connectivity, human-to-machine and M2M (machine-to-machine) communications will be new territories of priorities in 5G to help the IoT and tactile internet. Another relevant key differentiator in 5G from the ancient generations of cellular communication is interoperability and heterogeneity, which are represented in various sorts of the

5G cellular network. For instance, unique components of networks need to work in a combined manner to serve the different kinds of traffic demand with various QoS (qualities of service) and distinctive coverage requirements; the 5G cellular system should assist the utilization of various ranges of the spectrum, from both licensed and unlicensed bands. Moreover, the progression of computational and processing capability at both the infrastructure (network) and the devices empowers improved cognitive learning and intelligent network and resource management. To assist this, different context data on the network might be utilized for context-aware network and resource management. Therefore, rather than a comparatively simpler and conventional homogeneous network, Het-Net (heterogeneous network) will be a significant and key empowering technology for 5G NR. Fig. 4 shows the heterogeneity in 5G.

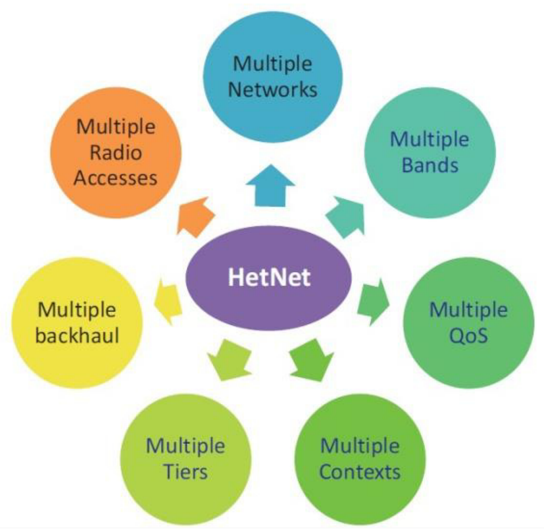


Fig 4. Heterogeneity in 5G

The 5G heterogeneous network ought to incorporate intelligently and flawlessly multiple component network, including the CRAN (cellular radio access network) and Wi-Fi (wireless fidelity) network utilizing distinctive RATs (radio access technologies) over various carrier (frequency bands), to obtain the QoS (quality of service) and QoE (quality of experience) ensured, as well as spectrum, energy, and cost-efficient 'Any One, Any Device, Anytime, Anywhere' connectivity [50]. Fig. 5 will show a scenario of 5G Heterogeneous Network.

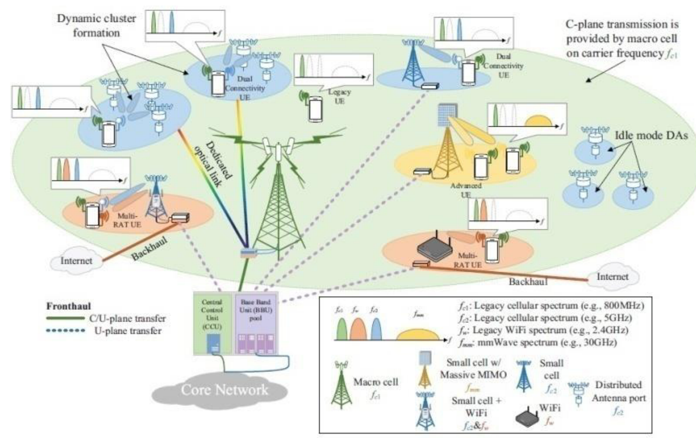


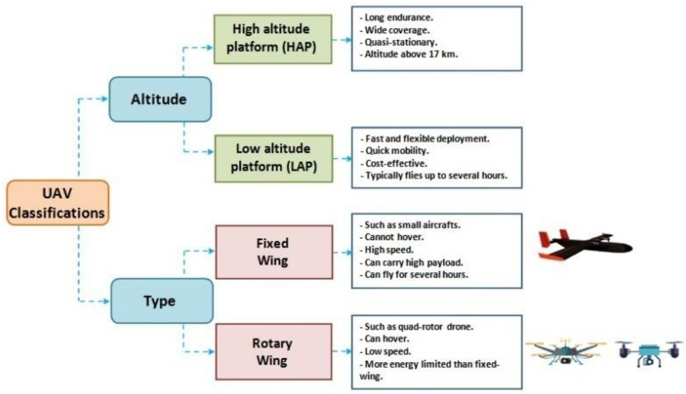
Fig 5. 5G Het-Net

There are plenty of research works on UAV assisted wireless communication frameworks available in several databases like IEEE, Springer, Elsevier, etc. But during the literature overview or study the author has found very few articles that included research on 5G, 5G mmWave, and 5G Heterogeneous Network architecture based on UAVs. Among them, the author has found the aforementioned articles which are containing sufficient research and surveys on UAV assisted 5G cellular frameworks. But the most important thing is that those papers are unable to establish a bridge among overall 5G architectures (5G NR, 5G mmWave, and 5G Het-Net) and utilizations of UAVs on those architectures of 5G. Moreover, according to the best of the author's knowledge after reviewing the literature the author has found that there is no single article which has performed research in terms of enhancement of communication links such as degradation of path loss, minimization of rain attenuation and increase of data rate after the incorporation of UAVs in the communication links. That is why the article can be considered as an extension of previous research works on UAV assisted 5G cellular communication framework.

III. PROPOSITIONS TO UTILIZE UAV IN 5G COMMUNICATIONS

UAV (Unmanned Aerial Vehicle)

The UAVs can be classified based on their flying or floating altitude and their wings [51]. The UAVs are classified below as mentioned above:

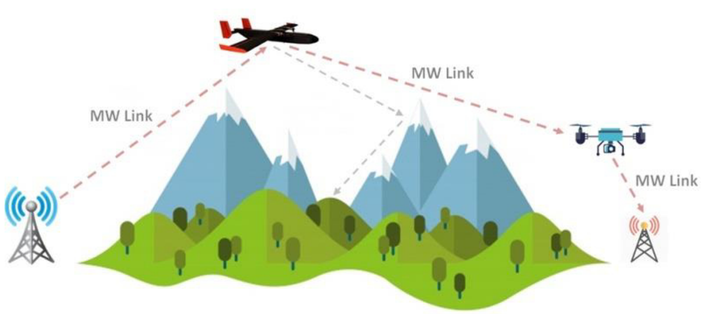


This article will emphasize fixed and rotary wing UAVs to assist the 5G network in different phenomena.

