A Survey on Challenges of Millimeter Wave Communications for Fifth-Generation Wireless Networks

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Abstract-Cellular networks rely heavily on downlink beamforming; however, calculating beamformers that maximize the weighted sum rate (WSR) under power constraints is an NP-hard problem. A weighted minimum mean square error (WMMSE) algorithm variant is suggested for a MU-MISO downlink channel in order to address this trade-off between complexity and performance. This variation avoids bisection searches, eigendata compositions, and matrix inversions—all of which are challenging to implement as conventional network layers. With a reduced complexity, the suggested network architecture outperforms the WMMSE algorithm truncated to the same number of iterations and adapts well to variations in the channel distribution. Many use cases for vehicles that demand high capacity, extremely low latency, and high reliability can be made possible by 5G. To facilitate this, 5G For a MU-MISO downlink channel, a variation of the weighted minimum mean square error (WMMSE) algorithm is proposed to address this trade-off between complexity and performance. This variation avoids complex network layer implementations such as matrix inversions, eigendata compositions, and bisection searches. The suggested network architecture generalizes well to changes in the channel distribution and performs comparably to the WMMSE algorithm truncated to the same number of iterations, but at a lower complexity. Numerous automotive use cases requiring high capacity, extremely low latency, and high reliability can be made possible by 5G. 5G suggests using highly directed mm Wave system deployment and dense small cell technology to support this. To reduce the cost of signaling, however, enabling vehicular communication necessitates strong mobility management strategies.

KEYWORD: Millimetre wave communications, propagation, channel measurements, channel models, MIMO, hybrid precoding, non-orthogonal multiple access (NOMA), multiple access techniques, simultaneous wireless information and power transfer (SWIPT), RF energy harvesting.

INTRODUCTION:

The rapid growth of information globalization has significantly scaled the capacity of wireless networks with increasing data traffic, mainly due to improved area spectral efficiency. Satellite communication has recently been introduced as one of the enabling technologies to realize the envisioned 5G backhauling, which will enable new applications such as enhanced mobile broadband (eMBB), massive machine type, and mission-critical services. Recent studies find that data traffic is expected to experience a 1000-fold capacity increase in the coming decade, and the microwave band (300 MHz to 3 GHz) where various radio access technologies (RATs) operate cannot provide this capacity demand.[1] The only unexplored alternative is the system bandwidth, and exploring new less-congested spectrum bands of extremely high frequencies (EHFs) such as the millimeter wave (mm Wave) bands (30 − 300 GHz) is a promising solution to increase network capacity. However, mm Wave waves have drawbacks, such as manufacturing the small mm Wave components requires more precision and increases costs, encounters low sensitivity in the receiving system due to reduced energy managed by the small antenna size, and has limited range due to strong atmospheric absorption with signal attenuation up to 15 dB/km. To address these stringent 5G requirements and concurrently manage the energy-efficient design, hybrid precoding for mm Wave is envisioned as an essential part of the 5G wireless communication networks. Conventional MIMO precoding techniques require a dedicated radio frequency chain for each antenna element, which becomes impractical with massive MIMO systems in mm Wave bands due to high hardware cost and power consumption. Hybrid precoding (HP) is likely to be used to realize beamforming with few numbers of RF chains to reduce hardware complexity and power consumption.

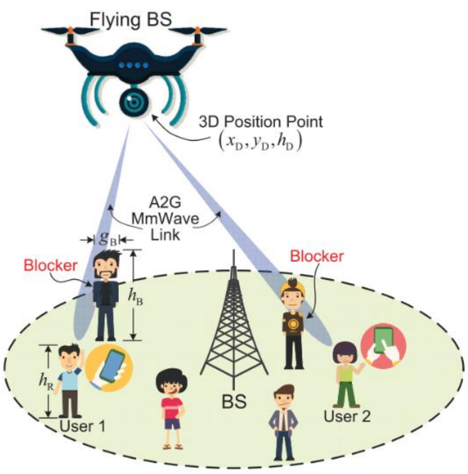

FIGURE1: Illustration of human-body blockage on mm Wave links of a flying BS with mm Wave communications. Here, the flying BS is currently located at a 3D position point

