ATTO: Wireless networking at fiber speed

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Abstract *To provide a tremendous wireless capacity (100Gbps/m^2) and latencies <10µs, ultra-small floor-integrated cells are proposed. RF-over-fiber, coherent communication and a dedicated 2D PON structure support the interconnection and selection of the cells and allow to minimize the required transceiver electronics.*

Introduction

The emergence of the fifth generation (5G) cellular network brings along new challenges in the wireless access domain [1]. A massive growth of devices and connected things is foreseen and the mobile data traffic is skyrocketing with the arrival of new technologies such as cloud computing, ultra-high definition video streaming and virtual reality.

To anticipate other future applications, such as distributed robotic systems in a factory-of-the-future environment, wireless access to high performance computing resources is required. It is envisioned that a futuristic factory will be populated by numerous autonomous robots (e.g. 100 robots in a 250 m^2 area). To perform the most difficult tasks in a versatile manner, these robots require a high degree of intelligence. Moreover, they should be able to react very fast to changing conditions (including interactions with humans) or operate within time-critical control loops. This human-like intelligence requires a tremendous amount of computing power. In the future, robots will be able to operate at tens of teraflops. Yet, allowing them to combine this with the computing power of the other robots sharing the same area and/or with local computing power in their immediate environment would empower them to become an integral part of a petaflops computer. However, the demands in terms of wireless communication greatly surpass the current proposed 5G specifications. The required interconnection speeds (dedicated bitrates up to 100Gbps), extremely low latencies (down to 10µs) – defined as the time between IP traffic entering and exiting the network –, high densities (e.g. 100 robots on 250 m^2) and high reliability are today only encountered in “wired”, datacenter-oriented, connection systems using e.g. cabled Infiniband technology. To satisfy these requirements, we propose a novel wireless access architecture (ATTO) that provides bitrates of 100 Gb/s with latencies below 10 µs, data densities of 100 Gbps/m^2 and this with very high reliability (for mobility of ground moving objects of less than 30 km/h, such as robots or humans). The system concept consists of a collection of very small cells (with a typical size of 15x15cm^2), which are integrated into the floor. The floor integrated antenna of the cell will be able set up a dedicated 100Gbps communication stream to a a floor-facing antenna of the mobile object positioned on top of the cell. A 3x3 line-of-sight MIMO channel using 64-QAM in the 60GHz band will be used. Compared to the proposed 5G specifications, this represents an increase of 1000x in bitrate/area, a reduction of 100x in latency and an increase of 10x in bitrate.

This paper continues with an overview of the performance of wireless standards, especially focusing on achievable data rate per area. Next, our ATTO concept is introduced and the optical subsystem principles are discussed in more detail. The paper ends with a conclusion.

Evolution of Wireless Performance

It is clear that currently no wireless technology is capable of delivering the required performance, being 100Gbps/m^2 and latencies of 10µs.

The bitrate densities per area of today’s major standardized wireless RF technologies [2,3] are

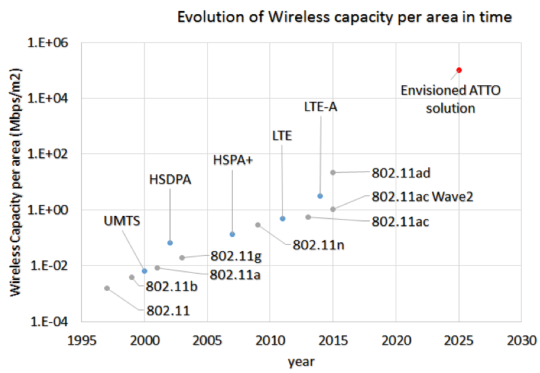

Fig. 1: Bitrate densities of today’s standardized wireless RF technologies

depicted in Fig. 1. The technologies considered include IEEE 802.11 (‘99, a, b, g, n, ac, ad), using their typical transmission range, and 3GPP