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.

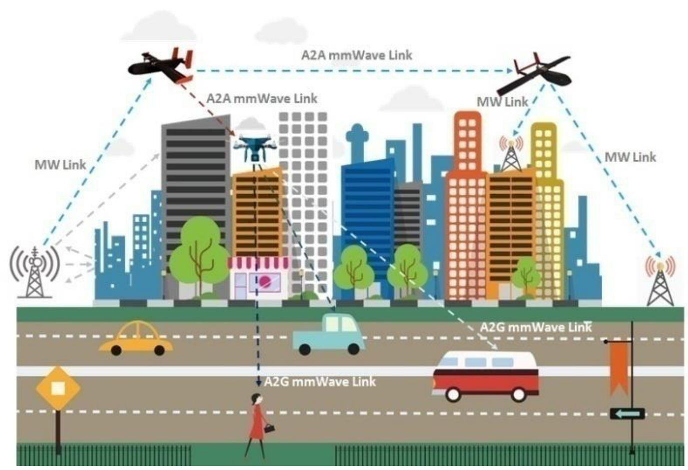


Fig 7. UAVs to assist the network in a dense city

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.

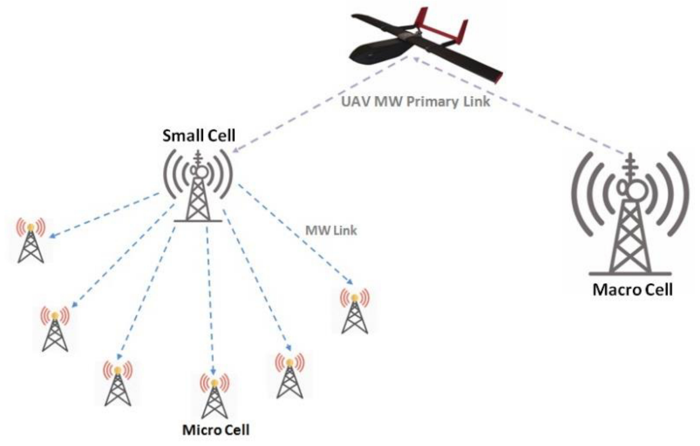


Fig 8. UAV supported macro to small cell primary link

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.

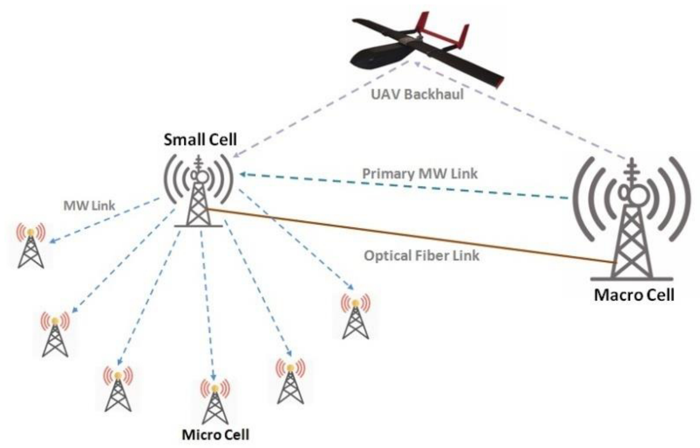


Fig 9. UAV backhaul link

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.

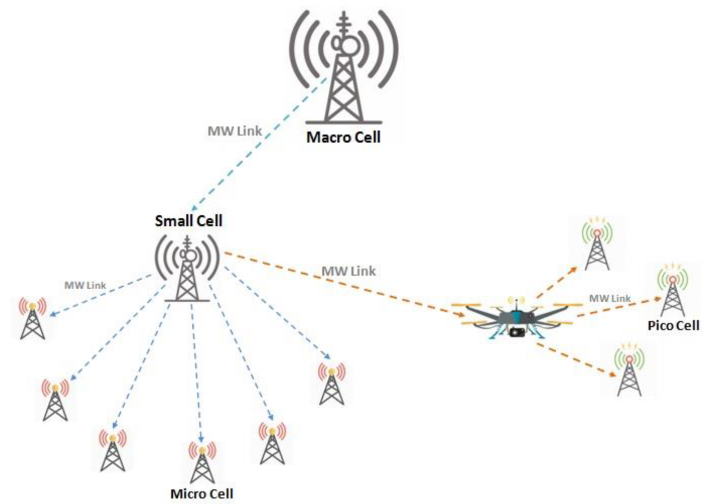


Fig 10. UAV assisted coverage extension

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.

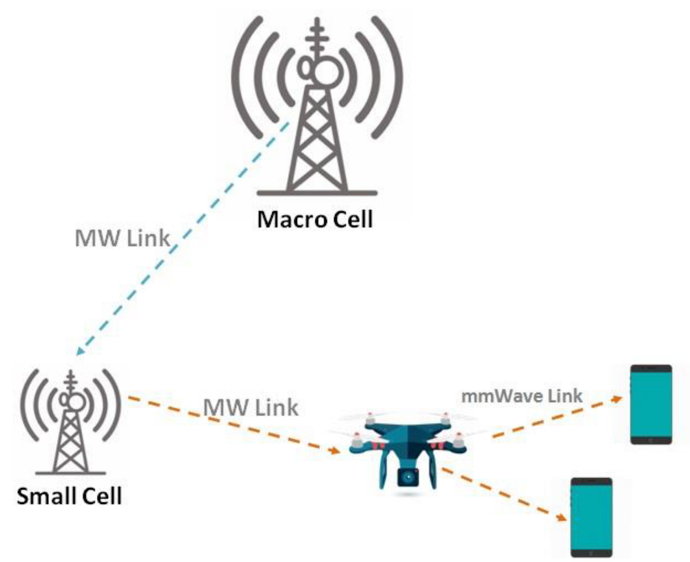


Fig 11. UAV Assisted Macro to Small Cell to UAV to UE connectivity

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.