The study focuses on the design of mm Wave wireless communication systems, specifically mm Wave MIMO, non-orthogonal multiple access (NOMA), hybrid precoding, backhaul technologies, and standardization. The research has been conducted at 28 GHz and 38 GHz to understand the angle of arrival, angle of departure, root mean square delay spread, path loss, building penetration and reflection characteristics. However, recent topics such as hybrid precoding, multiple access technologies, and mm Wave technical aspects have not been addressed. The research also discusses the fundamental characteristics of energy harvesting (EH) and SWIPT techniques for mm Wave wireless communication systems, as well as research challenges and recommendations. [2] The study also discusses the technical progress in mm Wave communications for mobile networks, including channel measurement campaigns, channel modeling, MIMO design, multiple access, performance analysis, backhauling, mm Wave standardization, and deployment. The study also tracks the development of massive MIMO system models with hybrid beamforming, hybrid transceivers structures, antenna configuration, and hybrid beamforming in heterogeneous wireless networks (HetNET). However, topics on NOMA, SWIPT, interference exploitation, and RF energy harvesting are not discussed. The study concludes by comparing the results of the survey with existing survey papers. In this paper, the difficulties and developments in beam-based mobility management for vehicular communications in 5G and beyond are discussed. Beam-level mobility involves switching beams within the same base station, whereas cell-level mobility involves handover between base stations. [3] In mm Wave, directional signals are used to guarantee that control signals are received even over extended distances. Strong and dependable links require precise beam alignment between the transmission and reception points; however, this could add to connection latency and affect control layer operations. For high-speed automobiles and trains, 3GPP specifies V2X technology with a 0 MS mobility interruption time. During the handover event, decisions must be made quickly and intelligently, depending on adequate link quality and data accessibility. The article offers a synopsis. Beam-level mobility involves switching beams within the same base station, whereas cell-level mobility involves handover between base stations. In mm Wave, directional signals are used to guarantee that control signals are received even over extended distances. Strong and dependable links require precise beam alignment between the transmission and reception points; however, this could add to connection latency and affect control layer operations.

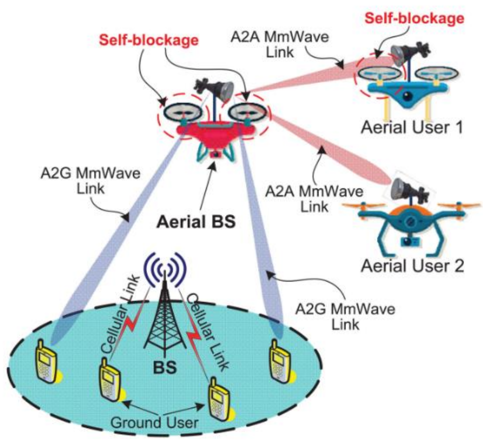

FIGURE2: Illustration of self-blockage of mm Wave signals incurred by the rotating propeller of UAV. Here, UAV-based aerial BS with the lightweight horn antenna can communicate with ground users and aerial users via A2G mm Wave links and A2A mm Wave links, respectively.

For high-speed automobiles and trains, 3GPP specifies V2X technology with a 0 MS mobility interruption time. During the handover event, decisions must be made quickly and intelligently, depending on adequate link quality and data accessibility. The paper looks at how beam-based mobility management is handled in 5G mm Wave networks and gives an overview of it in the current 3GPP 5G NR body.[5]

RELATED WORK:

The modern automotive industry aims to produce products that are more environmentally friendly, safer, and more desirable to use. Automated driving can significantly reduce road accidents, improve traffic flow, and minimize energy consumption of automated vehicles. To achieve this, vehicles must sense and understand their surroundings to safely control their motion without human intervention. Challenges in such applications include accurate and reliable localization, sensing and perception, and control. These functions are implemented through various sensor systems, such as cameras, radar, or laser rangefinders, and powerful computers running sophisticated AI algorithms.

To achieve superior safety levels, the components of the system, particularly the sensing system, must be highly capable of collecting and delivering sufficient information to the AI algorithms at the heart of perception and control functions of the vehicle. However, on-board sensing can be inherently impaired, particularly in complex road segments. Therefore, effective fusions of off-board data through V2X systems can make a crucial difference in the implementation of highly automated driving functions.[4]

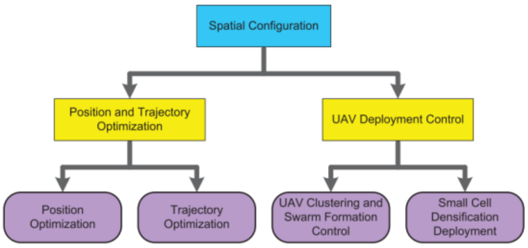

FIGURE3: The classification of spatial configuration solutions for UAV-assisted wireless networks with mm Wave communications.

