Beyond 5G Without Obstacles: mmWave-over-Fiber Distributed Antenna Systems

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Abstract

Beyond-5G wireless systems require significant improvement to enable the Internet of Everything, offering ultra-reliability, ultra-low-latency and high data-rates for holographic telepresence, immersive augmented and virtual reality, and cyber-physical systems in Industry 4.0. The mmWave frequency band (30 GHz-300 GHz) provides the required bandwidths, but very challenging propagation conditions exist. Conventional co-located multi-antenna systems counter higher path loss, but are insufficient in challenging real-life scenarios with frequent non-line-of-sight conditions. For distributed massive MIMO systems or large intelligent surfaces, we advocate optically-enabled distributed antenna systems (DAS) to alleviate these issues. To ensure tight synchronization and scalability, we propose a mmWave-over-fiber based architecture with low-complexity high-performance remote antenna units (RAUs). Strategically distributing and integrating RAUs in the user equipments' environment yield high throughput and reliable coverage. We demonstrate a mmWave-over-fiber DAS yielding multi-Gbps mmWave communication in a harsh indoor environment with non-line-of-sight conditions, measuring wireless data rates up to 24 Gbps, by selecting the RAU yielding the best link quality, and up to 48 Gbps, by leveraging distributed MIMO techniques.

Introduction

Through massive multiple-input multiple-output (mMIMO) wireless communication, the fifth-generation (5G) wireless mobile network provides enhanced mobile broadband (eMBB) access, but falls short as enabler for the Internet of Everything (IoE), where multiple devices require eMBB at millimeter-wave (mmWave) frequencies to communicate at high data rate, high reliability and low latency. The performance of current basic IoE and ultra-reliable low latency communication (URLLC) does not meet the ever-increasing demands of emerging wireless applications [1]. Holographic telepresence, immersive multisensory interactive augmented and virtual reality (AR/VR), and cyber-physical systems in Industry 4.0 require high data rates (up to multiple Gbps per-user and up to one Tbps aggregated), with strict reliability (99.99999 %) and latency (100 µs) conditions. Beyond 5G (B5G) and 6G networks must jointly meet all stringent network demands [2] (reliability, capacity, data rate, latency and energy efficiency).

Unleashing the full potential of B5G and 6G requires a holistic multi-disciplinary approach, based on disruptive communication technologies, innovative network architectures, and artificial intelligence (AI) [1]. To support extremely high data rates, mmWave (30 GHz-300 GHz) and TeraHertz (0.1 THz-10 THz) frequency bands play a key role. Yet, at these frequencies, challenging propagation conditions exist, such as increased path loss, higher penetration loss, and more severe shadowing. However, the very short wavelengths facilitate the integration of a massive number of antenna elements in a small footprint to counter the unfavorable path loss and to mitigate impact of user mobility through adaptive beamforming [3]. Moreover, MIMO algorithms can further optimize throughput and reliability. Still, a conventional co-located approach, with all antennas compactly grouped at a single location, cannot maintain the very high data rates in challenging, non-line-of-sight (NLoS), real-life conditions, due to shadowing or self-blocking, as illustrated in Figure 1 (Challenge #1), with the user equipment (UE) obstructing the line-of-sight (LoS) path. This represents a major issue in Industry 4.0 and interactive AR/VR applications, due to (1) very challenging UE antenna deployment conditions, on metal robots in the former and human bodies in the latter, and (2) the use of directive antennas with high antenna-to-integration-platform isolation. Additionally, link quality also deteriorates in other NLoS scenarios, as in Challenge #2, where obstacles (static machinery/racks or dynamic robots/humans) block the LoS-path between UE and access point.

To improve link reliability in case of LoS blockage, current solutions either revert to sub-6 GHz frequencies or advanced beamforming to exploit reflections in the environment. In Figure 1, fallback solution #1, implemented through multi-radio-access technology (multi-RAT) and/or dual connectivity, leverages more relaxed propagation conditions at sub-6 GHz frequencies to maintain the wireless link, compromising on data rate and network capacity. Alternatively, solution #2 maintains mmWave communication by beamforming along a strong reflection via existing or intentionally deployed reflectors. Unfortunately, this increases propagation loss, requiring larger array gain or increased transmit power.

