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FUTURE DEVELOPMENT OF IMT SYSTEMS

RESOLUTION COM6/20 (WRC-15)
Studies on frequency-related matters for International Mobile Telecommunications identification including possible additional allocations to the mobile services on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of International Mobile Telecommunications for 2020 and beyond.

The World Radiocommunication Conference (Geneva, 2015),
resolves to invite ITU-R to conduct and complete in time for WRC-19 the appropriate studies to determine the spectrum needs for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz, taking into account:
– technical and operational characteristics of terrestrial IMT systems that would operate in this frequency range, including the evolution of IMT through advances in technology and spectrally efficient techniques;
– the deployment scenarios envisaged for IMT-2020 systems and the related requirements of high data traffic such as in dense urban areas and/or in peak times;
– the needs of developing countries;
– the time-frame in which spectrum would be needed.
invites administrations
to participate actively in these studies by submitting contributions to ITU-R.

RECOMMENDATION 207 (REV.WRC-15)

Future IMT systems

The World Radiocommunication Conference (Geneva, 2015),

recommends

to invite ITU-R to study as necessary technical, operational and spectrum related issues to meet the objectives of future development of IMT systems.

The following frequency bands are currently identified for IMT in all three ITU Regions:
450 - 470 MHz, 694 - 960 MHz, 1452 - 1492 MHz, 1710 - 2025 MHz, 2110 - 2200 MHz, 2300 - 2400 MHz, 2500-2690 MHz, 3400-3800 MHz

Georgia

Mobitel (806-816, 847-847), (884.50-889.99, 929.50- 934.99), (1775-1785, 1870-1880), (1925-1935, 2115-2125),

MagtiCom (901.8-915, 946.8-960), (1740.1-1870, 1835.1-1865), (1935-1950, 2125-2140),

Geocell (890-901.8, 935-946.8), (1710-1725, 1805-1820), (1725.1-1740, 1820.1-1835), (1950-1965, 2140-2155)

2.5-2.7 GHz – MMDS

3.4-3.6 GHz -WiMax

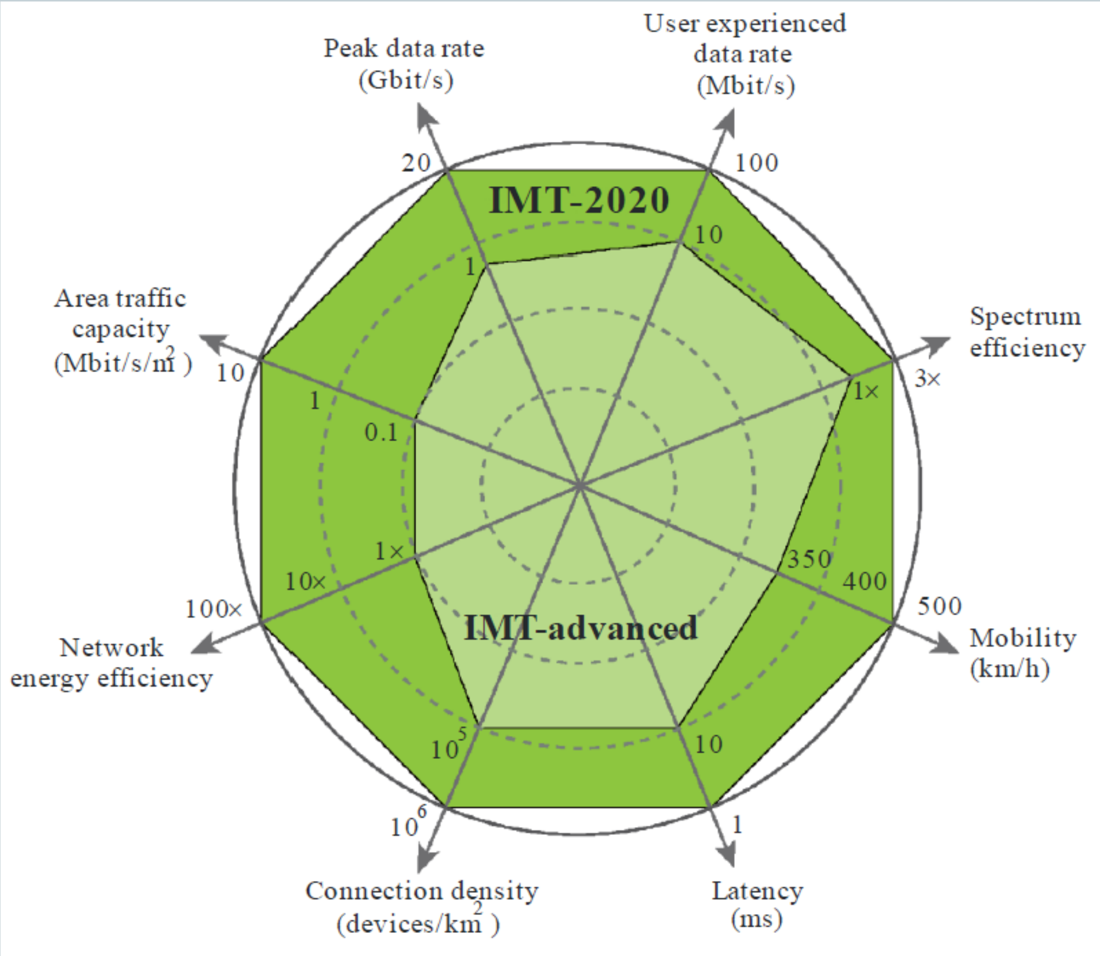

Figure 1. Enhancement of key capabilities from IMT-Advanced to IMT-2020

Technology trends:

Technologies to enhance the radio interface.