There have been two paradigms for enabling connected automated driving: 1) through direct V2V communications, and 2) through infrastructure - such as cellular networks. There seems to be a trend toward infrastructure-based approaches within the context of 5G systems. These are being developed on the basis of V2V: it allows communication between vehicles using cellular networks, allowing vehicles to exchange information with other vehicles via direct communication or through the road side unit in case of insufficient direct link.

The 3GPP community has introduced enhancements in cellular-based V2X support into consideration to meet stringent latency and reliability requirements of V2X applications. Due to current limitations of LTE to support ultra-low and highly reliable services, 3GPP has introduced 3GPP 5G support for V2X services in Rel. 15. The key enablers of 5G for V2X would be automated driving, safety-related services, and efficient road conditions. However, these use cases and services require ultra-low latency and highly reliable communication, which

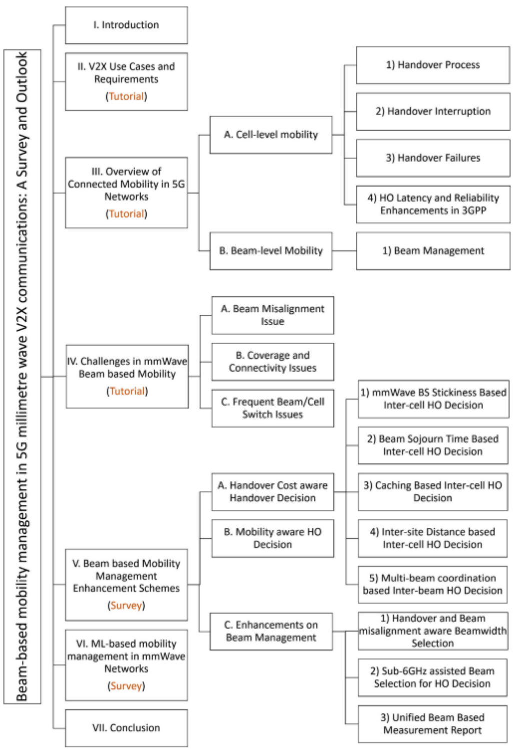

FIGURE4: Structure and focus of this survey paper.

For connectivity, there is a need for accurate beam alignment and connection robustness against rapid channel changes. New solutions for timely switching of beams are needed in the case of high mobility vehicles. The licensed shared access (LSA) regime in the European Union (EU) aims to acquire more spectrum at sub-6 GHz, making available about 500 MHz of Federal and non-Federal spectrum by 2020 for mobile broadband. This allows third-party use of underutilized spectrum resources exclusively on a licensed basis between non-mobile network operator incumbents and a mobile network operator (MNO) sharer under permitted frequency location and time-sharing conditions. However, part of the mm Wave spectrum from 6 GHz up to 100 GHz (i.e., ~ 94 GHz), where continuous and broad spectra exist, has stayed ignored. This allows for the added spectrum of future mm Wave cellular systems, higher data rates, improved connectivity, and higher system capacity compared to legacy sub-6 GHz cellular bands. The international telecommunication union (ITU) has designated frequency bands around 60 GHz in different parts of the world, such as 28 - 80 GHz being investigated in the United Kingdom (UK) to improve coverage and data transfer. The US federal communications commission (FCC) has interest in the following sub-100 GHz mm Wave spectrum bands, which it considers of high potential for mm Wave technology

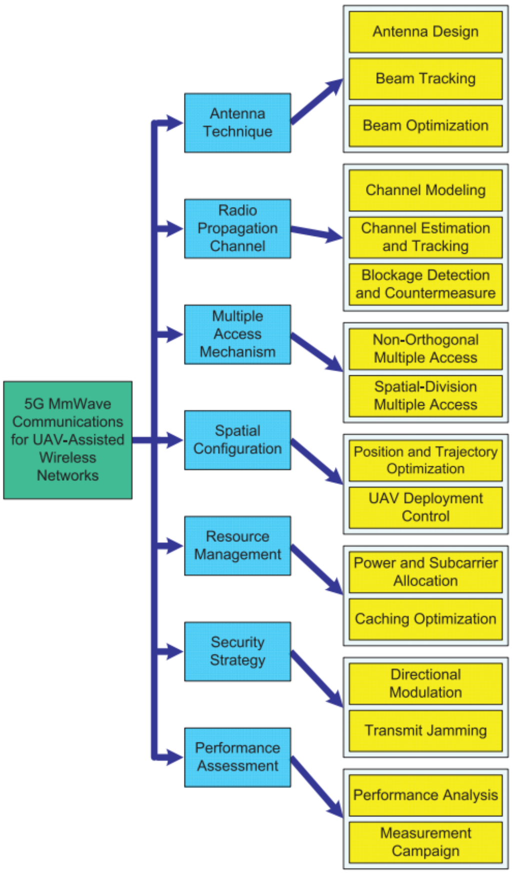

FIGURE5: Taxonomy of related research issues in 5G mm Wave communications for UAV-assisted wireless networks.