In recent years, many innovative concepts for reliable, high-data-rate wireless connectivity were proposed, such as active phased-array-based relays [4], intelligent reflective surfaces (IRS) [4], and large intelligent surfaces (LISs) [5]. Solution #3 (Figure 1) deploys a co-located antenna array at the access point, while judiciously distributing relays to improve coverage. These repeaters could be phased antenna arrays retransmitting an amplified version of the received signal, potentially applying intermediate (de)coding. Yet, promising advancements are being made in the field of IRS, which rely

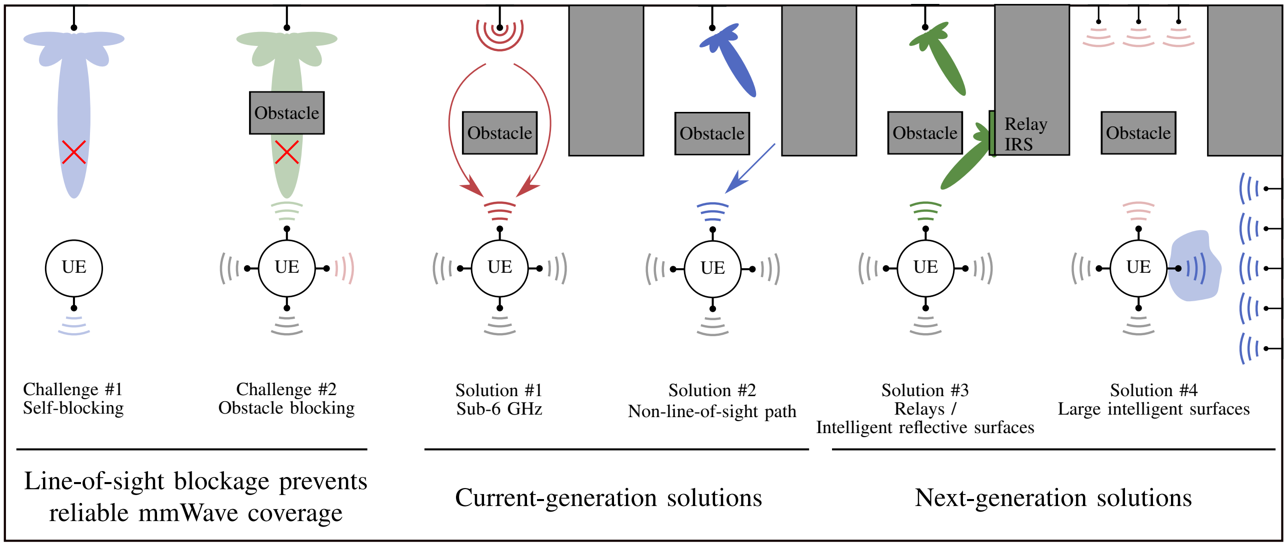

Fig. 1. Indoor millimeter-wave (mmWave) communication: Reduced indoor mmWave coverage to the user equipment (UE) due to difficult propagation conditions, such as (self-)blocking (left), solutions to maintain wireless communication at the cost of reduced throughput and/or higher power consumption (middle), and next-generation solutions for reliable high-data-rate mmWave communication by deploying active relays, intelligent reflective surfaces (IRSs) or large intelligent surfaces (LISs) (right).

on a holographic principle to steer the retransmitted signal. Compared to conventional phased-array-based repeaters, IRSs realize similar directivities while being less power-hungry. However, much more research is still required to practically implement this technology at mmWave frequencies [4]. Alternatively, a LIS, envisioned as an extremely large contiguous surface of electromagnetically active material, controls electromagnetic fields across a large area, implementing unprecedented energy focusing in three dimensions. This concept, illustrated by Solution #4 in Figure 1, makes the entire harsh and challenging environment smart to fulfill the boldest B5G and 6G requirements in terms of data rate, latency, and reliability. A controlled field across a contiguous LIS can be practically implemented by distributing a massive amount of antennas [5]. This places the UEs in the near field of the total system, enabling holographic beamforming, focusing energy at each UE and effectively suppressing inter-user interference. In general, a LIS promises exciting new features and substantial gains compared to co-located mMIMO systems [5], but also introduces significant challenges, such as efficient signal processing and low-loss distribution of broadband mmWave signals to a massive number of tightly synchronized distributed mmWave antennas, which are highly efficient, robust, and realized in a cost-effective technology compatible with large-scale deployment. This article analyses and demonstrates the potential of optically-enabled mmWave distributed antenna systems (DAS) to provide multi-Gbps wireless data rates to UEs in harsh indoor environments by:

- briefly reviewing the state-of-the-art in mmWave distributed antenna systems;
- proposing a novel optically-enabled mmWave architecture, consisting of a Central Office (CO), responsible for all signal processing, and ultra-low-complexity fiber-connected distributed Remote Antenna Units (RAUs);
- leveraging mmWave-over-fiber to efficiently exchange broadband mmWave signals between CO and distributed RAUs while guaranteeing tight synchronization;
- elucidating how robust and high-performance, yet low-cost and laser-free RAUs are realized by leveraging air-filled substrate-integrated-waveguide (AFSIW) technology and SiPhotonics transceivers, enabling the practical large-scale roll-out of distributed mMIMO antenna systems and LISs;
- describing the crucial role of machine learning (ML) and artificial intelligence (AI) technology in broadband mmWave mMIMO antenna systems and LISs for efficient channel estimation and real-time processing of the massive amount of data;
- demonstrating the proposed architecture's potential to establish reliable multi-Gbps wireless communication with multiple collaborating distributed RAUs via an extensive measurement campaign in an anechoic setup and a realistic Industry 4.0 environment.

mmWave Distributed Antenna Systems

At mmWave frequencies, unreliable communication due to very challenging NLoS propagation conditions must be avoided by a holistic multi-disciplinary approach. We propose an optically-enabled mmWave DAS, consisting of a CO and optically fed RAUs as shown in Figure 2, to implement high-data-rate mmWave communication with improved coverage in harsh environments. Strategically integrating RAUs in the building infrastructure surrounding the UEs guarantees line-of-sight communication in a substantial part of the operating range. [6] theoretically shows that the total capacity of the system increases by augmenting the number of RAUs. According to the number of UEs, the target application, and the envisioned deployment environment, the required number of RAUs can then be adequately determined. Depending on the CO's architecture, the DAS enables switching between

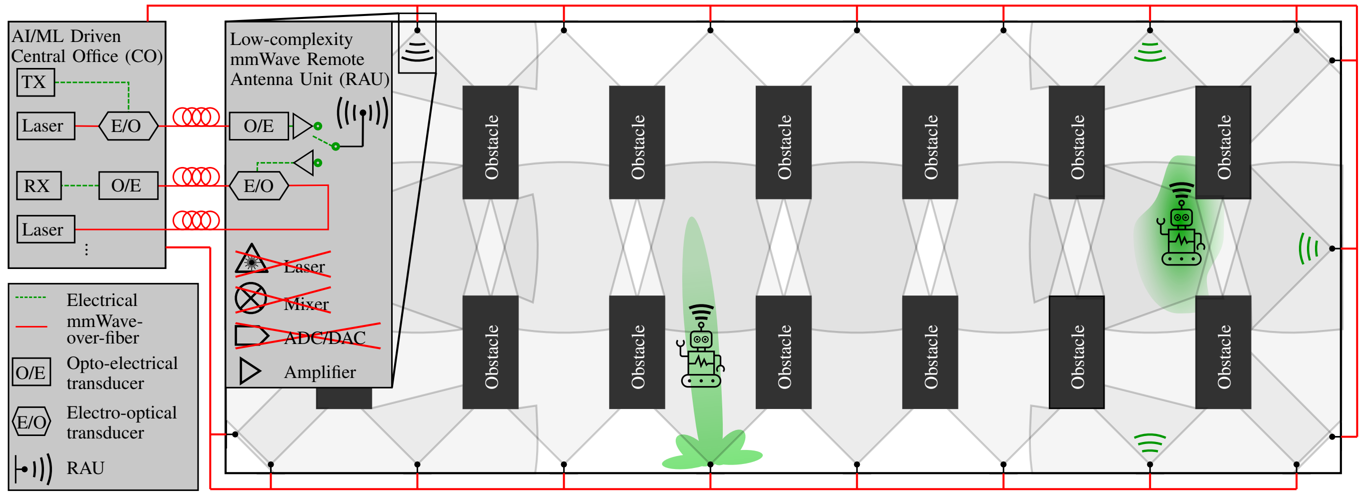

Fig. 2. Robust, high-data-rate indoor coverage in challenging Industry 4.0 environments by a distributed antenna system. Strategic deployment always provides at least one line-of-sight path. mmWave-over-fiber enables (1) centralization of all expensive hardware at the central office, (2) scalability, (3) low-loss routing of broadband signals, and (4) tightly synchronized RAUs, essential for distributed MIMO and LIS systems.

