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Multiplexing In Mobile Cells

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ABSTRACT

Mobile cell capacity can be increased by Space Division multiplexing by reusing frequencies in different directions. But, today's technology cannot provide Tb/s capacity. In this paper, I introduce time-to-space division multiplexing as a new scheme to steer multiple beams simultaneously to different users. The main advantage of the proposed method relies in the fact that simple hardware can be used to generate the beams. In other word, it provides the advantages of space division multiplexing without relying on the complex array feeders that are usually required. Thanks to this advantage, the proposed technique can be easily combined with millimeter Wave systems.

Keywords: Time-to-Space division, Tb/s Mobile Cells, Beam Forming, Beam steering

INTRODUCTION

Space Division Multiplexing (SDM) and millimeter wave communication together could offer Tb/s of wireless capacity. But, an affordable solution to merge the merits of both technologies is very challenging. SDM requires either massive hardware in the form of multiple phased-array antennas or large digital signal processing (DSP) systems. Yet, DSP is particularly costly at highest speed such as those needed to encode millimeter wave signals. If Tb/s wireless links are to become practical new solutions that rely on low complexity and low-cost hardware will be needed. Among the most promising implementations of next generation radio access networks (NG RAN), two trends can be distinguished: First, concepts relying on current 4G-LTE microwave frequencies (2.4, 5 GHz) with approaches such as massive multiple input, multiple output (MIMO) or smarter networks. Second, concepts based on millimeter wave (mm-Wave) technologies. In the case of massive MIMO, take advantage of low cost, reliable, and mass producible components to generate multiple beams, but suffer from the limited bandwidth available at microwave frequencies. On the other hand, mm-Wave technologies leverage the large bandwidth available at mm-Wave bands to considerably increase the bit rate. However, the increased cost and complexity of the components diminish the benefits and often prevent the implementation of advanced concepts such as massive MIMO. Nonetheless, combining advanced system architectures such as massive MIMO or smarter networks with mm-Wave technologies could potentially combine the benefits of both approaches to provide both a larger bandwidth and spatial diversity at the same time. Yet, merging both approaches has shown to be challenging with current designs due to the large number of mm-Wave components in the Base Band Units (BBU), the Remote Radio Head (RRH), and the User Equipment (UE).

The scheme, time-to-space division multiplexing (TSDM), increases the capacity of a mobile cell while simultaneously reducing the hardware requirements on the UEs. In other words, TSDM enables multiple beam steering capabilities comparable to concepts such as known from massive MIMO or multiple beam array feeders, but with a fraction of the hardware requirements at mm-Waves. Considering the advantages of TSDM, the design of a mobile cell with an aggregated capacity above 1 Tb/s, meeting the frequency band specifications of the IEEE 802.11ad standard. The paper is organized as follows: First, the requirements of a cell with Tb/s capacity is described. Second, the fundamental principles of TSDM are explained. After presenting results of a system level simulation the paper is concluded by summarizing the key aspects of TSDM.

Review of Literature:

1. Reducing the size from macro to Pico cells.
2. Better reuse of the available bandwidth.
3. Installation of smarter network schemes to reduce cell interference [4].

However, these solutions do not increase the capacity by several orders of mag- nitude, as would be required for the above-mentioned hotspots. In this paper, two of the major envisioned solutions to increase the capacity by orders of magnitude are reviewed: Namely millimeter wave communication and space division multiplexing. Ultimately, it is concluded that Tb/s cell capacity is achievable using existing hardware compatible with actual standard by combining both mm-Wave and SDM in the same system.