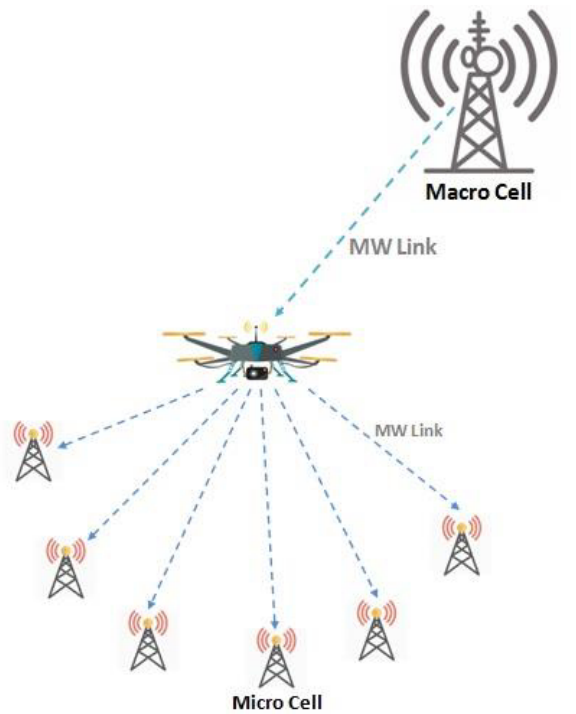


Fig 12. Macro cell to UAV to micro cell connectivity

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.

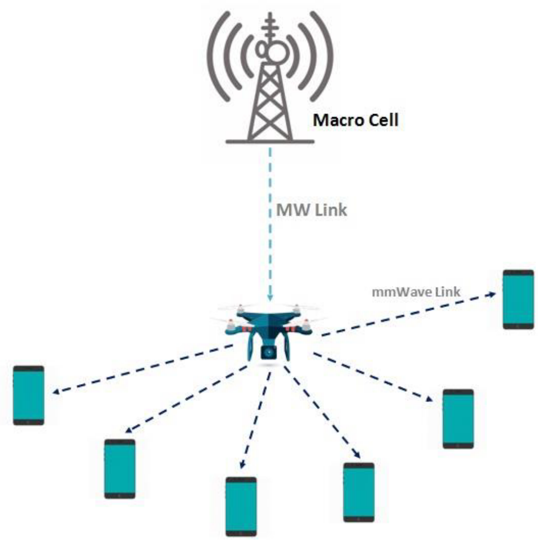


Fig 13. Macro cell to UE via UAV

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.

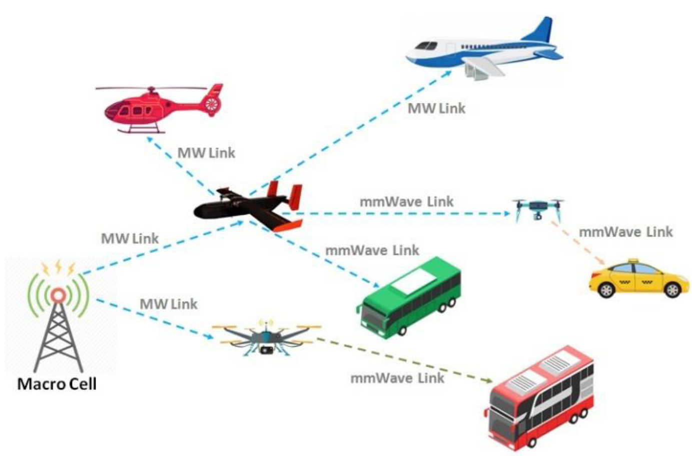


Fig 14. UAV Assisted Vehicular Communication

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.

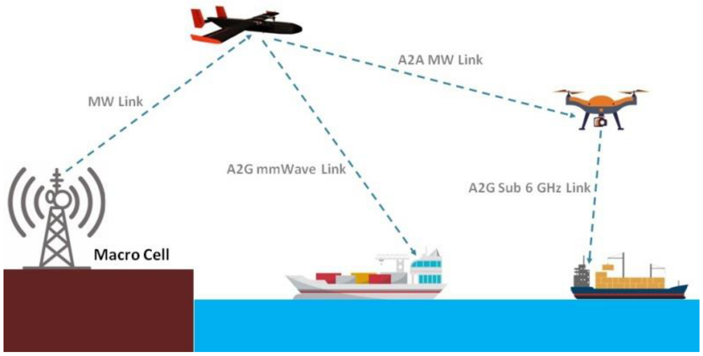


Fig 15. UAV assisted offshore communication

These are all the wireless networking scenarios where UAVs can be incorporated to establish communication links between distant base stations and also extend the 5G cellular network.

Power Source for UAVs

UAVs have to continuously fly to maintain a wireless communication link. Hence they required a kind of power source which can feed them with power continuously. The utilization of solar power [52], [53] can be a prominent source of power for the UAVs. Fig. 16 will show a solar-powered UAV.

Fig 16. Solar-powered UAV

Figure (fig. 17) below will show a battery back-up based solar power system.