RAUs or cooperation between tightly synchronized RAUs. Selecting the RAU with the best link quality, as in the middle of Figure 2, reduces the CO's hardware complexity, enabling maximum hardware reuse while yielding power efficient and reliable mmWave communication, provided that hand-over is properly implemented. Yet, effective cooperation between tightly synchronized RAUs enables the realization of a distributed mmWave mMIMO setup, with each RAU equipped with an appropriate number of antennas. By increasing the number of RAUs and their number of radiating elements, a massive number of antennas is deployed around the UEs, approximating a contiguous radiating surface that practically implements the LIS-concept. Eventually, this realizes holographic beamforming (robot to the right in Figure 2), focusing energy in a confined three-dimensional volume around each UE [5].

Although optically-enabled DASs allow realizing a reliable cell-free high-data-rate mmWave network, several multi-disciplinary challenges remain. High-performance, power-efficient, low-cost and low-complexity RAUs are vital to scale this concept to an economically viable LIS. A novel architecture should be conceived to efficiently distribute broadband mmWave signals to a large number of tightly synchronized RAUs. Finally, all signals generated and received by this massive number of radiating elements must be efficiently processed in real-time.

mmWave-over-fiber for Efficient Signal Distribution

The architecture in Figure 2 leverages the advantages of optical fiber (large bandwidth, low loss, no interference issues,...) to efficiently distribute broadband signals to a large number of RAUs. In literature, most realized DASs rely on sub-6GHz analog radio-over-fiber (ARoF) and adopt an intermediate frequency-over-fiber (IFoF) approach, with the CO providing a downconverted IF signal to each RAU. The distribution of a dedicated synchronous carrier with mixing at the RAU significantly increases its complexity. Other works [7] apply digitized-radio-over-fiber (DRoF) or sigma-delta-over-fiber (SDoF), but without achieving the same spectral efficiency and RAU simplicity as the proposed mmWave-over-fiber scheme, in which the broadband signal is directly modulated onto the optical carrier. Now, RAUs only implement opto-electrical/electro-optical conversion and amplification, while all expensive hardware remains centralized at the CO. Shifting up- and down-conversion from RAU to CO both eliminates power-hungry mixers at the RAU and tightly synchronizes all RAUs, enabling distributed mMIMO and LIS implementations. Still, this requires high-speed opto-electronic devices and entails chromatic dispersion fading in the fiber [8]. To realize a highly efficient transceiver for mmWave-over-fiber communication, a high-speed ISIPP50G silicon-photonic photodetector and electroabsorption modulator were co-optimized and compactly integrated with dedicated GaAs amplifiers to maximize power transfer within the targeted mmWave frequency band [8]. Yet, even faster opto-electric transducers are actively researched, currently reporting devices with sub-THz bandwidths [9]. Here, we leverage the link in [8] together with low-complexity and cost-effective RAUs to realize a scalable mmWave DAS. To increase the number of RAUs, while providing every RAU with a dedicated signal, required for next generation mMIMO or LIS systems to serve a large number of users, one may adopt a star configuration, with a dedicated point-to-point fiber link from the CO to each RAU, or a ring configuration, with wavelength division multiplexing (WDM) and optical filtering. At lower mmWave frequencies and with standard fibers, chromatic dispersion fading only becomes problematic after kilometers of fiber, which is typically not encountered in indoor environments. Yet, if longer fiber connections are needed, as in large factories of the future, or operation at higher mmWave frequencies is targeted, this problem can be countered by optical single sideband architectures [8]. Figure 2 shows that such a bi-directional time-division-duplex (TDD) mmWave-over-fiber link yields a distributed mmWave antenna system that overcomes LoS-blocking, as required to meet the very challenging specifications of future-generation applications in realistic environments.

