SATELLITE AND SPACE COMMUNICATIONS **SSC**

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IEEE COMMUNICATIONS SOCIETY

SSC Newsletter **Vol. 26, No. 1, May 2016**

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The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.
Location: ICC’16, Kuala Lumpur, Malaysia
Parkview 3, Mandarin Hotel
Date: Thursday May 26th, 2016
Time: 12:30-14:00

Future SSC Meetings
Dec. 2016, Washington, USA
June 2017, Paris, France
Dec. 2017, Singapore, Singapore

ICC 2016 SSC Committee Activities:

Symposium on Selected Areas in Communications:
Tuesday, 24 May 2016, 11:00 - 12:30
Room: Meeting Room 309, Level 3
SAC/SSC 1: Satellite Networking
Chair: Bohao Feng (Beijing Jiaotong University, P.R. China)

Tuesday, 24 May 2016, 14:00 - 15:30
Room: Meeting Room 309, Level 3
SAC/SSC 2: Management
Chair: Deze Zeng (China University of Geosciences, P.R. China)

Tuesday, 24 May 2016, 16:00 - 17:30
Room: Meeting Room 309, Level 3
SAC/SSC 3: Antennas
Chair: Christian A Hofmann (Munich University of the Bundeswehr, Germany)

Wednesday, 25 May 2016, 16:00 - 17:30
Room: Ballroom 1, Level 3
SAC/SSC_IS6: Analysis (Interactive)

Thursday, 26 May 2016, 14:00 - 15:30
Room: Ballroom 1, Level 3
SAC/SSC_IS8: Communications (Interactive)

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
If you like to join SSC Mailing List: Instructions on how to subscribe/unsubscribe are available at http://lists.scnl.dist.unige.it/listinfo/ssc/.

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MESSAGE FROM THE CHAIR

Prof. Igor Bisio

This is my very last "Message form the Chair" of the IEEE Communications Society (ComSoc) Satellite and Space Communications (SSC) Technical Committee (TC). This similar beginning was used two years ago when I was finishing my first term as SSC Chair.

Now eight years are passed, I am SSC Officer since July 2008 and, of course, other Members of our Community must take the responsibility to steer the TC. It has been a great honor to serve firstly as Secretary (2008-2010), then as Vice-Chair (2010-2012) and two times as Chair (2012-2014 and 2014-2016).

I think that good achievements have been obtained during this long period. For that, I want to deeply thank the outgoing Vice-Chair, Dr. Tomaso de Cola e the outgoing Secretary, Prof. Song Guo, for their enormous and precious work. In these years, thank to many active Members, the TC activities have been always sufficiently intense and the TC has been always recertified by the IEEE ComSoc. Now as last duty of my term, a new recertification phase has to be processed. I am working in strict contact with the SSC Chair Elect and I am fully confident that we have all the elements to receive, again, a positive feedback.

It is worth noticing that to keep a TC alive is not simple. Many emerging technologies TCs (and/or sub-TCs) were born in the last years. It is obvious being the Communications Engineering discipline in continuous evolution, fortunately. Nevertheless, the new emerging communities erode opportunities to traditional and consolidated TCs. Even if the new Officers' team is deeply conscious of this, I would warmly invite all Members to participate to the SSC initiatives and to continuously renew the research so maintaining the SSC related topics always hot and fashionable.

This represents a very important aim. Indeed, the scientific community working on satellite and space communications and networking topics is wide and develop heterogeneous research activities. This is a peculiar characteristic of our community and requires a common framework where Members can exchange opinions, share research ideas, coordinate common initiatives. To the best of my knowledge, the IEEE ComSoc SSC TC is the sole explicitly defined and permanent framework for such a heterogeneous community worldwide.

Operatively, the recently appointed Work Groups (WGs) - about IEEE and IEEE ComSoc Awards DLs and Fellowships, Standards and Editorial Initiatives - could represent useful tools to reach the aforementioned aim and to strengthen the role of the SSC TC within the IEEE ComSoc.