Millimeter Wave Communications

In communication standards at millimeter wave frequencies (mm-Wave), such as IEEE 802.11ad - 2012 (60 GHz), the channel bandwidths can be as high as 2.16 GHz. The maximal physical data rate defined therein is 6.757 Gb/s for a chip rate of 1.76 GBd, using an OFDM 64-QAM modulation scheme and a 13/16 low density parity-check code (LDPC). To simplify the discussions in this paper, a symbol rate 2 GBd (still fitting in the 2.16 GHz channel bandwidth) instead of 1.76 GBd is considered. Combined with a 4 bit/symbol modulation (16QAM) a bit-rate 8 Gb/s is encoded in the channels. In the band definitions of the IEEE 802.11ad standard, up to four channel at various carrier frequencies can be used.The cell capacity is thus given by

$$C_{tot} = R_b . n_{channel} . n_{sector} \qquad (1)$$

Advanced Beam Forming

Another way of increasing the cell capacity by orders of magnitude is to use SDM. SDM is based on reusing the same frequency band in various directions by forming spatially separated, non-interfering radio beams [2]. This corresponds to the creation of virtual cell sectors with considerable coverage. If a user receives the signal from only one beam at a time, it results in two advantages: first, the cell capacity is increased by the number of spatially separated beams. Second, the full UE capacity can be used since neither time, code, nor frequency multiplexing is required. Hence, there is a need of Phased Array Antenna (PAA) concepts capable of simultaneous and independent steering of multiple antenna beams. In order to compare the various implementations of PAA, three main categories of feeders can be defined. In Fig. 1, a simple feeder for a PAA is depicted. The signal provided at the input of the PAA is transmitted in a direction defined by

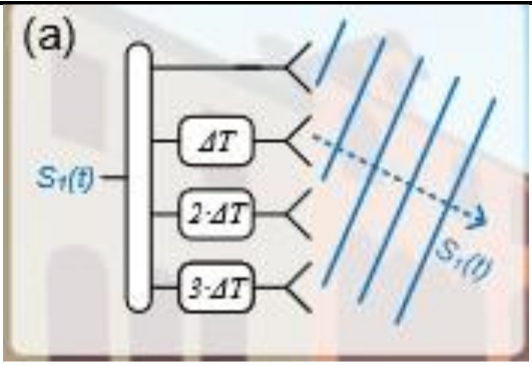

Figure 1: A simple PAA with one feeder

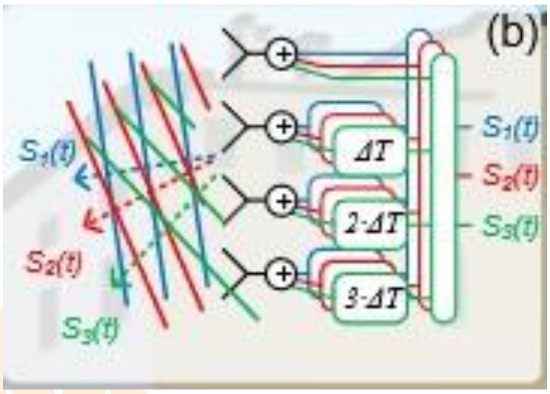

Figure 2: Analog PAA capable of multiple beam steering

the phase or delay T added in front of each antenna. Such concepts allow for electronic scanning and longer reach, but they do not offer multi-beam capability and therefore cannot increase the cell capacity. In Fig. 2, a PAA with multiple feeders is depicted. The fundamental principle to add multiple feeder networks in parallel (depicted here with different colors). Such concepts enable larger capacity by creating fully independent multiple beams. Yet, the hardware requirements for a large number of beams make this approach complex and costly.

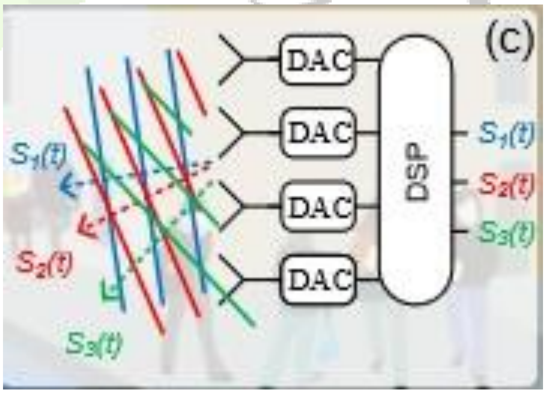

Figure 3: DSP based array feeder

In Fig. 3, the most flexible multi-beam system is shown. This is usually referred to as massive MIMO or digital beam forming and relies on digital signal processing to form the different beams. The signals for each antenna with their requested delays are generated by a DSP stage with a dedicated digital to analog converters (DAC). It is rightfully claimed that the cost and complexity of the hardware is not an unsurmountable issue at microwave frequencies. But this statement cannot be extended to mm-Waves frequencies [2].