Cost-Effective and High-Performance Remote Antenna Units

Robust and high-performance, yet cost-effective RAUs are of major importance in the roll-out of large-scale distributed mMIMO systems and LISs. The mmWave-over-fiber architecture already eliminates up- and downconverters at the RAU and local oscillator (LO) signal distribution. Shifting the laser for uplink communication to the CO further reduces RAU complexity, cost and power consumption, only implementing electro-optical conversion, amplification, and radiation [8]. With all expensive hardware located at the CO, the laser-free RAUs efficiently reuse this equipment in case only a subset of RAUs is active. AFSIW technology is put forward as a prime candidate for photonic-enabled antenna systems as efficient, broadband mmWave antenna integration platform, facilitating compact integration of all required RF amplifiers and opto-electronic transducers [10]. Highly efficient, robust multi-antenna systems may be realized in low-cost lossy substrates, such as FR4, silicon, cork, ABS and particle board through standard fabrication technology [3]. By exploiting metallized air cavities, dielectric losses are eliminated, yielding unprecedented radiation efficiencies. Furthermore, surface waves are blocked, enabling compact arrays with low mutual coupling, stable radiation patterns, and high antenna-to-integration-platform isolation, providing robust stable performance in harsh environments. Therefore, the antenna elements and array proposed in [3] are deployed at the UE and RAU in all presented experiments. To exploit this technology in the higher mmWave bands and beyond with a performance comparable to that in the lower mmWave frequency bands, further research on silicon micromachining, 3D printing and PCB manufacturing [11] is needed. Silicon micromachining provides precise fabrication, yet currently lacks the potential to integrate active electronics or photonics. Implementing AFSIW in PCBs at higher frequencies requires custom stack-ups. This provides a more cost-effective and lower-loss alternative to dielectric-filled SIW antennas. Moreover, advancements in 3D printing and surface-roughness-reducing treatments also provide opportunities to realize competitive antennas, but more research is needed to efficiently integrate active circuitry.

Machine-learning for large-scale mmWave DAS

In B5G and 6G wireless communication networks, machine learning (ML) will be exploited at each abstraction layer to predict users/services demands and evolution of the wireless channel to conceive self-optimizing and self-updating networks. Specifically for broadband mmWave cell-free distributed mMIMO systems and LISs, traditional multi-antenna signal processing techniques no longer suffice due to the massive number of radiating elements, the extreme data rates and ever-increasing number of mobile users. In contrast to conventional approaches, which require excessive computational power and lead to unacceptable latencies, deep-learning-based approaches that exploit inherent channel sparsity to efficiently precode and modulate the data onto multiple streams towards the distributed RAUs have shown near-optimal effective data rates at significantly lower computational complexity for coordinated distributed beamforming systems [12], cell-free distributed mMIMO systems [13] and LISs [14].

Providing Robust and High Data Rate Coverage

We now experimentally demonstrate the mmWave-over-fiber-based DAS's potential to generate high-data-rate wireless mmWave links at symbol rates of 3 GBd and 6 GBd. The setup in Figure 3 was first deployed in a controlled anechoic chamber environment. A metal cylinder with a diameter of 25 cm and height 30 cm, resembling the body of a robot, serves as UE. Fujitsu H74M-5208 lithium niobate Mach-Zehnder Modulators (MZMs) perform the electro-optical transduction in both downlink and uplink, while the photoreceiver in [8] implements the opto-electric conversion. An optical laser power of 10 dBm and fibers of 20 m are used. At the RAU, a 1x4 corporate-fed [24.25-29.5] GHz AFSIW antenna array [3], with a peak gain of 10.1 dBi at broadside, is applied. At the UE, a single antenna of the same topology, with 7.4 dBi peak gain and 70° half-power beamwidth, is deployed on the metal shaft [3]. A variable-gain amplifier (HMC943APM5E) ensures a constant transmit power of 20 dBm to overcome losses due to the wireless path of 2 m. Link quality in our setup is evaluated through the root-mean-square error vector magnitude (EVM), after zero-forcing (ZF) equalization over a QPSK symbol stream, quantifying the discrepancy between received transmitted symbols and the symbols in the transmitted constellation. According to 3GPP, reliable transmission of QPSK, or higher-order 16-QAM or 64-QAM symbols requires an EVM below 17.5 %, 12.5 % and 8 %, respectively [15]. The baseband symbols, generated by a Keysight M8195 arbitrary wave form generator, are upconverted by Analog ADMV1013 mixers to an RF carrier of 26.5 GHz. At the receiver, the signal is sampled by a Lecroy LabMaster 10Zi-A real-time oscilloscope. Next, the EVM is calculated in post-processing, selecting part of the symbol stream as pilot symbols. The mmWave-over-fiber link does not pose any condition on the applied symbol constellation, making the link signal-transparent. Therefore, the architecture supports 5G signals and is future-proof. Across the different experiments, we stress the different challenges that were resolved and point out remaining pitfalls.