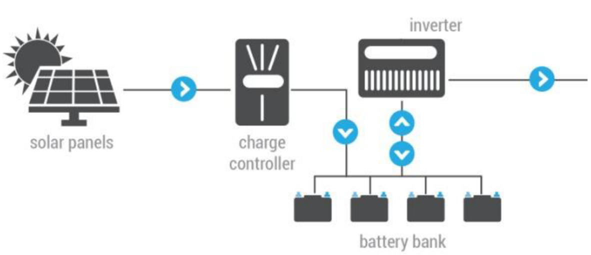


Fig 17. Battery back-up based solar system

IV. Path Loss and Atmospheric Attenuation

Communication links of higher frequencies suffer path loss and attenuation due to various conditions. Moreover larger transmitter-receiver (actually transceiver BSs) separation distance is also a reason for higher path loss. As 5G NR cellular communication is based on the high-frequency spectrum, the transmitted signal suffers a significant amount of path loss when the transmitter-receiver distance is much longer. Additionally, the higher frequencies have lower penetration capability that means 5G signals (especially mmWave) are not so much capable of penetrating obstacles like the wall, buildings, etc. Furthermore, the high-frequency signals also suffer atmospheric attenuation (such as rain attenuation). So that, to preserve the signal strength of 5G signal UAVs are highly assistive. The incorporation of UAV between two base stations (5G gNB) will reduce the actual propagation path and hence can be able to reduce the path loss at a significant amount. In this case, the UAV will work like a signal booster which will boost the propagating signal to enhance the communication. UAV will also be able to reduce the effects of atmospheric attenuation as the actual distance between the base stations will be reduced and the UAV will work as a signal repeater or booster. Fig. 18 & 19 will show the utilization of UAV in LOS and NLOS communication to enhance the connectivity by reducing the path loss and atmospheric attenuation.

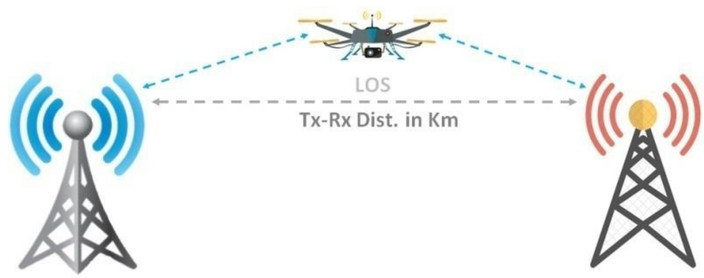


Fig 18. UAV in LOS communication

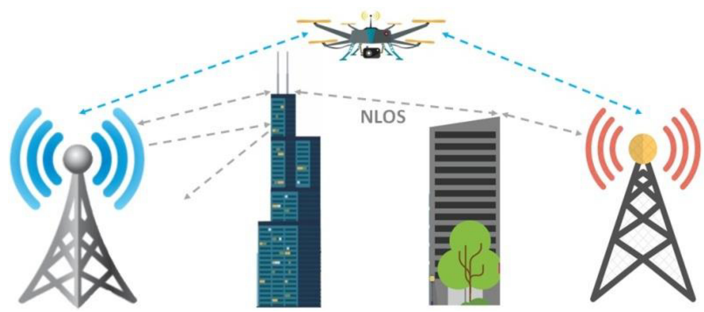


Fig 19. UAV in NLOS communication

A. Free Space Path Loss

The free space path loss is the loss in signal strength of a signal in terms of radio energy when it travels between the feed points of two antennas through free space (i.e., unobstructed LOS channels in the air) [54]. The signal strength of a signal can be measured as the transmitter power output received by a receiving antenna at a transmission distance from the transmitting antenna. We generally employ the Friis transmission equation as follows to calculate the power (denoted by P_R) received from a receiving antenna with gain G_R, when transmitted from the transmitting antenna with gain GT [55]:

$$\frac{P_T}{P_R} = G_T G_R d^{-n} \left(\frac{\lambda}{4\pi}\right)^2 \quad (1)$$

where P_T is the transmit power, λ is the signal wavelength, d is the transmission distance between the Tx and Rx antennas, and n is the path loss exponent. For free space scenario, $n = 2$. We also note that n usually has different values that depend on radio propagation channels for various complex environments [56], e.g., $n \in [2:7; 4:0]$ for normal urban area cellular radio and $n \in [1:6; 1:8]$ for indoor LOS scenarios. According to (1), free space path loss can be expressed by $PL^{FS} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi d f}{c}\right)^2$ where f is the signal frequency and c is the speed of light. We can use PL^{FS} to predict the signal strength of a signal at a given distance d of interest. For the typical applications of wireless communications and networking, PL^{FS} can be described through a convenient way in a unit of *dB* by adopting f in *GHz* and d in *km*:

$$PL^{FS}\,[\text{dB}] = 20\log_{10}(d) + 20\log_{10}(f) + 92.45 \quad (2)$$

Based on (2), PL^{FS} can be obtained in direct proportion to signal frequency and transmission distance [57].

Fig. 20 will show the free space path loss at a transmitter-receiver separation distance of 6 km.

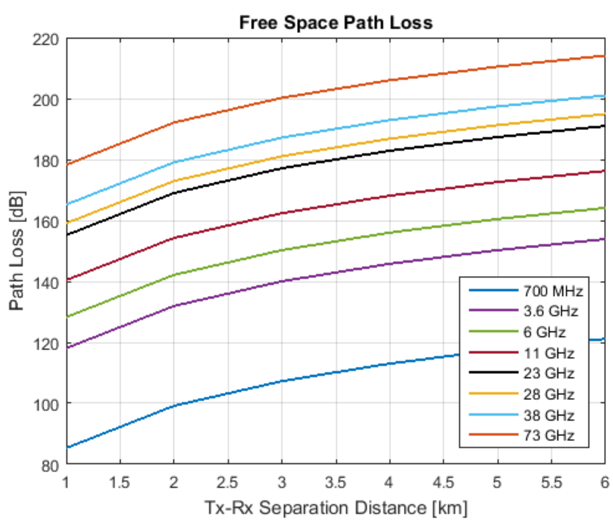


Fig 20. Free space path loss at Tx-Rx separation distance of 6 km

B. ABG (Alpha-Beta-Gamma) Path Loss Model

The ABG model aims to model large-scale path loss as a function of frequency as well as distance [58], and is expressed as follows:

$$PL^{ABG}(f,d)[dB] = 10\alpha \log_{10}(d) + \beta + 10\gamma \log_{10}(f) + X_\sigma^{ABG} \quad (3)$$

where $d \geq 1$ m and $f \geq 1$ GHz.

where $PL^{ABG}(f, d)$ denotes the path loss in dB over frequency and distance, α and γ are coefficients showing the dependence of path loss on distance and frequency respectively, β is an optimized offset (floating) value for path loss in dB, f is the carrier frequency in GHz, d denotes the Tx-Rx separation distance in meters, and X_σ^{ABG} ABG is the shadow fading SF standard deviation describing large-scale signal fluctuations [59].

