Measured Capacity of mm-Wave Radio Link Under IQ Imbalance

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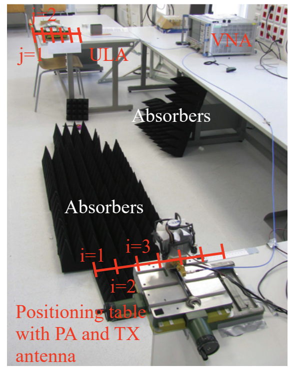
***Abstract*—Millimeter waves represent a promising solution to provide a sufficiently wide spectrum to satisfy the future requirements on broadband services. In this paper we evaluate the capacity of a short-range indoor wireless 60 GHz channel affected by quadrature imperfections of a real RF transceiver with orthogonal division multiplex approach. In our investigation, we consider spatially-dependent channel transfer function coefficients obtained from real measurements.**

I. Introduction

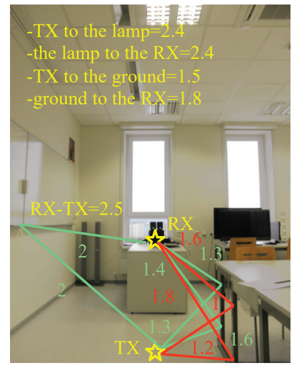
The use of millimeter waves (mm-waves) to provide sufficient bandwidth for enhanced Mobile BroadBand services in the 5-th generation (5G) of mobile services is envisaged. The most promising is the 28 GHz band, but also the 60 GHz band is interesting for the research community. An extensive research has been done in the last decades in the area of mm-wave channel sounding [1] and the capacity of the mm-wave radio channel has also been analyzed recently [2]. Similarly to 4G systems, the orthogonal frequency division multiplex (OFDM) or its filtered successors are considered for 5G [3]. The capacity of the radio link is affected not only by the channel itself, but also by the imperfections of radio frequency (RF) transceivers, such as nonlinear effects of the amplifiers or IQ up/down converters. In [4], the theoretical influence of the IQ imbalances on the ergodic and outage capacity of generic OFDM-based link has been investigated. The aim of this short paper is an attempt to join the results of channel sounding and RF transceiver characterization to estimate the capacity of real mm-wave RF link with impairments.

II. Channel Measurement

The channel sounder was formed by a vector network analyzer (VNA), a power amplifier and transmitter (TX) and receiver (RX) antennas (open-ended waveguides). A short-range time invariant channel, where we emulate a mutual RX-TX movement by shifting the RX-TX locations (antenna placements) on a precise xy-table (see Fig. 1) was considered. The measurement was performed in frequency domain (discussed in e.g. [5]) in a range of 55-65 GHz, while the RX-TX locations were stationary during the channel transfer function (CTF) recording. Via the spatial shifting of the antennas, we captured 160 CTF snapshots for three different indoor locations,



(a) Measurement site I



(b) Measurement site II

Fig. 1: Two out of three measurement sites. Site III is similar to the site II, but the xy tables are on top of the desk with 12 cm antenna height from the surface. The dimensions are in meters.

as ilustrated in Figure 1. Thus, although our channel is stationary, it exhibits the spatially-related variations due to the RX-TX location change. More information concerning this measurement campaign and the data processing can be found in [6], [7].

III. IQ mismatch measurements

Although the measurement of the RF channel was taken in 10 GHz bandwidth (BW), many of the currently available RF transceivers are limited to 1 GHz BW, such as Infineon BGT60 [8] we used as the RF up/down converter. The baseband part of the setup shown in Fig. 2 was created based on high speed A/D and D/A converters with FPGA interface board from Texas Instruments, complemented with an in-house designed front-end module. With this setup, we measured the frequency-dependent amplitude and phase imbalances, shown in Fig. 3. In order to cover the 10 GHz BW to characterize the device completely, the center frequency has been swept. Based on the imbalances, the Image Leakage Ratio (ILR) at OFDM subcarriers n (with corresponding image at carrier $-n$) can be computed [4]. Hereinafter, a frequency spacing of 10MHz has been considered.