High-Data-Rate Bi-directional Fiber-Wireless Link

First, the above wireless mmWave-over-fiber setup implements bi-directional multi-Gbps communication between one antenna on the UE, and a four-antenna-element RAU. Figure 3 shows the link quality. Because of the highly efficient directional antenna systems, guaranteeing robust performance on the robot platform, and the dedicated photoreceiver design, a 6 GBd signal can be supported, providing 24 Gbps in both uplink and downlink. While ensuring sufficient link budget, even after deployment on a conducting platform or human body, the mmWave link is only maintained over a field of view of 90° due to the metallic cylinder and the antenna directivity. A reduced symbol rate of 3 GBd still achieves a data rate of 18 Gbps (64-QAM) [15], showcasing a TDD half-duplex bi-directional link providing multi-Gbps communication using mmWave-over-fiber and cost-effective,

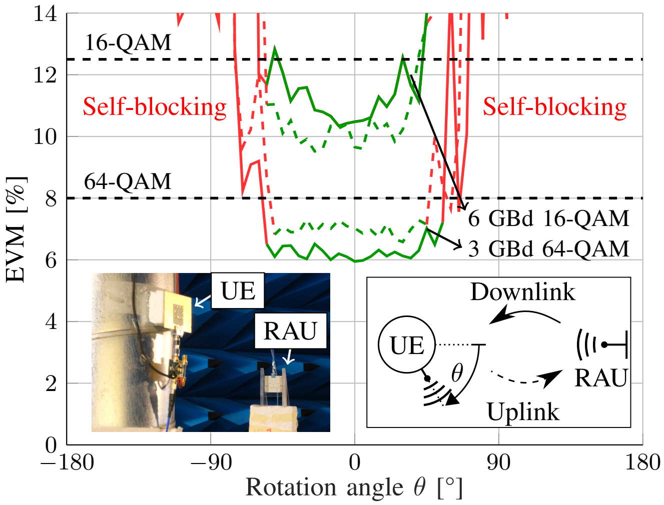

Fig. 3. Measurement of bi-directional fiber-wireless mmWave link supporting 24 Gbps or 18 Gbps in line-of-sight conditions. Self-blocking prevents high-data-rate mmWave communication.

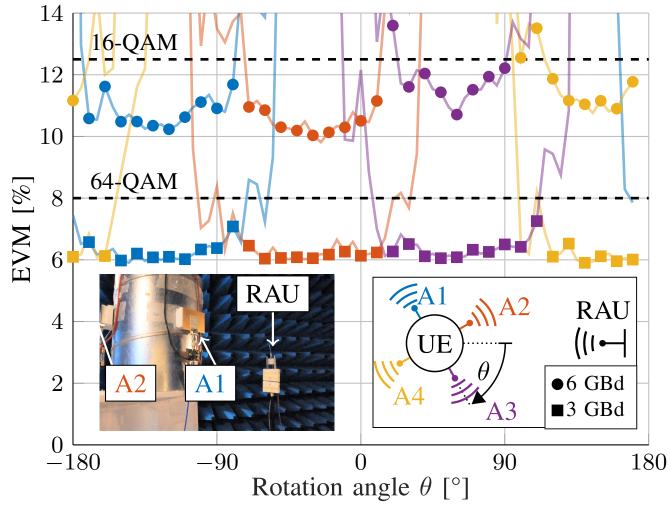

Fig. 4. Self-blocking problem resolved: Measurement of spatial diversity at user equipment (UE) ensures 24 Gbps (6 GBd) or 18 GBps (3 GBd) over 360° by combining signals at Antennas 1, 2, 3 and 4 (A1, A2, A3 & A4).

highly efficient custom RAUs. While this experiment used dedicated fibers for up- and downlink, the approach in [8] can be leveraged for bidirectional transmission over a single fiber, facilitating the interconnection of a large number of RAUs for large-scale deployment. Still, the link remains unreliable due to self-blocking. Since up- and downlink communication yield very similar performance, the remainder of the measurement analysis focuses on downlink communication.