Fig. 21 will show the path loss of a communication link where the transmitter and receiver are at a distance of 2000 meters. The path loss was determined using the ABG model considering UMa (Urban-Macro) NLOS scenario.

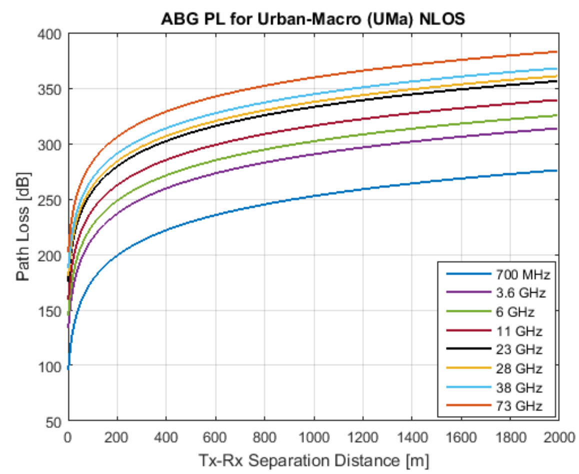


Fig 21. ABG UMa NLOS (2000 m).

Fig. 22 shows the path loss using the ABG model for UMi (Urban-Micro) street canyon NLOS scenario for 1000 meters distance.

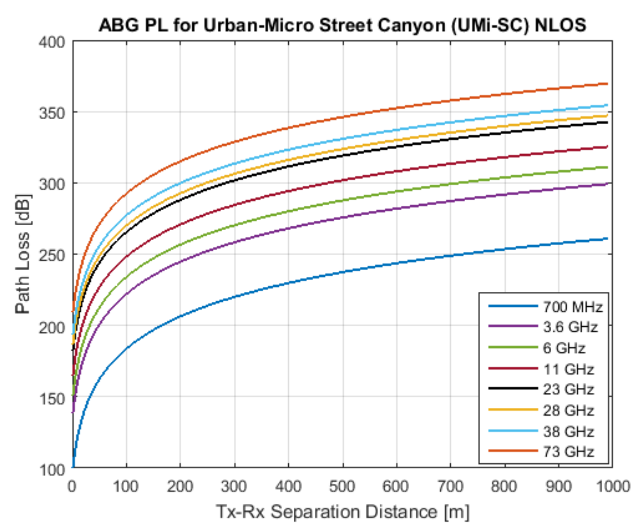


Fig 22. ABG UMi-SC (1000 m)

The fig. 23 will show the path loss for ABG UMi open square NLOS condition for a path length of 1000 meters.

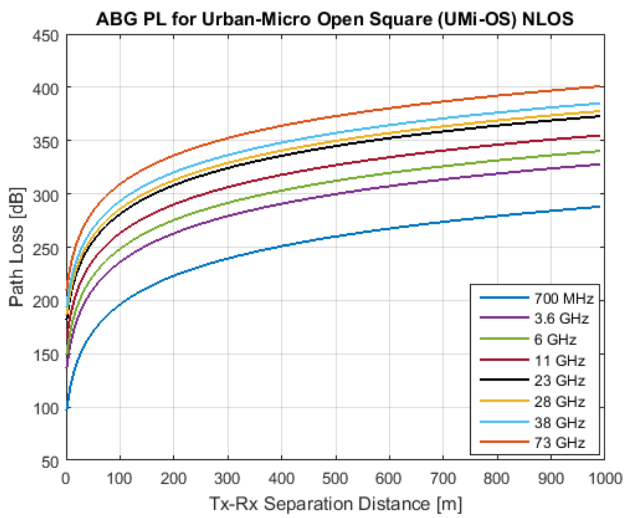


Fig 23. ABG UMi-OS (1000 m)

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 $PL^{\mathrm{FI}}(d)$ 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.

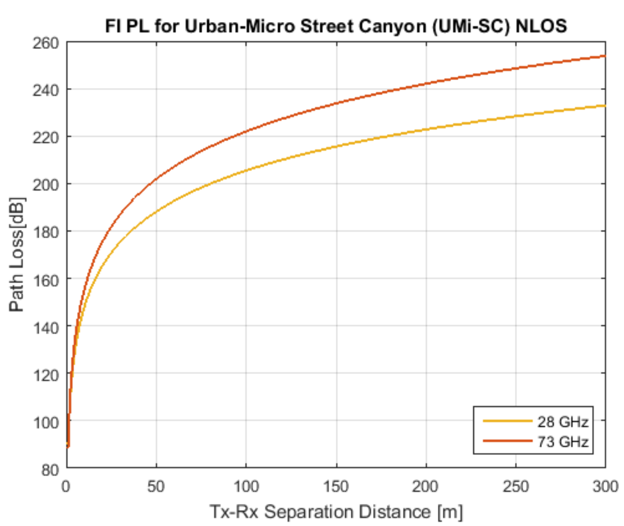


Fig 24. FI UMi-SC (300 m)

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

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

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

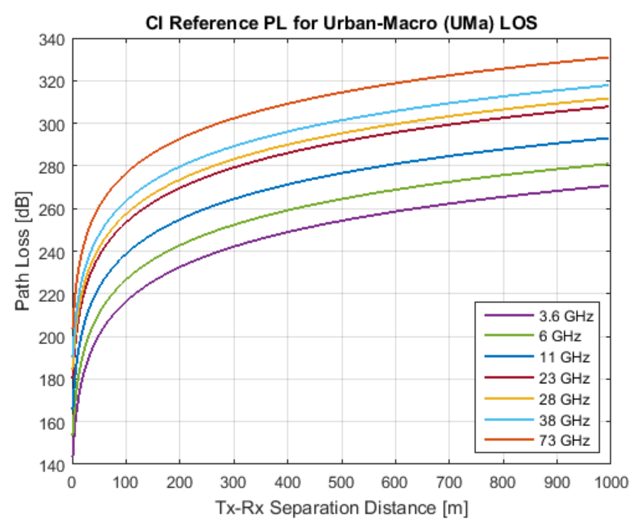


Fig 25. CI UMa LOS (1000 m)