Finally, I wish to the SSC TC, and to the new Officers, whose election has been completed few days ago, Dr. Tomaso de Cola SSC Chair, Prof. Song Guo SSC Vice-Chair, Prof. Pascal Lorenz SSC Secretary, a term rich of positive achievements for our community. On my side, I will be happy and honored to continuously contribute to the SSC initiatives.

Prof. Igor Bisio, Chair
Satellite and Space Communications TC

SCANNING THE WORLD

Dr. Tomaso de Cola

A particular attention can be devoted to communication and networking aspects in space missions, for what concerns both deep-space and near-Earth initiatives. Although not always receiving the necessary attention, the role of standardization in this context is of paramount importance since the execution of a space missions does not merely consist in data communication and the related networking design, but also entail the overall management of the space network as well as the cross-support in case of multi-agency assets. All the aforementioned aspects are carefully addressed by the Consultative Committee for Space Data Systems (CCSDS), which is the body responsible for producing the relevant standardization recommendations.

In particular, the first half of year 2016 has seen the consolidation of the protocol specification related to DTN (Delay/Disruption Tolerant Networking), with possible extensions to support multimedia streaming in space. In this respect, critical analysis of LTP (Licklider Transmission Protocol) specification is currently performed, in order to identify possible shortcomings, which could necessitate the revision of the current LTP blue book. The evaluation is currently carried out by different space agencies, also bearing in mind the currently available implementation (e.g., Interplanetary Overlay Network, ION)

Moreover, the design of a comprehensive data link layer is under way, in order to allow the use of a signal protocol sublayer layer, running on top of the coding and synchronization sublayer according to the specification provided for telemetry (TM), telecommand (TC), proximity-1 (Prox-1), and advanced orbiting systems (AOS). The protocol specification is under definition with the name of unified space link protocol (USLP) and will be subject to revision and consolidation in the near future. An additional item of upcoming standardization is the upgrade of the channel coding for telecommand link, so as to incorporate LDPC binary codes, which proved to be more powerful than BCH codes currently present in the specification.

More details about the overall CCSDS standardization activity can be found at http://www.ccsds.org, where also the most recent news in the context of space communications are often reported.

Dr. Tomaso de Cola, Vice Chair
Satellite and Space Communications TC

FORTHCOMING GLOBECOM AND ICC CONFERENCES

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

MILCOM 2016
November 01-03 2016, Baltimore,MD
http://www.milcom.org

MILCOM 2016 celebrates the 35th anniversary of the premier international conference for military communications. “Leveraging Technology – The Joint Imperative” gathers the leading minds of government, military, industry and academia in an interactive forum to further explore and define the benefits that joint-level collaboration bring to current and future communication challenges. The annual conference will take place November 1-3, 2016 at the Baltimore Convention Center in Baltimore, MD. Leaders from around the world will address the critical role communications plays in military readiness and operations. MILCOM offers industry the opportunity to discuss communications technologies and services with decision makers from all branches of the armed forces, the Department of Defense, federal agencies and multinational forces.

In the MILCOM tradition, the conference will feature an outstanding series of technical presentations, discussions and tutorials, as well as nearly 30,000 square feet of industry exhibits all under one roof. It will include more than 300 unclassified and restricted technical presentations, tutorials and panel discussions led by experts in defense communications. Topics will include the spectrum of command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) technologies and capabilities that address 21st century communications challenges related to national defense, homeland security, disaster response and interoperability. Continuing education credits will be available to all attendees.

GLOBECOM 2016

December 4-8, 2016, Washington,DC, USA

http://globecom2016.ieee-globecom.org/about

IEEE GLOBECOM is one of two flagship conferences of the IEEE Communications Society (ComSoc), together with IEEE ICC. Each year the conference attracts about 3000 submitted scientific papers and dozens of proposals for industry events. A technical program committee of more than 1,500 experts provides more than 10,000 reviews, and from this a small fraction of the submitted papers are accepted for publication and presentation at the conference. The conference meets once a year in North America and attracts roughly 2000 leading scientists, researchers and industry practitioners from all around the world. IEEE GLOBECOM is therefore one of the most significant scientific events of the networking and communications community, a must-attend event for scientists, researchers and networking practitioners from industry and academia.