Reaching Tb/s Cell Capacity

Cell capacity in Tb/s can be realized by combining mm-Wave with multiple beam solutions as depicted in Fig. 2 and 3. Merging a mobile cell at mm- Wave fulfilling 802.11ad and a SDM system supporting 11 beams could bring the total capacity to

$$C_{tot} = R_b . n_{channel} . n_{sector} . n_{beams} \qquad (2)$$

With a bit-rate of 8 Gb/s, 4 channels, 3 sectors, and 11 beams, the aggregated capacity is now 1056 Gb/s. By generating separated beams, each user can use the full channel capacity (8 Gb/s). In systems implementing SDM, the total cell capacity is increased by the number of beams. If more users are located in the proximity of the cell, the capacity of each beam could still be shared by closely located users using time or frequency division multiplexing.

TIME-TO-SPACE DIVISION MULTIPLEXING

In RANs such as 4G LTE and most of the IEEE 802.11 wireless protocols, multiple UEs share the same transmission channel using time division multiplexing (TDM) and/or frequency division multiplexing (FDM). This requires components with processing capabilities corresponding to the full capacity of the base station. A drawback of this scheme is that only a fraction of the receiver's capabilities is exploited. On the other hand, SDM implementations do not suffer from this limitation: in SDM-based mobile networks, the total cell capacity can be increased without changes to the UEs by parallelizing multiple streams. As explained in the last section, combining mm-Wave and multiple beam steering is an attractive solution for 5G RAN, but new architectures are needed to overcome the hardware complexity or high costs of approaches such as those depicted in Fig. 2 and 3

A promising solution with the hardware of Fig. 1 but the capacity of the moreadvanced approaches relies on a PAA with ultra-fast beam steering capabilities a system in which the beam direction could be adjusted with extremely short settling times and is called time space division multiplexing. The concept of TSDM is to emulate a multiple beam system by steering a single beam in between the transmission of each symbols. To perform this operation, a PAA with low settling times is needed.

Steering Multiple Beams with Simple PAAs

The principle of TSDM is illustrated in Fig.4. First, the signals for the different user equipment (UE) are time-division multiplexed (TDM) symbol-by- symbol. This feeding TDM signal could be, depending on the implementation of the feeder, in baseband, passband, or encoded onto an optical carrier. The different colors in Fig. 4(I) represent the time slots allocated to the different beams. The TDM sequence is subsequently transmitted to the PAA in the base station (BS). In a realistic scenario, the transmission would likely rely on radio-over-fiber [3].

In the BS, see Fig. 4(II), a control signal synchronized with the incoming data stream is used to perform time-to-space mapping to redirect the different tributaries in their time slots, to a specific direction. Using this symbol-by-symbol steering, the different UEs receive signals that correspond to a return-to zero modulation scheme, see left part of Fig. 4(III). Therefore, a low-pass filter can be applied to the signal without causing Inter-Symbol-Interference (ISI). As can be seen from the signals after the low-pass filter, right part of Fig. 4(III), the sequence assigned to each user is received at a symbol rate 3 times smaller than the one of the transmitter. In other words, TSDM enables steering of multiple beams with a PAA built using a simple array feeder.