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

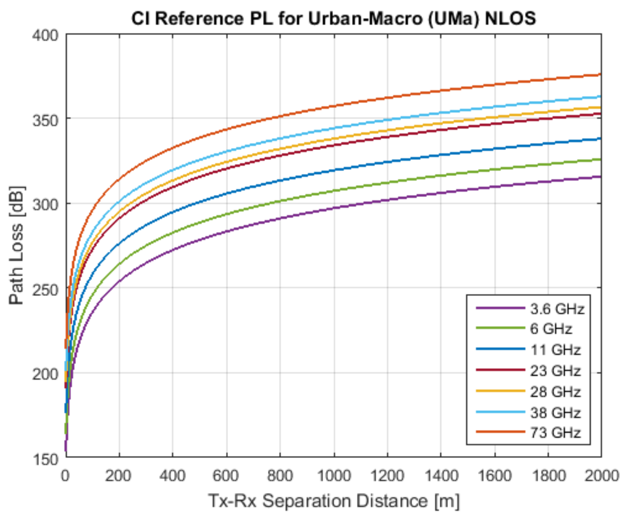


Fig 26. CI UMa NLOS (2000 m)

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

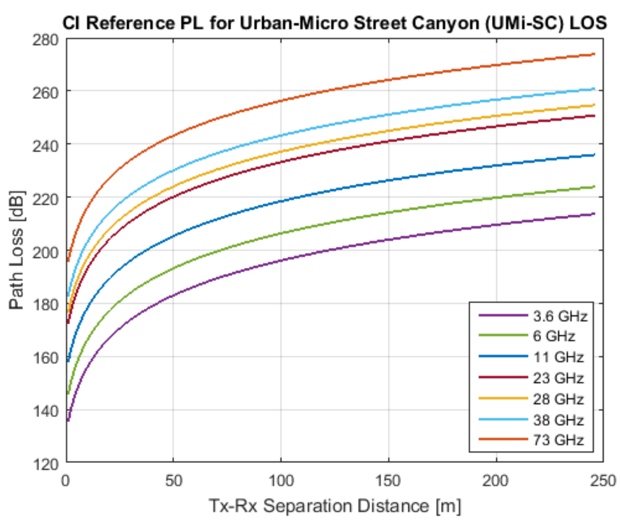


Fig 27. CI UMi-SC LOS (250 m)

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

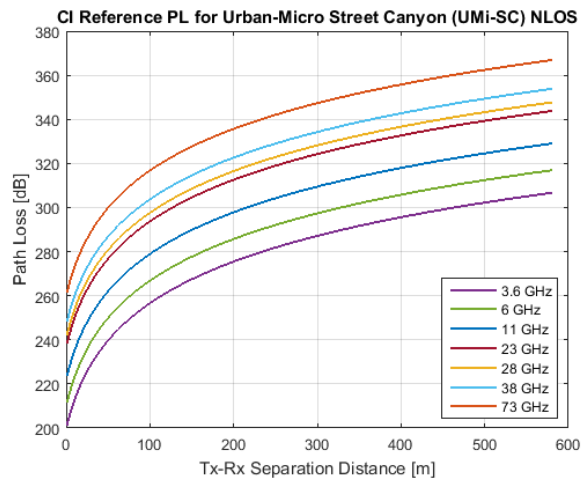


Fig 28. CI UMi-SC NLOS (600 m)

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.

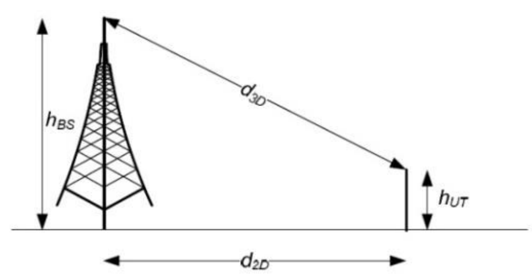


Fig 29. The definition of 3D separation distance

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.

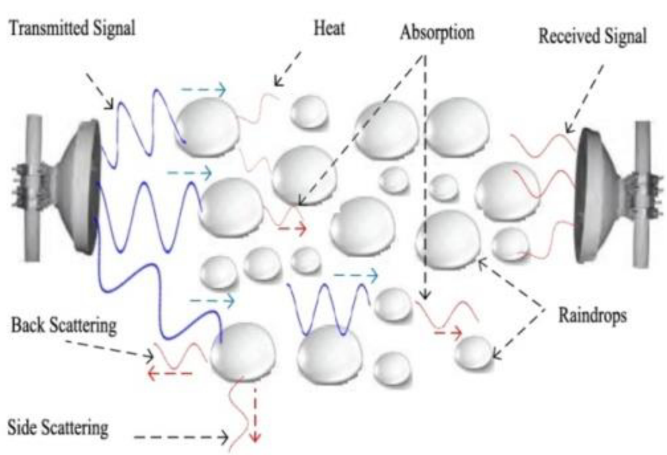


Fig 30. Effects of rainfall

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]:

$$\gamma = kR^{\alpha} \tag{7}$$

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].

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

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

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]:

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

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.

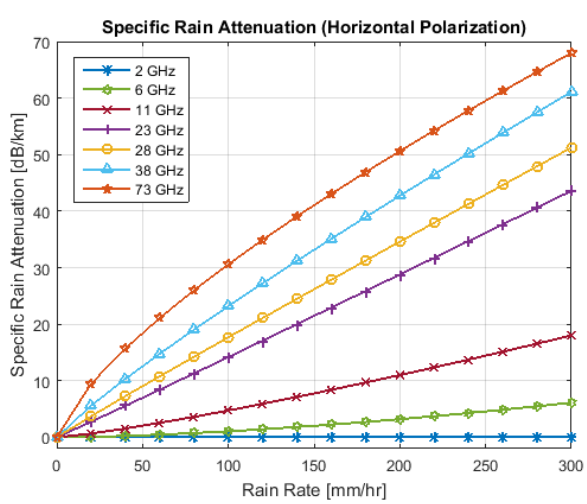


Fig 31. Specific Rain Attenuation (Horizontal Polarization)