1) 28 GHz local multipoint distribution service (LMDS) band (27.5 - 29.5 GHz band): Mainly, LMDS was granted the primary name in the 850 MHz located in the 27.5 - 28.35 GHz portion under FCC Part 101 rules and regulations for fixed microwave services. The portion of 150 MHz, that is 29.1 - 29.25 GHz in the band, is shared on a co-primary basis restricted to LMDS hub-to-subscriber transmission.
2) 37 GHz band (37 - 38.6 GHz band): The 37 GHz band consists of 1 GHz of the contiguous, mm Wave spectrum at 37.6 - 38.6 GHz band, and presently holds no commercial terrestrial wireless incumbent licensees.
3) 39 GHz band (38.6 - 40 GHz band): The 39 GHz band consists of 1.4 GHz of the contiguous, mm Wave spectrum at 38.6 - 40 GHz band. Existing licenses in the 39 GHz band enclose unpaired 50 MHz blocks licensed via partial economic area (PEA), leading to encumbered licenses. 60 GHz Bands (57 - 64 GHz and 64 - 71 GHz (extension): The 60 GHz or V-band is very attractive for license-exempt broadband services for high capacitance transmissions over short distances. The Wireless Gigabit (WiGig) Alliance, also known as IEEE 802.11ad, is standardized for the usage of the 60 GHz unlicensed band in contrast with Wi-Fi 6 and other "traditional" versions of Wi-Fi that employ spectrum in the 2.4GHz or 5GHz bands. In 2010, the

Chinese wireless personal access network (CWPAN) standard working group set up ITU-T Study Group 5 (SG5), also called SG5 QLINKPAN, to investigate the possibilities of the 45 GHz band for WLAN application. In China, the issued 60 GHz consists of 5 GHz of the contiguous, mm Wave spectrum at 59 - 64 GHz band. In 2018, South Korea auctioned mm Wave 5G spectrum with 2400 MHz bandwidth in the 28 GHz band to three mobile operators. In late 2018, three national mobile network operators launched 5G services with mobile hotspots in South Korea. In early 2017, South Korea issued a national broadband plan suggesting the possibility to extend the spectrum in the 28 GHz band by up to 2 GHz to provide access to a total of 3 GHz, 26.5 - 29.5 GHz. The ITU Radio regulations body has allocated frequency bands around 60 GHz, which is the global unlicensed band in different regions of the world. The mm Wave bands allocated through ITU Radio regulations are 55.78 - 66 GHz, 71 - 76 GHz, 81 - 86 GHz, 92 - 94 GHz, and 94.1 - 100 GHz. To secure the right 5G spectrum, significant efforts are required to align allocations among countries. The European Conference of Postal and Telecommunication Administration (CEPT) regularity body allocates mm Wave bands for mobile services, radio local area networks, broadband mobile systems, road transport information, and radio astronomy observing programs.

The mm Wave spectrum region is experiencing growing interest in 5G usage due to its unique radio emission fields compared to legacy 4G generation mobile radio systems. The Canada, Japan, and Australian regularity bodies have allocated bands for low power license-exempt devices, with 59-64 GHz bands for unlicensed use and 54.25-59 GHz bands for licensed use. The Australian Communications and Media Authority (ACMA) has allocated 59.4-62.9 GHz bands for unlicensed usage. However, new spectrum issues, such as rulemakings at the FCC, require balancing objectives in the allocation of 5G spectrum. This requires addressing decisions based on spectrum allocation among different users and technical standards, including geographical assignments, in parallel. Therefore, regulators must balance their objectives in their 5G spectrum allocation.

PROPOSED METHOD:

The mm Wave communications in 5G and B5G wireless systems offer significant technical advantages, including larger bandwidth availability, shorter wavelength, narrow beam, and increased security/interference immunity. These advantages enable network capacity increases of orders of magnitude, making them a crucial component in wireless systems.