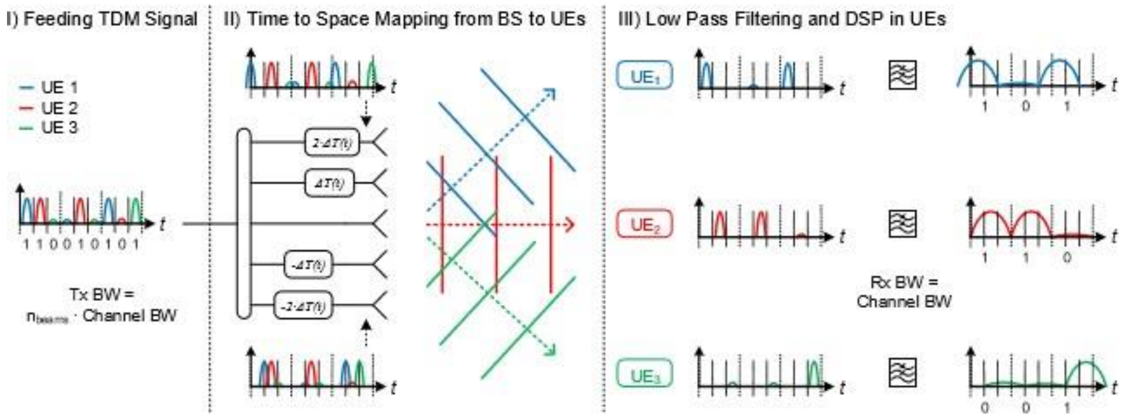

Figure 4: Principle of time-space multiplexing

TSDM-BASED MOBILE CELL

In Fig.5 (a) the three conditions stated above are exemplary plotted for a con- figuration with 5 time slots in the frame. The figure shows the supported area (green) in which the TSDM scheme will work when using a 10 GBd transmitted signal with 50 percent RZ in a 60 GHz carrier cell covering 120 ˚. The ideal work-ing point corresponds to 4 equispaced users and requires at least 13 antennas. In addition, the results show that RZ of 50 percent is not needed for the system to perform correctly, as the ideal working point requires only a RZ of 21.6 percent.

The array weights are tapered with a Dolph-Chebyshev side lobe level of 30 dB. Serving 4 active users implies a cell capacity increase by a factor 4. In Fig. 5(b), the corresponding transmitted frame is depicted. Fig. 5(c) describes the beam switching scheme. In the simplest case, the beam will be steered from theleft to the right from users 1 to 4. Once the beam has been scanned through the sector, an additional slot is used to return to the initial angle. The systemhas been optimized for three frame length configurations. The total cell capacity in Gb/s corresponds to the sector capacity in GBd multiplied by the number ofsectors per cell (3 for 120 cells), the number of possible carrier frequencies (4 in 802.11ad-2012), and the spectral efficiency (4 b/s/Hz using 16-QAM).