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

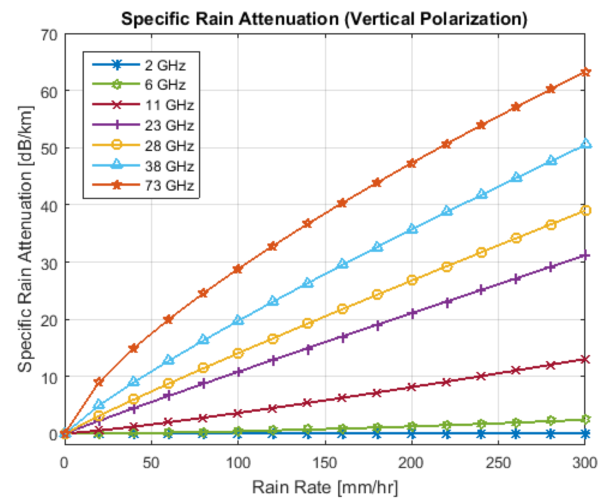


Fig 32. Specific Rain Attenuation (Vertical Polarization)

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.

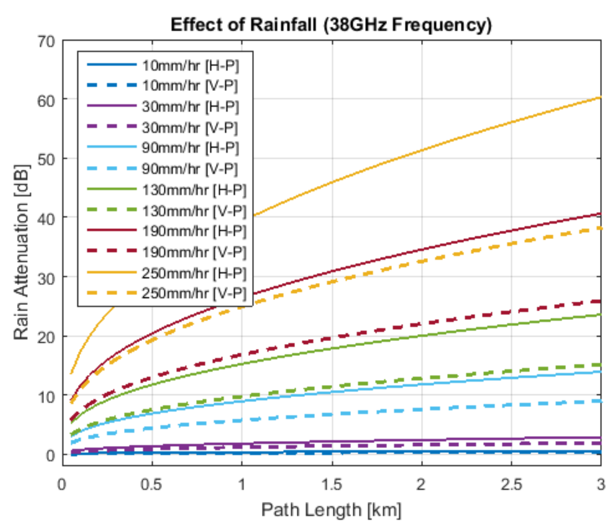


Fig 33. Effect of rainfall (3 km, 38 GHz)

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.

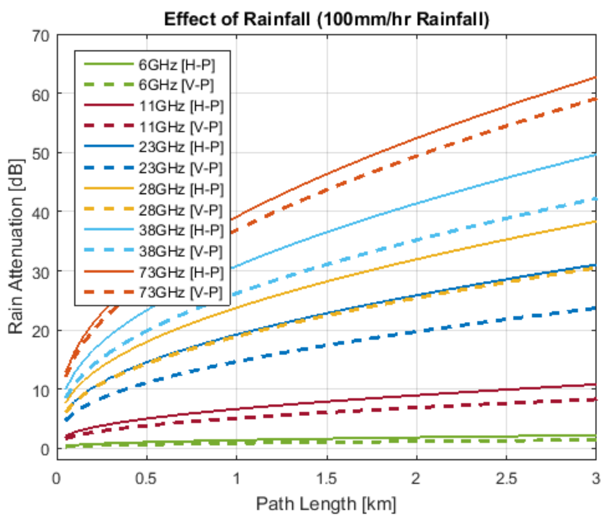


Fig 34. Effect of rainfall (3 km, 100 mm/hr)

The fig. 35 below will visualize the amount of rain attenuation on different carrier frequencies for a rain rate of 250 mm/hr for a 3 km Tx-Rx separation distance.

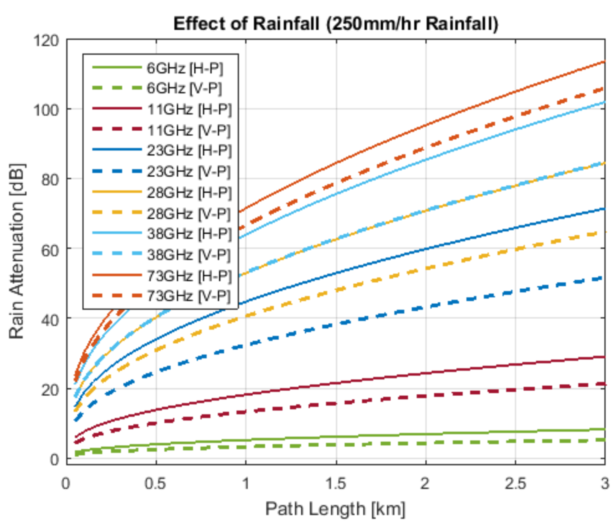


Fig 35. Effect of rainfall (3 km, 250 mm/hr)

The figures (fig. 33-35) is showing the simulation results of rain attenuation in terms of distance. These figures represent that the amount of rainfall attenuation will be decreased significantly if UAV is utilized in the wireless communication link or channel of 5G NR as a signal booster or repeater between the transmitter and receiver as the actual communication distance between the transmitter and receiver is reduced. (Consider the utilization of a UAV at half of the total distance between transmitter and receiver separation distance, the rain attenuation will be decreased significantly which can be realized by the figures 33-35).

The figures above also have been showing that the low-frequency carrier signals suffer less attenuation compared to the high-frequency carriers. To combat the effect of rainfall in UAV assisted communication link, low-frequency carriers can be utilized during the high rainfall and the system can be designed in such a way that it can switch to the high-frequency carriers when there is no rainfall or the rainfall is low or moderate.