IEEE GLOBECOM is a five-day event. Two days are dedicated to tutorials and workshops, while the remaining three days are dedicated to the IF&E program and the technical symposia. The program of the technical symposia includes oral or poster presentations of about 1000 scientific papers, grouped into 13 thematic symposia, and more than 15 parallel sessions. In addition to the technical program, IEEE GLOBECOM 2016 will feature an industry forum and exhibition (IF&E) program, including industry-focused workshops, tutorials, keynote talks from industrial leaders, panel discussions, a large exposition, and business and industrial forums.

ICC 2017

May 21-25, 2017, Paris, France

http://icc2017.ieee-icc.org/

The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 - 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. We invite you to submit your original technical papers, and industry forum, workshop, and tutorial proposals to this event. Accepted and presented papers will be published in the IEEE ICC 2017 Conference Proceedings and submitted to IEEE Xplore®.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
SPECTS 2016 International Symposium on Performance Evaluation of Computer and Telecommunication Systems	July 2016 Montreal, Canada	http://atc.udg.edu/SPECTS2016/
ASMS/SPSC 2016 8th Advanced Satellite Multimedia Systems Conference 14th Signal Processing for Space Communications Workshop	September 5-7, 2016 Palma de Mallorca, Spain	http://www.asmsconference.org/
ICL-GNSS 2016 International Conference on Localization and GNSS	June 28-30, 2016 Barcelona, Spain	http://www.icl-gnss.org/2016/index.html
PIMRC 2016 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications	Sept. 4-7, 2016 Valencia, Spain	http://www.ieee-pimrc.org/
Ka-Band/ICSSC The 22nd Ka and Broadband Communications Conference and the 34th AIAA International Communications Satellite Systems Conference (ICSSC)	October 18-20, 2016 Cleveland, Ohio, USA	http://www.kaconf.org/
VTC-Spring 2016 2016 IEEE 83rd Vehicular Technology Conference (VTC-Spring)	May 15–18, 2016 Nanjing, China	http://www.ieeevtc.org/vtc2016spring/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://committees.comsoc.org/ssc/.

MIMO Applications for Communications Satellite Systems

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***Abstract* — Multiple input – multiple output (MIMO) systems are an integral part of today's terrestrial wireless communications standards due to their potentially linear increase of bandwidth efficiency. This newsletter highlights the basic results available on spatial MIMO today, followed by a comprehensive summary of the most promising mid-term prospective applications for this novel technology.**

INTRODUCTION

In satellite communications (SATCOM) the applicability of the multiple input – multiple output (MIMO) technology with spatially distributed antenna elements is subject to contentious discussions in the scientific community [1]. Most of the research has been focused on the land mobile satellite (LMS) channel using two different directions of polarization to establish a MIMO channel. In that case a fading channel due to multipath signal components provides a MIMO gain over single-input single-output (SISO) transmission.

The satellite channel for Fixed Satellite Services (FSS) or Mobile Satellite Services (MSS) in frequency bands above 10 GHz is characterized by a strong Line-of-Sight (LOS) signal with no or negligible multipath components (MPCs). It has already been shown by theory that high gains in strong LOS channels are possible if particular antenna geometries are considered. This idea has been applied to SATCOM in [3], and a criterion has been developed for the optimal positioning of the antennas on Earth and in the geostationary Earth orbit (GEO).

This paper gives an overview how the challenges for the realization of MIMO SATCOM systems can be solved and which prospective applications are imaginable. Finally, the results of a proof-of-concept test campaign are presented briefly.