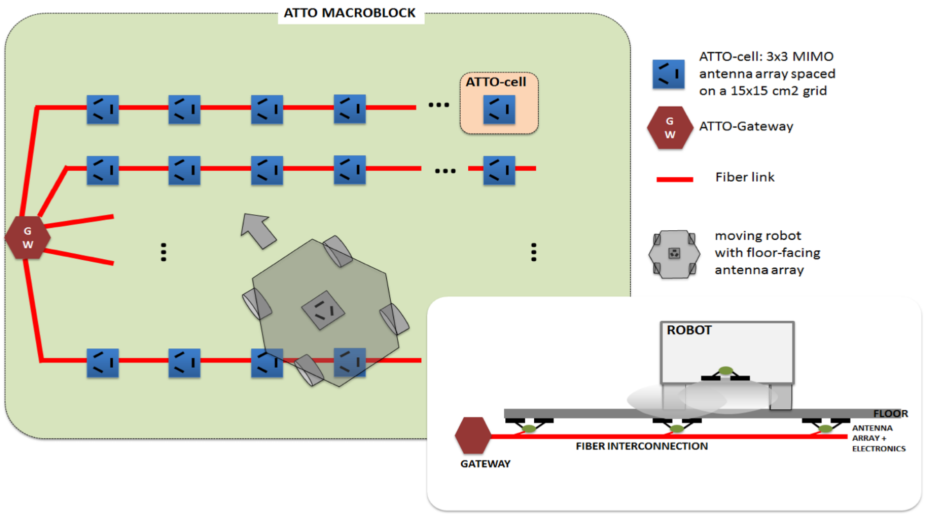

Fig. 2: ATTO-concept: highly intelligent robots on a sea of antennas

(UMTS, HSDPA, HSPA+, LTE, LTE-Advanced), using femto cells with a radius of 10 meters. For example, the 20Mbps/m^2 point corresponds to today's 60 GHz IEEE 802.11ad technology with a typical indoor range of 10m. The envisioned goal, being a bitrate density of 100Gbps/m^2, as indicated in red, is targeted for the year 2025.

None of the mentioned standards were specifically developed to increase the capacity per unit of area. To maximize the available data rate, the total available spectrum should be exploited in an optimal manner. To instantaneously minimize the latency, a dedicated cell or access point per user is required. Hence, when aiming for a wireless capacity density of 100Gbps/m^2, ultra-small cells become critically important. To be consistent with the existing scaling paradigm, these cells are denoted ATTO-cells.

ATTO-Cells

Currently, there is no technology that can meet all these very stringent requirements. A very large bandwidth is needed to realize the required 100Gbps throughput and, as a result, only millimeter-wave frequencies can be considered feasible candidates. To increase the available capacity per square meter, the cell size needs to be reduced as much as possible, together with the interference between adjacent active cells. Therefore, we introduce a radically new approach: the deployment of very small antenna cells (ATTO-cells) integrated in floors.

An overview of this system is given in Figure 2. The depicted ATTO-macroblock, comprising multiple ATTO-cells, has a dedicated gateway, where most of the electronics is aggregated and which provides access to the Internet or other ATTO-macroblocks. The gateway connects to the different ATTO-cells using a RF-over-fiber passive optical network (PON) connection.

Antenna system interconnection

Due to the high number of cells, it is no longer economically feasible to integrate a complete transceiver at every ATTO-cell. Hence, we provision only a limited number of transceivers, integrated into a common ATTO-gateway. In this way, the cost of an ATTO-cell can be kept low. The total amount is part of the planning process and relates to the number of mobile nodes foreseen in the area covered. In fact, the number of transceivers used simultaneously corresponds to the number of active cells, which is much smaller than the total amount of ATTO-cells.

Another major challenge is the development of an optical interconnection network that efficiently connects the ATTO-cells with the ATTO-gateway using a dedicated path (using wavelength division multiplexing over different fibers). It is important to recall that the primary service offered to each user is access to a full 100Gbps stream that is not shared amongst other users. The different transceivers need to be dynamically connected to the different ATTO-cells, requiring a flexible, high-bandwidth reconfigurable optical fiber interconnection network. To allow flexible addressing of the different ATTO-cells, a parallel coherent PON is proposed in Figure 3a.