V. OPTIMIZATION OF DATA RATE

For 5G NR, the approximate data rate [74] for a given number of aggregated carriers in a band or band combination is computed as follows,

$$Data\ Rate\ [Mbps] =$$

$$10^{-6}.\sum_{j=1}^{J}\left(v_{Layers}^{(j)}.Q_m^{(j)}.f^{(j)}.R_{max}.\frac{N_{PRB}^{BW(j),\mu}.12}{T_s^{\mu}}.\left(1-OH^{(j)}\right)\right) \quad (14)$$

where J is the number of aggregated component carriers in a band or band combination, $R_{\max}$ = 948/1024 (just a number), $v_{Layers}^{(j)}$ is the maximum number of transmitter receiver layers (e.g. 2, 4), $Q_m^{(j)}$ is the maximum modulation order, $f^{(j)}$ is the scaling factor (The scaling factor can take the values 1, 0.8, 0.75, and 0.4; is signaled per band and/or band-to-band combination), μ is the numerology (as defined in TS 38.211 [76]), T_s^{μ} is the average OFDM symbol duration in a sub-frame for numerology μ ($T_s^{\mu} = \frac{10^{-3}}{14x2^{\mu}}$), $N_{PRB}^{BW(j),\mu}$ is the maximum RB allocation in bandwidth $BW^{(j)}$ with numerology μ, as defined in 5.3 TS 38.101-1 [77] and 5.3 TS 38.101-2 [78], where $BW^{(j)}$ is the UE supported maximum bandwidth in the given band or band combination, and $OH^{(j)}$ is the overhead (takes values 0.14 for frequency range FR1 for DL, 0.18 for frequency range FR2 for DL, 0.08 for frequency range FR1 for UL, 0.10 for frequency range FR2 for UL). The table below (Table IV) will show the data rates according to the varied parameters.

TABLE IV: DATA RATES FOR CORRESPONDING PARAMETERS

Carrier Aggregation	Tx-Rx Layers	Modulation Order	Carrier	µ	SC Spacing (Channel BW)	NRB	DL (Mbps)	UL (Mbps)
1	2	4	< 6 GHz (FR1)	0	15 kHz (50 MHz)	270	288.91	309.07
				1	30 kHz (100 MHz)	273	584.25	625.01
				2	60 kHz (100 MHz)	135	577.8	618.1
			> 6 GHz (FR2)	2	60 kHz (200 MHz)	264	1130	1208.8
				3	120 kHz (400 MHz)	264	2154.8	2365.1

				4	240 kHz (400 MHz)	138	2252.8	2472.6
1	4	6	< 6 GHz (FR1)	0	15 kHz (50 MHz)	270	866.74	922.26
				1	30 kHz (100 MHz)	273	1752.8	1875
				2	60 kHz (100 MHz)	135	1733.5	1854.4
			> 6 GHz (FR2)	2	60 kHz (200 MHz)	264	3232.3	3517.6
				3	120 kHz (400 MHz)	264	6464.5	7095.2
				4	240 kHz (400 MHz)	138	6758.4	7417.2
2	8	8	< 6 GHz (FR1)	0	15 kHz (50 MHz)	270	4622.6	4945.1
				1	30 kHz (100 MHz)	273	9348.0	10000
				2	60 kHz (100 MHz)	135	9245.3	9890.3
			> 6 GHz (FR2)	2	60 kHz (200 MHz)	264	17239	18921
				3	120 kHz (400 MHz)	264	34477	37841
				4	240 kHz (400 MHz)	138	36045	39561

In wireless communication systems for long-distance or lossy channel lower parameters such as lower-order carrier aggregation, the lower order of modulation and lower number of transmitting and receiving antennas are used to reduce the significant amount of loss and maintain favorable data rate. But these also reduce the required data rate as lower orders of parameters are used. In such case, if UAVs are implemented in the communication channel between the transmitter and receiver the actual long-distance gets reduced hence higher order of parameters (carrier aggregation, the order of modulation and number of transmitting and receiving antennas) can be used which can significantly increase the data rate. In 5G NR ensuring a higher data rate is one of the important priorities hence using the UAV higher data rate can be achievable. The table (Table IV) above shows the increase of data rate when higher order of communication parameters are utilized compared to lower order parameters.

VI. CHALLENGES AND SCOPES

A. Challenges for UAV Assisted Communication

Link design and budget – Utilizing more numbers of UAVs can reduce the path loss and also can ensure a higher data rate (shown by the simulation results) but as well it will increase the overall cost and budget for link design. So that a favorable link budget and designing is an issue to be concerned.

Adoption of waveforms – The selection of modulation technique, multiple access techniques for the waveform of the UAV assisted communication link is also a concerning point that required to be highly focused during this kind of communication system design.

Antenna designing – UAVs are small, lightweight aerial vehicles that are capable of carrying loads having smaller weight. That is why during the communication link design utilization of favorable antenna for UAVs in UAV assisted communication is required a special concern.

Maintenance – Every electrical and mechanical component or device required maintenance after a certain period of time and which is a continuous process. UAVs also required maintenance checks on a regular basis. As UAVs fly at high above the ground, performing the maintenance procedures for UAVs during their fly is not possible. That is why for maintenance they are required to be brought down to the ground and after maintenance required to be re-launched. Now the concerning matter is that when a UAV of a communication link is pulled out for maintenance, another UAV or some other technique is required to keep the link alive.

Power – As UAVs have to float continuously into the sky they are required to be fed with adequate power in a continuous manner. So that the issue of power for UAVs are also required a high priority.

Environmental issues – Rain, thunderstorm, fog, and snow are major environmental issues which can cause challenges for UAV assisted communication link.

Collision avoidance – Communication UAVs are not the only flying objects in the sky. There are airplanes, helicopters, and other aerial vehicles which fly in the sky. If proper positioning of UAVs is not maintained, a collision can occur with other flying objects or vehicles. That is why adequate maintenance and control is required to avoid collisions.

B. Scopes for Enhancements

Distinguished by the research directions and their related difficulties and issues, next, the UAV assisted communication has to put concentration towards the improvements of such networks by redesign, reconfigure, analyze, and enhance the utilization of UAVs for wireless communication purposes. Indeed, this research topic is profoundly interdisciplinary and requires the theoretical and practical knowledge from conventional fields, for example, communication theories, optimization theories, and network design and configuration, as well as emerging fields, for example, stochastic geometry, 3D geometry [79], AI (artificial intelligence) [80], game theory [81], [82], machine learning [83], [84] or deep learning [85] and so on.

VII. CONCLUSION

The utilization of UAVs is rapidly increasing in wireless networking. UAVs can be utilized to provide wireless network 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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