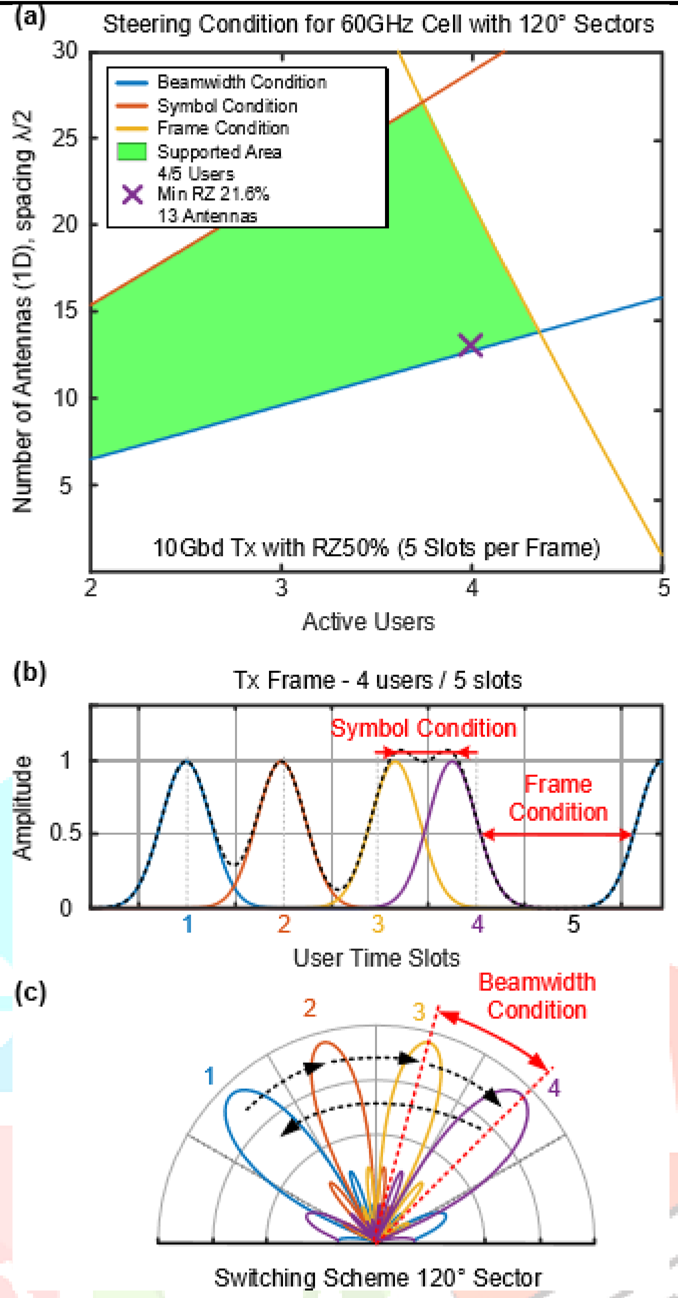

Figure 5: Conditions for TSDM

Reaching Tb/s

Symbol-by-symbol beam steering has been implemented. It comprises the fol- lowing key features: For the generation of the feeding TDM signal, multiple De- Bruijn sequences are multiplexed onto the various tributaries. The calculationof the delay lines is made with finite impulse response (FIR) filters. Here, the development was very specific as the requested delays are changing for each transmitted symbols, thus, the FIR filter is updated for each symbol from a look-up table supporting various types of delay lines. The array transmission is computed considering the applied delays and various array shapes (typically rectangular), taperings (typically Dolph-Chebyshev), and element patterns (typically isotropic). The 3 dB beamwidth is typically 120 degree divided by “n users”. The channel is only modeled through its free-space path losses, this assumption holds as focused beam are used. The filtering is performed either in pass-band in front of the antennas of the array or in the baseband in the receivers. In the receivers, standard digital signal processing is performed such as timing estimation, carrier recovery,and equalization.

OFDM Implementation

In most mobile communication standards, the highest bit rates are reached by switching from single carrier (SC) to multicarrier data formats, more specifically orthogonal frequency division multiplexing (OFDM) is commonly used. In the example of 802.11ad, the maximum bit rate is based on 512 subcarriers using a 64QAM modulation scheme.

As depicted on Fig. 6, OFDM is compatible with TSDM if the multiplexing is performed at the correct rate. As an example, I have depicted the situation where 2 OFDM sequences are TDM multiplexed to one TSDM frame. In our example, the OFDM symbols of two users (Fig. 6(a) and Fig. 6(b)) are generated and time division multiplexed sample by sample in the central office, see Fig. 6(c). The system rate in Fig. 6(c) is twice as high as the one of Fig. 6(a) and Fig. 6(b). The signals transmitted to the PAA, see Fig. 6(c), would thus be unreadable with standard OFDM techniques as two OFDM symbols are interleaved. Yet, after the sample based beam steering occurring in the PAA, Fig. 6(e), the two original sequences (a and b) will be mapped to separate directions (f) and 6 (g). The steering control signal is, in this simplified case, rectangular, see Fig. 6(d). In the UEs, low pass filtering could also be implemented to restore the original OFDM sequence.