MIMO SETUPS FOR SATCOM

Let us consider the channel coefficients of a satellite MIMO system with N antennas in the GEO and M antennas on Earth. With pure LOS conditions, the equivalent baseband channel coefficient H_{mn} of the frequency flat channel between the n-th satellite and the m-th Earth station antenna is given by

$$H_{mn} = a_{mn} e^{-\frac{j2\pi f_c}{c_0} r_{mn}} \qquad (1)$$

where a_{mn} stands for the complex channel gain, f_c and c_0 denote the carrier frequency and the speed of light, respectively, and r_{mn} is the distance between the antennas. In the following we make the reasonable assumption of equal gains $a_{mn} = a, \forall\, m, n$ and for the ease of the calculations w.l.o.g. we set $a = 1$. Thus, the MIMO channel transfer matrix (CTM) $\boldsymbol{H}$, which contains all $M \times N$ channel coefficients, is only determined by the propagation path length differences of all antenna combinations. Thus, the spectral efficiency C of the MIMO channel is a function of the antenna positions as well. According to [2] it is

$$C = \log_2[\det(\boldsymbol{I}_M + \rho_{Rx}\, \boldsymbol{H}\, \boldsymbol{H}^H\,)] \qquad (2)$$

where ρ_{Rx} is the signal-to-noise ratio (SNR) at the receiver, $\boldsymbol{I}_M$ stands for the identity matrix of dimension M and $(\cdot)^H$ denotes the complex conjugate transpose. The maximum C_{max} for the spectral efficiency is given by [2]

$$C_{max} = M \log_2[1 + \rho_{Rx} \max(M, N)\,] \qquad (3)$$

Figure 1 shows an exemplary scenario with two satellites and a MIMO downlink channel. In the right part the achieved spectral efficiency is depicted in dependence on the antenna distances d_T and d_R in orbit and on Earth, respectively. The figure reveals that with decreasing d_T larger distances d_R are required to establish an optimum channel. The maxima appear periodically with d_R. The curves have been calculated for satellites at 13° East and ground stations in southern Germany.

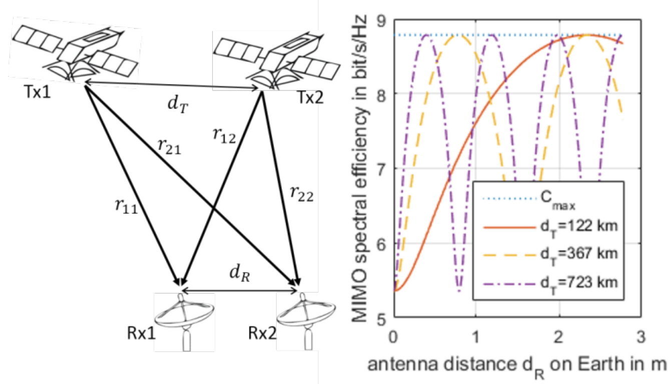

Figure 1: 2x2 MIMO setup (left) and spectral efficiency vs. antenna spacing on Earth for various distances in orbit

The design criteria for optimum 2x2 MIMO channels are derived in [3] for arbitrary orbit positions. Figure 2 gives a rough estimation of required minimum antenna distances to achieve the first possible maximum in the spectral efficiency curvature.

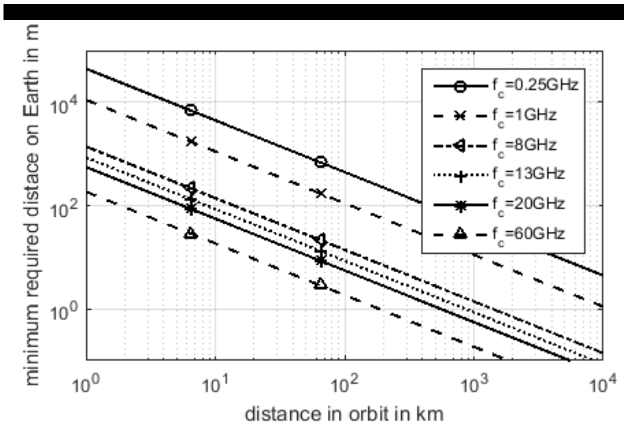

Figure 2: Minimum required antenna distance on Earth vs. antenna distance in orbit for optimum MIMO spectral efficiency

PRACTICAL CHALLENGES

The realization of future MIMO SATCOM systems is facing some challenges. In the recent years we have devoted our work on MIMO to research on these challenges and their solutions. In particular we have addressed three major aspects:

1. The optimum MIMO channel capacity is achieved by a particular antenna geometry on Earth and in the orbit. Thus movements of the satellite in terms of station keeping might change the MIMO channel properties. In [4] it has been shown that such variations of the satellite position have only a negligible impact on the achievable spectral efficiency.

