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ARoF-Fed Antenna Architectures for 5G Networks

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Abstract: 5G mm-wave communications requires a highly densified network of radio access stations to ensure sufficient coverage. Low-complexity nodes based on C-RAN and ARoF fronthaul combined with advanced antenna concepts offer a suitable and potentially low cost technology for single and multi-beam 5G applications.
OCIS codes: (060.5625) Radio frequency photonics, (060.4510) Optical communications;

1. Introduction

5G is targeting data-rates of up to 10 Gbps per user, requiring much higher system capacities. In order to achieve this, additional frequency bands have to be allocated. Here, the millimeter-wave (mm-wave) band is considered an attractive option. However, the free space path loss at mm-wave frequencies is significantly larger than for currently used sub-6 GHz frequencies. Therefore, high gain antenna systems that allow the generation and steering of multiple beams are required at the base-station side in order to serve multiple users simultaneously. However, mm-wave signals suffer from blockage of buildings and humans more than sub-6 GHz signals, resulting in outages of the communication link. This problem can be solved using the centralized radio access network (C-RAN) architecture where each cell is populated by several remote radio nodes, also called remote units (RU's), as illustrated in Fig. 1. The RU's are connected to a central office (CO) via a front-haul link using several add/drop optical multiplexers (A/D's). Due to the vast amount of data that needs to be transported via fronthaul links, fiber-optic cables are usually considered as preferred technology choice here. However, since the RU's need to be integrated into existing urban environments, complete wired fronthauling is often not possible or prohibitively expensive [1]. In addition, mobile RU's (e.g. drone-based) can also not be supported by fixed fiber-optic networks. Here, mm-wave wireless fronthauling is an attractive solution. Especially mm-wave point-to-point (P2P) and point-to-multipoint (P2MP) systems are generally considered a suitable choice for this [1]. However, wireless fronthaul antenna systems at mm-waves require a high antenna gain to generate a high effective isotropic radiated power (EIRP) to overcome the large path loss [2]. Due to the large antenna gain, these antenna systems have a very narrow beamwidth. As a consequence, electronic beam-steering is required to facilitate flexible use of the wireless fronthaul system, both in P2P and P2MP, allowing multi-beaming and flexible routing of the data streams. In addition, electronic beam-steering avoids misalignment during installation as well as due to twist and sway in heavy weather conditions [2].

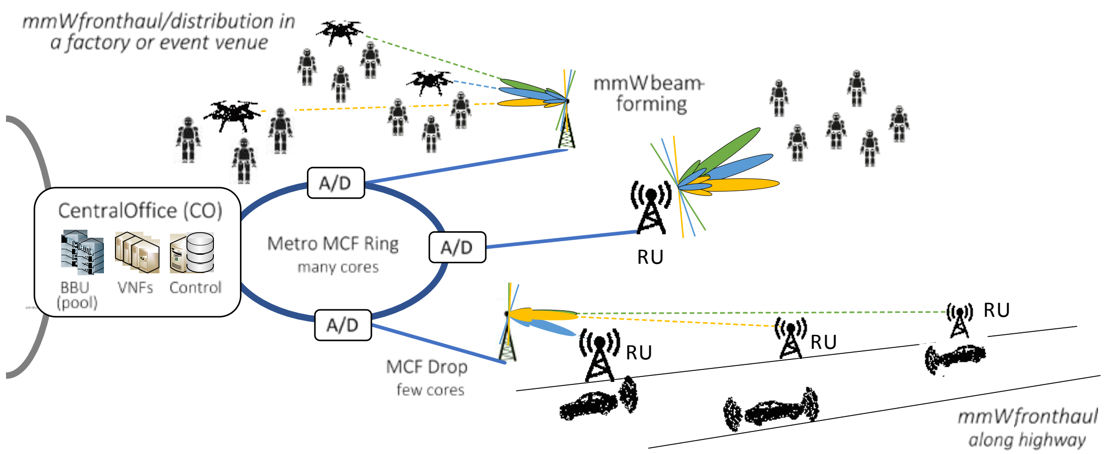

Fig. 1. C-RAN concept using analog radio-over-fiber fronthauling between the CO and a set of remote radio nodes; A/D refers to an "Add/Drop" multiplexers used to connect multi-core fibers with different number of cores.

While the requirements stated above add complexity to the physical radio design, the mobile communications market requires low-cost solutions in order to achieve acceptable prices for the end user. At Eindhoven University of Technology, antenna architectures fed by analog radio-over-fiber (ARoF) signals have been investigated in order to meet these demands. Here, special emphasis has been placed on the development of focal-plane-array (FPA) concepts as they allow high EIRP at low transmit power levels. In this paper, P2P and P2MP antenna architectures for wireless fronthaul and mm-wave RU's are described in Section 2 and 3, respectively.