The mm Wave range in the electromagnetic spectrum, which lies between microwaves and infrared waves, is considered one of the key advantages of 5G mm Wave communications compared to limited microwave spectrum resources below 6 GHz currently used by conventional wireless systems and existing 4G LTE. The available bandwidth in mm Wave frequency bands of 71 - 76 GHz and 81 - 86 GHz (widely known as E-band) is more than the sum total of all other licensed spectrum available for existing wireless systems. This larger bandwidth translates to extremely high data rates, easily achieving peak data rates of 10 Gbit/s or more with full duplex capability, which is much greater than the limit rate of 1 Gbit/s by using lower microwave frequencies.

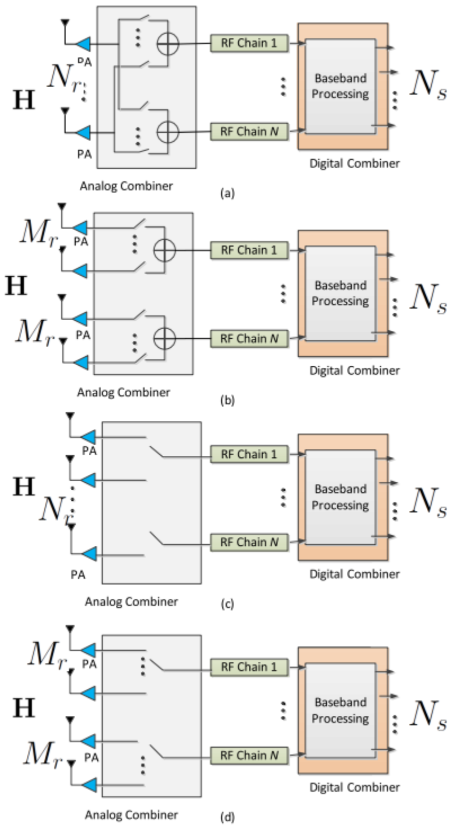

Figure6: Analog architectures for the RF combiner. (a) Antenna selection with analog combining. (b) Antenna selection in subsets with analog combining. (c) Antenna selection. (d) Antenna selection in subsets

Huwae proposed a multi-layer spectrum approach based on the advantage of larger bandwidth availability, selecting the 24.25 - 29.5 GHz and 37 - 43.5 GHz mm Wave frequency bands for early deployment of 5G mm Wave systems in accordance with the 3GPP Release 15. The International Telecommunication Union (ITU) initially allocated the E-band (71 - 76 GHz and 81 - 86 GHz) to support ultra-high-capacity point-to-point communications as early as 1979. In 2015, the Federal Communications Commission (FCC) proposed flexible service rules for the mm Wave frequency bands, including 28 GHz, 37 GHz, and 39 GHz for licensed usage and 64 - 71 GHz for unlicensed usage. Some service providers, such as AT&T and Verizon, are fighting to establish their 5G commercial networks by using the extraordinary amount of bandwidth available at mm Wave frequencies. Qualcomm has developed the world's first fully-integrated 5G NR mm Wave antenna module, QTM052, for next-generation smartphones and mobile devices. This module packs a tiny phased antenna array with a compact dimension, roughly the size of a one-cent coin. With these smaller antenna modules, equipment manufacturers will have more options for antenna placement, providing them with more freedom and flexibility in the design of 5G NR devices.

Higher antenna gains can be achieved through shorter wavelengths of mm Wave signals, which can obtain proportionally higher antenna gains under the given effective antenna aperture. Large-scale multi-element antenna arrays enable greater antenna gain and achieve highly directional beamforming. By integrating massive MIMO with dozens to hundreds of antenna elements, mm Wave communications are more specifically suited to ultra-high-capacity point-to-point transmission. Additionally, mm Wave antennas with narrow directional beams can send and receive much more energy to compensate for stronger propagation attenuation and higher free space path loss of mm Wave signals.

Increased security and interference immunity are also advantages of mm Wave communications. In contrast to congested spectrum and easily intercepted signals caused by wide beams at lower microwave frequencies below 6 GHz, narrow beams of mm Wave signals allow the ability to obtain highly directional signals and greater resolutions. When malicious eavesdroppers want to intercept and decode confidential messages successfully, they need to physically be within the transmission path of mm Wave signals with narrow beams. However, the inherent benefits include highly directional beams and greater solutions make the interception of mm Wave signals much more difficult and costly because mm Wave signals are only restricted to a relatively small area.