2. The phase of the signals might be disturbed by effects in the Earth's atmosphere, which would lead to non-optimal phase relations for MIMO. In [5] we have demonstrated that phase distortions have an impact on the MIMO performance, but the truly measured values are low and the impact on the spectral efficiency is negligible.

3. The realization of optimal antenna setups requires large distances either between the antennas on Earth or between the antennas in orbit. Large antenna distances on Earth between satellite dishes (several km) require a terrestrial network for the signaling between the antennas. Hence, they are only imaginable for gateway-links. Large distances in space (several degrees) provoke the problem of a simultaneous transmission to all antennas in orbit with highly directional antennas. In that case the main lobes of the Earth station antennas need to be wide enough to simultaneously illuminate all MIMO satellites in space. A loss in effective antenna gain is the result and, thus, the capacity is reduced. Therefore, multiple-satellite scenarios with several degrees of orbit separation will most probably be limited top low frequencies. However, also small orbit separations might be reasonable in case of satellite collocation.

PROSPECTIVE APPLICATIONS

1. *Collocated satellites*

The collocation of satellites and the application of Multiple-Satellite MIMO is a possibility to enhance the throughput at a certain orbit position without the need for additional spectrum. With optimum positions, the throughput is increased linearly with the number of satellites used. For example at Ku-band, given that the satellites contribute one antenna each to the MIMO antenna array in orbit, the distances between the collocated satellites between 10km and 100km would require manageable distances on Earth between 30m and 100m for the MIMO antenna array. However, a collocation strategy has to be used which allows to fly the satellites as a formation, keeping the satellite separation perfectly constant. First analysis indicates that such highly precise collocation strategies exist.

2. *Gateway links for high throughput satellites (HTS)*

HTSs with numerous spot beams require a large number of gateways to enable high throughput in the limited but fully used spectrum. The gateways need to be distributed over a large number of sites not only for site diversity but also to enable a frequency reuse. If the throughput of the gateway link is doubled by the use of a second Earth station per beam and a second antenna at the HTS, the number of required beams per gateway station is halved. Thus, MIMO is useful f to reduce the number of gateway sites required.

3. *Military UHF SATCOM*

The military P-band around 300MHz is a highly scarce ressource. The spectrum at P-band is limited and a frequency reuse is not feasible due to the wide coverage per UHF satellite antenna. At the same time the Earth station antennas have a wide beam and thus, multiple satellites could be simultaneously illuminated by a single antenna. Even satellites that are several tens of degrees separated in orbit can communicate to a single antenna on Earth without a significant loss in antenna gain. This enables the application of MIMO with manageable antenna distances on Earth. An exemplary scenario with two UHF-satellites separated by 50 degrees in orbit allows a distance between the Earth station antennas of around 70cm for optimum MIMO spectral efficiency. The exact distance is dependent upon the location on Earth. Especially for terminals mounted on vehicles or ships this is a realizable antenna separation. Future tactical radios could use MIMO with multiple antennas on car rooftops or ship decks, likewise it is done today for antenna diversity.

4. *Multi-User MIMO*

Large antenna distances on Earth could be realized if multiple individual user terminals with a single antenna are used to establish a multi-user MIMO channel. If for example a satellite with two antennas is used, pairs of users could be found that are located at optimum distance for a maximum MIMO gain. For the downlink to the users precoding is required either at the satellite or at the gateway. For the user uplink the satellite or the gateway terminal on Earth need to equalize the MIMO channel. This application of MIMO would help to linearly increase the number of users or the user data rate within a single beam. Especially in use cases where the antennas are at fixed locations, like for example in direct-to-home (DTH) video on demand (VoD), pairs of antennas for a multi-user MIMO scenario could be once identified and then continuously used.

PROOF-OF-CONCEPT TEST CAMPAIGN

In the context of the project "MIMO SATCOM", which was funded by the German Aerospace Center – Space Administration and involved several project partners from industry and academia, in 2015 we were able to perform a proof-of-concept test campaign that followed a two-step approach. First we measured the MIMO spectral efficiency in a real satellite scenario. Second we performed a MIMO data transmission via GEO satellites for the first time.