IV. Capacity analysis

An expression for capacity at OFDM subcarrier n as a function of ILR_n and instantaneous values of normalized

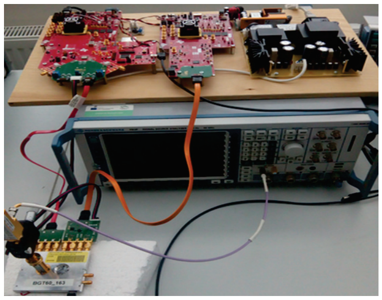


Fig. 2: Setup for IQ imbalances measurements, based on BGT60

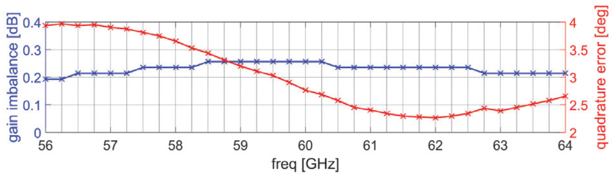


Fig. 3: Measured amplitude and phase imbalances of BGT60

channel amplitude coefficients ψ_n, ψ_{-n} at $n-$th and its mirror subcarrier $-n$ was derived [4]:

$$C_n = \log_2\left(1+\frac{\psi_n^2 \mathrm{SNR}}{1+\mathrm{ILR}_n(\psi_{-n}^2\mathrm{SNR}+1)}\right), \qquad (1)$$

with SNR being the average signal to noise ratio. The ergodic channel capacity can then be obtained by averaging over the joint probability density function (PDF) $p(\psi_n, \psi_{-n})$ of channel amplitude coefficients:

$$\overline{C}_n = \int_0^\infty \int_0^\infty C_n p(\psi_n, \psi_{-n}) d\psi_n d\psi_{-n}. \qquad (2)$$

Based on our channel sounding campaign described above, we estimated the sampled version of the joint PDF $p(\psi_n, \psi_{-n})$ as shown in Fig. 4. The PDF was smoothed with a 2D median filter. Note that as the instantaneous bandwidth of BGT60 is limited to 1 GHz, we used hereinafter only the 1 GHz portion of RF spectrum around 60 GHz center frequency to estimate the PDF.

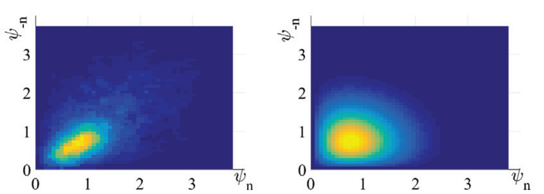


Fig. 4: Estimated $p(\psi_n, \psi_{-n})$ (left), joint Rayleigh pdf [4] (right)

Based on $p(\psi_n, \psi_{-n})$, the ergodic capacity at n-th subcarrier has been estimated as a function of average SNR. We considered several cases of ILRs - the case of perfectly compensated IQ transceiver corresponding to ILR=-50 dB, the case of uncompensated IQ transceiver with nominal value [8] of ILR=-20 dB and the case of measured average ILR=-27 dB. Fig. 5 shows the ergodic capacity, together with the Shannon limit case and the case of Rayleigh channel expected in [4].

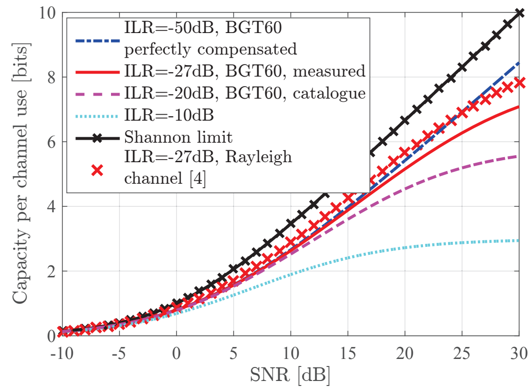


Fig. 5: Capacity of the measured channel under IQ imperfections

V. Conclusion

In this short paper, we have demonstrated how the ergodic capacity of a real millimeter-wave channel is affected by the IQ mismatch of real RF transceiver. For the future, we will estimate how the application of frequency-independent and frequency-dependent IQ compensation methods will practically affect the capacity on different center frequencies.

Acknowledgment

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