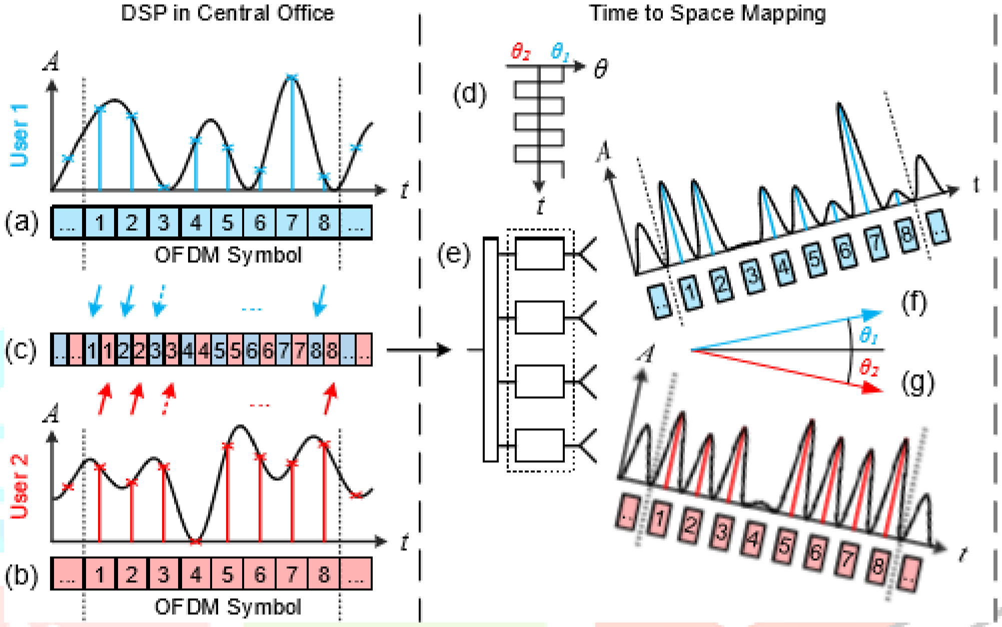

Figure 6: OFDM implementation of TSDM

TSDM Challenges

The main challenge specifically tied to TSDM lies in the fabrication of the microwave array feeder that performs the time-to-space mapping in the RAU. TDSM also shares limitations with other SDM approaches, yet standard solutionscan be reused:

- To steer the beam towards one specific user, the position of the user must be known in the transmitter. Yet, an easier way of solving this issue with TSDM would consist of having fixed beam directions, equidistantly split through the sector. The system would then perform standard handover between the generated virtual pico-cell.
- Normally uplink bandwidth requirements are lower than downlinks, a future- proof RAN concept should still increase the capacity of the uplink. In this paper, the downlink scheme is discussed primarily. TSDM can also be used for uplink. In this case, the users would continuously transmit in the full 2 GHz bandwidth while the RAU would scan through the sector to perform a direction based sampling.

- The practical implementation of an electronic system with very large fractional bandwidth is extremely challenging when using electronic systems. To avoid this challenge and thus reduce the complexity, the demonstrations done on microwave photonic processing in the array feeder. TSDM could be implemented using electronic subsystems.

CONCLUSION

This paper has been presented as a solution to increase the capacity of future radio access network (RAN) without changing the user equipment (UE) require- ments by, time-to-space division multiplexing (TSDM). Simulations have been performed to demonstrate a mobile cell reaching an aggregated capacity over 1 Tb/s while fulfilling the frequency band restrictions of the IEEE 802.11ad stan- dard. The capacity is augmented by generating multiple beams from the remote antenna unit (RAU) in the RAN. TSDM can thus be considered as a space di-vision multiplexing concept that enhances the spectral efficiency by generating multiple beams in different directions. The same capacity enhancement could also be reached with multiple feeders based phase array antenna (PAA) or with a digital signal processing (DSP) based PAA. Yet, both approaches are complex to implement for mm-Wave communication systems.

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