2. Point-to-Point Antenna Architecture

Most P2P antennas are traditional dish antennas, consisting of a parabolic reflector and a single antenna element that illuminates the reflector. While this antenna concept is inherently simple by design and achieves a large antenna gain, it also exhibits some disadvantageous. First, the transmit power is limited by the available output power of the amplifier. Hence, rather costly III-V semiconductor technologies have to be used or the reflector size has to be increased in order to obtain large EIRP levels. The latter also yields a narrower beamwidth, which leads to alignment difficulties during installation and under heavy weather conditions, resulting in low net data-rates. Especially for dynamic movements of the antenna, this effect cannot be compensated by the traditional approach.

These shortcomings can be overcome by the use of a FPA concept, where the reflector antenna is fed by an antenna array rather than a single antenna element. A demonstrator of such an approach is shown in Fig. 2. By adjusting the amplitude and phase on the feed array, electronic beam-steering can be accomplished. In the example shown in the figure, a 2^0 scanned beam could be achieved by a 4x1 antenna array fed by optical phase shifters. Such a scan range is suitable for fine-alignment as well as movement compensation of the antenna. Moreover, the FPA concept also allows the distribution of the transmit power over several array elements and, thus, amplifiers. The reduced peak-power requirement per element results in the possibility to use silicon-based technology, as shown in [3, 4], which would reduce the overall cost of the solution.

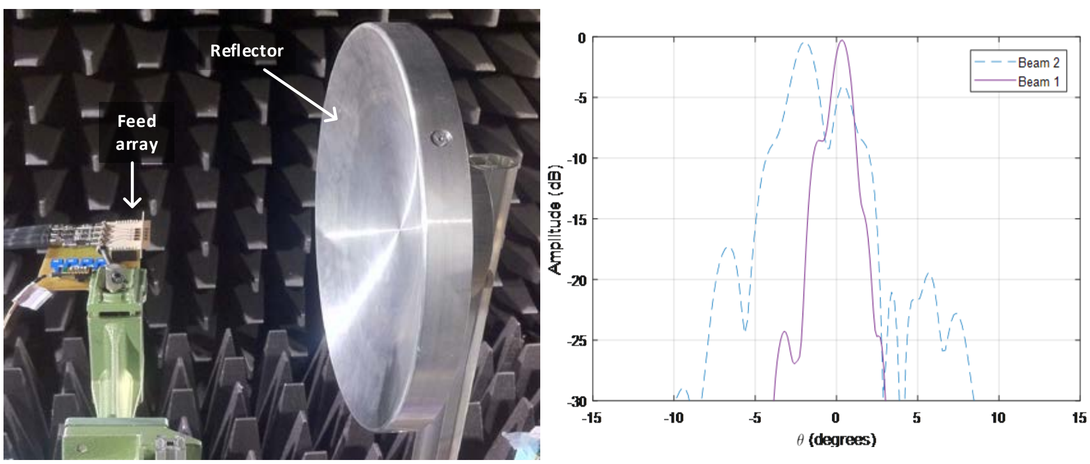

Fig. 2. Experimental setup and radiation patterns at 28 GHz for 0^0 (beam 1) and 2^0 (beam 2) scan angle of a P2P concept.

3. Point-to-Multipoint and Base-Station Antenna Architecture

For applications such as fixed wireless access (FWA), P2MP antennas are required. Here, a scan range far larger than $\pm 2^0$ is needed. As shown in [4], by using a shaped sub-reflector in combination with an antenna array, a scan range of $\pm 20^0$ can be achieved. A prototype along with its radiation pattern for a single feed excitation is depicted in Fig. 3. In order to shape the beam and achieve the full scan range with this reflector configuration, a 200 element antenna array is needed. However, for a single beam only a small sub-set of these elements has to be active, making this approach suitable for multi-beaming applications. Fig. 4 shows a possible feed structure for such antenna array, which is currently being developed in the projects SILIKA [5] and 5G STEP FWD [6]. It consists of a photo diode (PD) array at the transmitter input to convert the optical ARoF signals to radio frequencies. The radio signals are connected via a switch (SW) matrix to antenna sub-arrays that form the 200 element feed array. The location of the individual sub-array determines the scan angle of the resulting beam. Hence, depending on the user location, each radio signal is forwarded to one of the sub-arrays only. In order to allow for beam calibration and fine-tuning, analog beamformer (ABF) chips are used that can alter the phase and amplitude on each of the array elements. In this way, the beams shown in Fig. 4 can be generated.