Solving Self Blocking

Spatial diversity solves self-blocking by deploying multiple antennas on the UE or installing several RAUs in the room to form a DAS. For the former, selection combining with four antennas maintains the 24 GBps link for almost all rotations, significantly mitigating self-blocking. However, in the hand-over regions, the EVM exceeds the 12.5 %-threshold for 16-QAM modulation, which can be resolved by upscaling the number of antennas at the UE, performing analog beam-forming at the RAU or exploiting equal gain or maximum ratio combiners. Alternatively, reducing the baudrate to 3 GBd achieves a steady data rate of 18 Gbps without degradation due to self-blocking. For the latter, similar findings were found when distributing three RAUs around the targeted UE. When the link quality towards a particular RAU drops below a set threshold, another RAU takes over. This approach also further reduces the CO complexity through hardware re-use. In general, this experiment shows that self-blocking can either be solved by applying spatial diversity at the UE or through a DAS. Yet, the number of UE antennas and RAUs should be tailored to the application, environment and the antenna topologies used at the UE and RAU. Furthermore, the largest pitfall of this setup remains shadowing by external static or dynamic obstacles obstructing the LoS-path.

Solving Shadowing and Increasing Link Capacity

To overcome LoS-blocking effects, UE spatial diversity should be combined with a DAS. After detailed analysis of the targeted environment and potential UE locations, multiple RAUs are strategically distributed and the UEs are equipped with a suitable number of antennas. Drops in link quality, either due to self-blocking or an external static or dynamic blocker, are then resolved by simply selecting the best-positioned RAU and UE-antenna, as in Figure 2 (middle). Conceptually, this approach closely relates to coordinated multi-point (CoMP) techniques, first introduced in LTE release 11, where multiple coordinating transmission/reception points (TRPs) serve a UE. Specifically, it is similar to dynamic point selection, where the TRP offering the best channel conditions connects to the UE. Although originally proposed to mitigate interference and improve throughput at the cell edge, CoMP techniques will be leveraged in future 5G systems to enhance reliability in challenging propagation conditions. Moreover, when ensuring tight synchronization among all RAUs, as in our setup, multiple RAUs can collaborate to further improve performance, such as UE data rate. In Figure 5, two cooperating RAUs transmit two simultaneous data streams to an UE equipped with four antennas, at a symbol rate of 3 GBd or 6 GBd. At the UE, both data streams are recovered properly, resulting in a data rate of 36 Gbps or 48 Gbps, respectively, for all rotation angles of the UE. Again, conceptually, this compares to CoMP joint transmission mode. Whereas our synchronized architecture enables coherent beamforming, LTE has no plans for such features. Hence, an optically-enabled DAS, combined with UE spatial diversity not only offers a very promising path towards robust mmWave coverage in challenging environments, mitigating the effects of LoS blockage, but also boosts wireless data rates to unprecedented levels through distributed MIMO techniques.

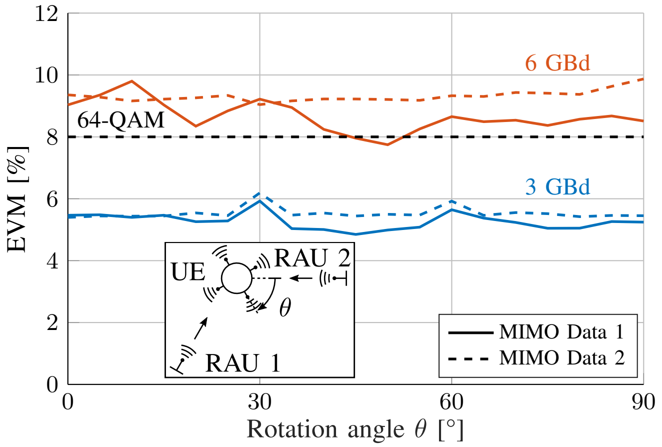

Fig. 5. Increased data rate through distributed MIMO: 48 Gbps measurement without self-blocking.

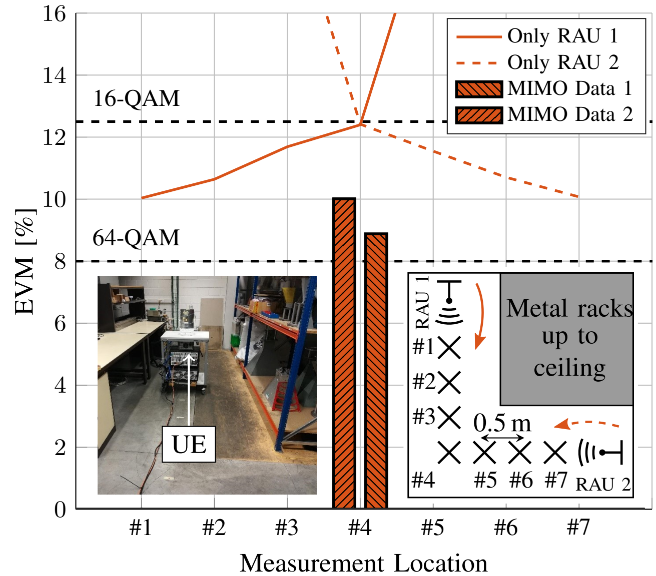

Fig. 6. Robust mmWave coverage ensuring 24 Gbps at every position by RAU selection. Throughput at position #4 doubled to 48 Gbps by distributed MIMO. Adjacent measurement positions spaced 0.5 m.