To establish a MIMO channel, signals from different antennas in space are required that provide overlapping coverage, frequency, polarization and time. Usually this is avoided by frequency coordination in conventional SATCOM. Hence, we had to apply a workaround to create a true spatial MIMO channel as follows: We were able to form a space-to-Earth MIMO channel using two EUTELSAT satellites at 7° and 10° east. Both satellites provide transparent payloads and share a part of the Ku-band spectrum in up- and downlink. The downlink forms a 2x2 MIMO channel with two dishes of 0.75m in diameter. Both Rx dishes point at the GEO at longitude 8.5° east, i.e. exactly between E7B and E10A, so that both downlink signals can be received by each Rx antenna simultaneously via the edges of the main lobe. Details on the setup and the results are presented at the current ICC 2016 [6].

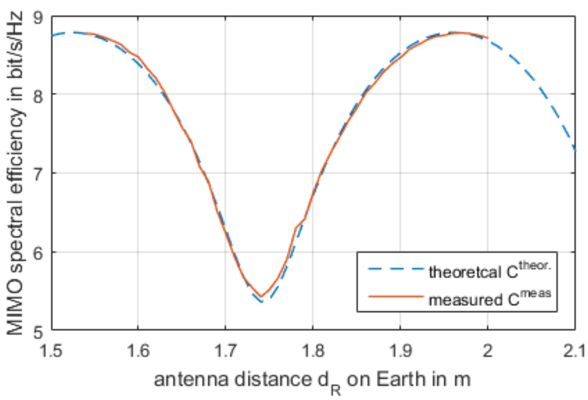

Figure 3: Theoretical and measured values for the spectral efficiency at 10dB SNR

We obtained a theoretical achievable spectral efficiency $C^{(\text{theor.})}$ by calculation of $\boldsymbol{H}$ and C from (1) and (2), respectively, using the known positions of the satellites and the Earth stations. The distance d_R between the Earth station antennas has been varied to demonstrate the dependence of C upon the geometry. The results depicted in Figure 3 show a perfect match of the measurement result with theory.

The second step for our proof-of-concept was a MIMO transmission via satellite. Therefore two different data streams were transmitted via two SISO uplinks towards the two satellites at the same time. The signals overlapped in downlink, as it formed a 2x2 MIMO channel. After synchronization and MIMO channel estimation, we were able to equalize the received signals applying a frequency domain equalizer. Figure 4 shows the results for the bit error rate (BER) for different code rates of the used LDPC-code. By variation of d_R we changed the MIMO channel from optimal to suboptimal conditions with maximum and minimum spectral efficiency, respectively.

CONCLUSIONS

We have demonstrated and proved through measurements, that the MIMO transmission with parallel data streams is possible via satellite and that the maximum spectral efficiency can be achieved even in pure LOS conditions. Distinct geometrical antenna arrangements with comparably large antenna separations either on Earth or in orbit are required in order to obtain high MIMO gains. In this paper some major challenges and the most promising prospective applications for MIMO over satellite have been highlighted.

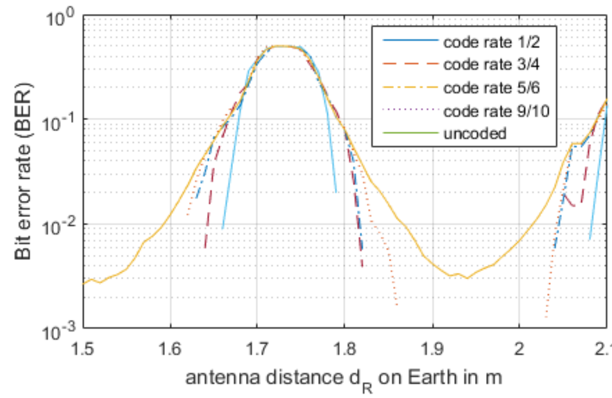

Figure 4: Achieved bit error rate of the MIMO transmission for different code rates over the antenna distance on Earth

ACKNOWLEDGMENTS

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