Despite these advantages, there are several technical challenges and limitations that need to be overcome for mobilizing mm Wave. 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). The Friis transmission equation is generally used to calculate the power received from a receiving antenna with gain GR, when the signal strength is measured.

RESULT:

Antenna technology is crucial in UAV-assisted wireless networks with 5G mm Wave communications, serving as a wireless interface for transmitting and receiving signals. As the extension from conventional microwave frequency bands to mm Wave frequency bands increases propagation attenuation and free space path loss, the design of high gain and high-efficiency antennas is essential for the realization of UAV-assisted wireless networks with mm Wave communications. The high mobility and physical structures of UAVs pose additional challenges in accurate tracking of dynamic mm Wave beam directions. Recent efforts and solutions on antenna-related research include antenna design, beam tracking, beam optimization, and beam tracking.

The successful deployment of UAV-assisted wireless networks with 5G mm Wave communications has led to the development and design of wireless antennas, focusing on various factors such as frequency bands, propagation characteristics, circuit components, gain rating, mounting device geometry, transceiver architecture, and communication system performance. Research has been conducted on the design issues and solutions of two representative antennas: array antennas and beam antennas. The use of UAVs flying at high altitudes for building high-altitude platform stations (HAPS) and stratospheric-platform (SPF) systems has been recognized as a low-cost and flexible method for future wireless infrastructure. Tsuji et al. conducted experiments to test the performance of digital beamforming (DBF) antenna and multi-beam horn (MBH) antenna for mm Wave frequency band under stratospheric conditions.

Frequency Range	2 Antenna elements	4 Antenna elements	6 Antenna elements
0	0	0	0
50	17	15.5	12
100	20	18.5	16.5
150	21.5	20	18
200	23.25	21.75	19.25
250	24.25	22.5	20.25
300	24.15	22.75	21.15
350	25.15	23.75	22
400	25.75	24	22.5
450	26	24	22.75
500	27	25	23.5

Table1: Array gain for different antenna elements at η=1,0.75,0.5.

They proposed an electronically controlled mm Wave DBF antenna for HAPS, which was mounted on a helicopter and operated under stratospheric conditions with temperatures below -60°C and Bandwidth enhancement and miniaturization for microstrip antennas are major challenges in designing conventional compact antennas. Siddiq et al. designed the dual-band mm Wave printed microstrip antenna patch for UAV applications, which resonated at 29-30 GHz and 57-66 GHz mm Wave bands. The authors proposed two types of star-shaped antenna atmospheric pressure 1/20 of that on Earth. Bandwidth enhancement and miniaturization for microstrip antennas are major challenges in designing conventional compact antennas. Siddiq et al. designed the dual-band mm Wave printed microstrip antenna patch for UAV applications, which resonated at 29-30 GHz and 57-66 GHz mm Wave bands. The authors proposed two types of star-shaped antenna

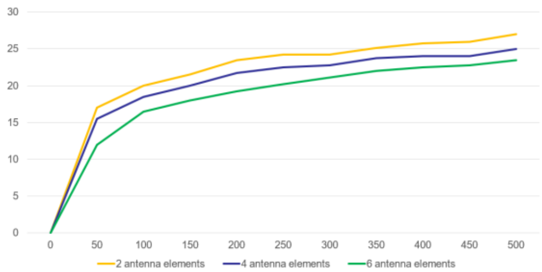

Figure7: Array gain for different antenna elements at η=1,0.75,0.5.

arrays: 1 × 2 array and 1 × 4 array. In conclusion, the success of UAV-assisted wireless networks with 5G mm Wave communications has prompted the development and design of wireless antennas, addressed various design issues and improved communication system performance.

CONCLUSION:

Emerging 5th Generation mobile networks are expected to play a crucial role in providing services to various V2X applications due to their ultra-low latency and reliable communications. However, as networks evolve, mobility management becomes a challenge, especially for highly mobile V2X nodes. 3GPP focuses on avoiding long delay and achieving zero mobility interruption, but mobility interruptions still occur due to link failures. Three main research directions focus on improving mobility: reducing handover cost, enhancing handover decision based on user mobility dynamics, and enhancing beam management for better beam selection and alignment. Modern techniques, particularly machine learning algorithms, have been explored for adaptive data-drive decision in beam-based mobility management. As new technologies emerge, existing mobility management techniques may become under-performing, directly challenging overall network performance. The emerging IRS technology has attracted attention as a solution to overcome blockages in mm Wave networks for future generations, such as 6G.

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