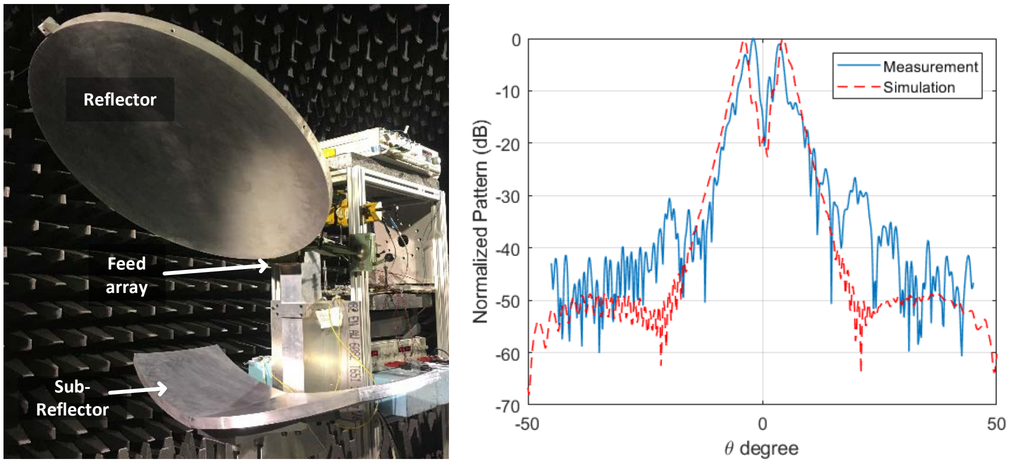

Fig. 3. System demonstrator (left) and its radiation pattern for a single element excitation (right).

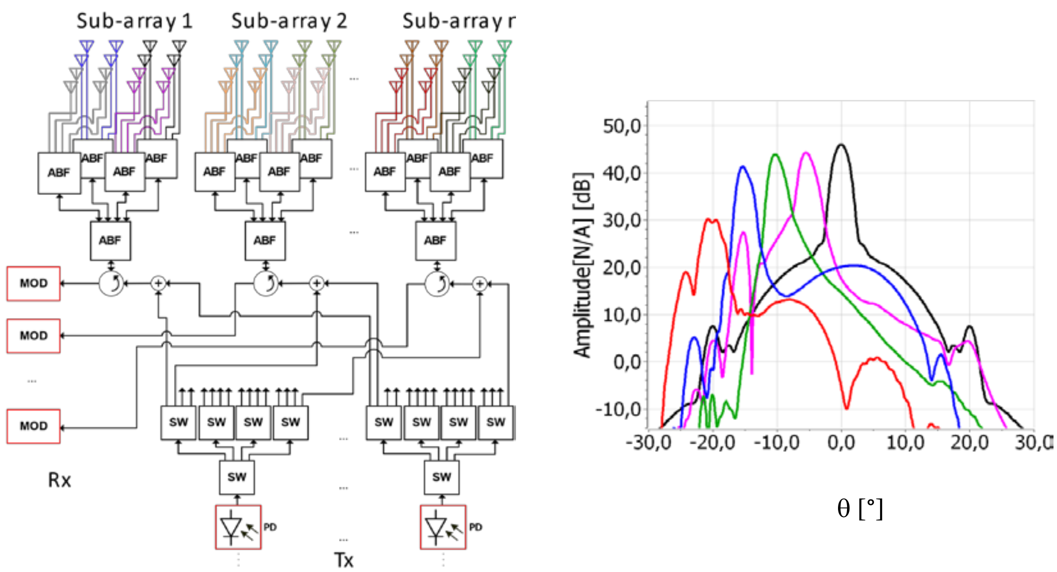

Fig. 4. Proposed feed structure (left) and simulated radiation patterns for different scan settings (right) of the antenna concept shown in Fig. 3.

5. Conclusions

Advanced antenna concepts with high-gain and flexible multi-beam transmission have been discussed for 5G deployment. Direct feeding of such antennas through analog radio-over-fiber allows their use for fiber-wireless access, adaptive hybrid 5G fronthaul and deployment of large bandwidth mm-wave 5G communications.

6. Acknowledgement

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7. References

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[5] “SILIKA, “ research project funded by European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska Curie grant agreement No 721732 (www.silika-project.eu)

[6] “5G STEP FWD,” research project funded by European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska Curie grant agreement No 722429 (https://www.5gstepfwd.eu/)