The application of RF-over-fiber limits the electronics required at the ATTO-cells to amplifiers and opto-electrical components. Due to the high number of ATTO-cells, it is not cost-effective to use a dedicated fiber for each cell, while the gateway would require the same

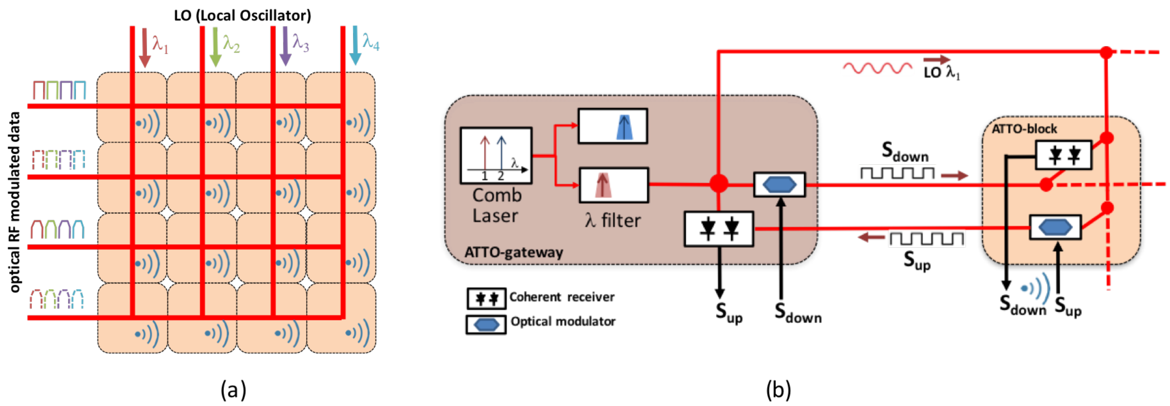

Fig. 3: (a) Basic concept of the optical interconnect architecture using "horizontal data" PONs and "vertical selection" PONs, (b) Principle of the use of a single laser to produce both the data carrier and LO in upstream and downstream, drastically reducing complexity in the ATTO-cell

amount of optical transceivers. To limit the number of fibers and to limit the split factor, we propose an interconnection network consisting of "horizontal data" and "vertical selection" PONs, as depicted in Figure 3a. The downstream data streams for a particular row are multiplexed on different wavelengths (N in total) and the combined signal runs from left to right. The wavelength associated with a particular antenna is selected naturally in a coherent receiver by the Local Oscillator (LO) wavelength provided via the vertical PONs. Both the modulation wavelength and the LO wavelength are generated by the same source (see Figure 3b).

The upstream signals from right to left can reuse the same LO carrier using external optical modulators, but travel on a separate horizontal PON to avoid crosstalk. Furthermore, all the different wavelengths used in the architecture originate from one comb laser in the ATTO-gateway. As a result, frequency drift is mitigated and no expensive temperature stabilization is required in the ATTO-cells. Moreover, because the local oscillator used to generate the signal is reused at the receive side, the specifications on the laser linewidth are relaxed. The coherence time of the laser should be longer than the difference in traveling time of the data signal and local oscillator signal. This difference can be made small by careful floor planning of the ATTO-floor.

The use of the LO wavelength to select the right ATTO-cell results in a non-blocking flexible architecture. Applying a single laser for the signal carrier and LO in both upstream and downstream direction leads to very efficient reuse of components at the ATTO-gateway. Thereby, the complexity of the ATTO-cells is strongly reduced. Moreover, if a sufficiently strong LO is used, the coherent detection introduces gain in the optical-electrical conversion, compensating the splitting losses in the PON architecture.

Conclusions

A prototype of the wireless part is illustrated in figure 4: the robot, the 15x15 cm2 ATTO-cells and the slotted antennas integrated in the floor.

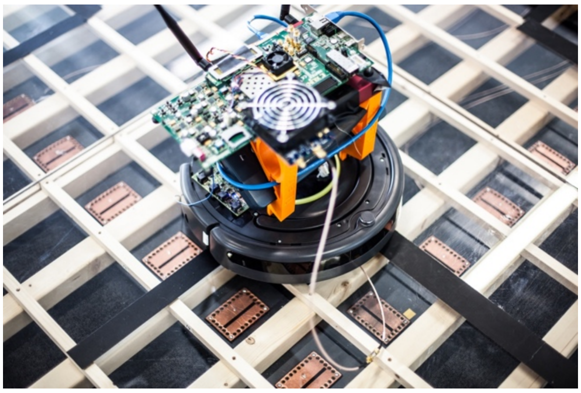

Fig. 4: 3 Gbps/m^2 (unidirectional), 3.5 GHz.

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