Workplace Environment

After validation in an anechoic environment, our optically-enabled DAS was deployed in a lab environment with 4-m-high ceilings, concrete floors, metal walls and metal racks, mimicking the harsh environments encountered in Industry 4.0 applications, to demonstrate robust, high-data-rate coverage in a realistic environment. The measurement setup (Figure 6) consists of two RAUs, at both ends of a corner, formed by metal walls, communicating with a metal cylindrical robot, equipped with four antennas. The robot is then positioned at seven different locations, at 0.5 m intervals, in between both RAUs. The link quality between RAU 1 and the UE, which applies selection combining, gradually deteriorates due to increasing path loss. Once the robot turns around the corner, the link quality drops significantly. A similar behavior is observed when only RAU 2 is active and the robot moves from position #7 to #1. Hence, by deploying these RAUs in this complementary way, a stable connection of 24 Gbps is maintained along the track, thereby fully resolving shadowing by the corner. Additionally, at position #4, two data streams were sent to the UE by leveraging distributed MIMO techniques at both cooperating RAUs. At the UE, both streams were recovered, achieving an EVM below 10 % (Figure 6), thereby doubling the data rate to 48 Gbps (two 16-QAM 6 GBd data streams). Hence, our approach provides stable high-data-rate coverage in harsh and challenging real-life environments, typically encountered in industrial settings. Moreover, through tight synchronization between the distributed RAUs, MIMO techniques increase wireless data rates even further. Yet, to fully unleash the potential of optically-enabled mmWave DAS, many challenges still remain. The highly complex environments and the large number of parameters and expected users need advancements in ML to determine the optimal positions of RAUs in real-life environments and the optimal number of antenna elements at each RAU and UE, to efficiently estimate the channel and to perform ultrafast precoding of all data streams to a large number of RAUs in real time, providing these high data rates in dynamic application scenarios. In this process, the impact of next-generation compression techniques on wireless data rates and latency should be analyzed. First, the generation and collection of large, accurate, real-world datasets, gathered within the small coherence time of the highly mobile users, is of major importance to further develop robust and efficient ML algorithms. Second, dedicated AI hardware is needed to efficiently implement these ML/AI techniques to process massive amounts of data at both CO and UE, within stringent latency constraints at an acceptable power level. It is important that (1) a hardware-algorithm co-design strategy is adopted for hardware-aware algorithms and algorithm-friendly transceiver structures, and that (2) a modular architecture enables reuse of AI hardware in the UE and a scaled-up version in the CO. Third, synchronized ML procedures in each layer, and not only the PHY layer, will fully exploit the potential of ML and ensure highly secure data transfer. Moreover, higher level of integration at the RAU side should also be pursued.

Conclusion

The potential of mmWave-over-fiber distributed antenna systems (DAS) for simultaneous reliable high-data wireless communication in future generation networks was demonstrated. Such a DAS is highly scalable owing to centralized processing and low-complexity, high-performance, laser-free remote antenna units (RAUs) composed of co-optimized opto-electric components and highly efficient air-filled substrate-integrated-waveguide antennas. Strategic distribution and integration of tightly synchronized RAUs in the user equipments' environment enables the roll-out of a distributed mMIMO system or a large intelligent surface. Measurements in a controlled anechoic chamber and a realistic environment, resembling an Industry 4.0 setting, show the potential of optically-enabled DAS architectures, establishing and maintaining multi-Gbps wireless communication, while resolving self-blocking and line-of-sight blockage issues. Our current setup obtains wireless data rates up to 24 Gbps by selecting the RAU with the best link quality, while achieving wireless data rates up to 48 Gbps through distributed MIMO techniques. However, large scale, efficient real-time signal processing and a suitable distribution of RAUs remain of major importance for practical roll-outs in high-data-rate, low-latency and maximal-coverage communication environments, as such fulfilling the boldest B5G requirements. Machine learning forms a promising technology to tackle these challenges.

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