Network technologies.

Technologies to enhance mobile broadband scenarios.

Technologies to enhance massive machine type communications.

Technologies to enhance ultra-reliable and low latency communications.

Technologies to improve network energy efficiency.

Terminal technologies.

Technologies to enhance privacy and security.

Technologies enabling higher data rates.

Technologies to enhance the radio interface and enabling higher data rates

Advanced waveforms.

New spectral and energy efficient modulation and coding schemes.

New multiple access schemes.

Advanced antenna technologies:

3D-beamforming (3D-BF);

Active antenna system (AAS);

Massive MIMO;

Network MIMO;

Spatial modulation.

Filtered-OFDM (f-OFDM)

Bandwidth available for the channel is split up into several sub-bands.

In this way, f-OFDM is capable of overcoming the drawbacks of OFDM whilst retaining the advantages of it.

1: With subband-based filtering, the requirement on global synchronization is relaxed and inter-subband asynchronous transmission can be supported.

2: With suitably designed filters to suppress the out-of-band emission, the guard band consumption can be reduced to a minimum level.

3: Within each subband, optimized numerology can be applied to suit the needs of certain type of services.

In general, the overall spectrum efficiency can be improved.

Among all the 5G waveform candidates f-OFDM appears as the most promising one, in terms of the overall performance, the associated complexity, and the cost and smoothness on the evolution path from 4G LTE.

Different types of services are accommodated in different sub-bands with the most suitable waveform and numerology.

This enables a much better utilization of the spectrum for the variety of services to be carried.

Filter bank multicarrier (FBMC)

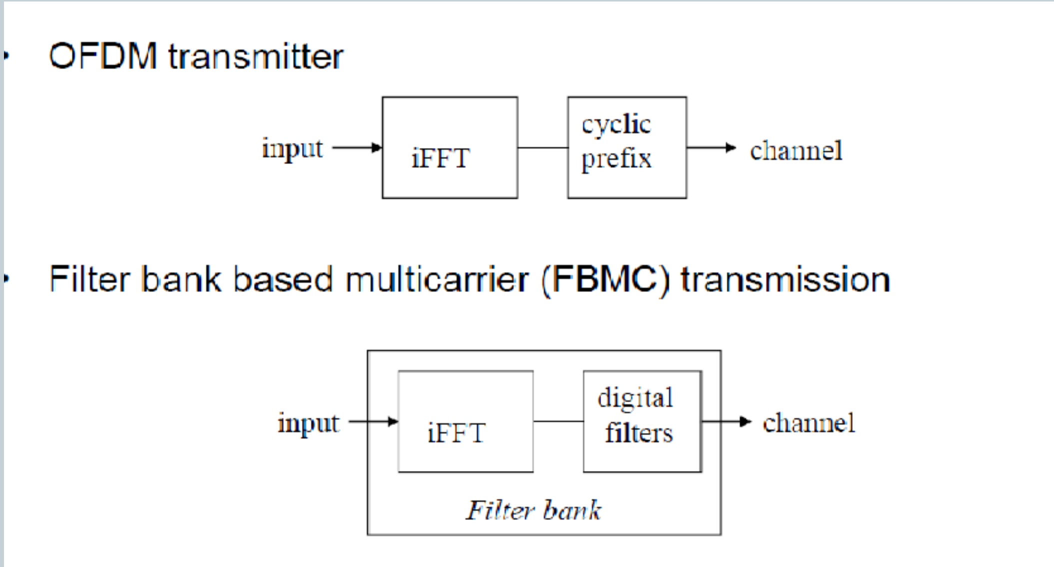

Figure. 2.

FBMC characteristics:
-no sidelobes with the filter bank
- no guard time (no cyclic prefix)
- a very high level of spectral efficiency

•Instead of filtering the whole band as in the case of OFDM, FBMC filters each sub-carrier individually.
•The subcarrier filters are very narrow and require long filter time constants. Typically the time constant is four times that of the basic multicarrier symbol length and as a result, single symbols overlap in time.
•To achieve orthogonality, offset-QAM is used as the modulation scheme, so FBMC is not orthogonal with respect to the complex plane.
•FBMC can make spectral holes. Suitable for cognitive radios.
•FBMC can support unsynchronized stations in a multiuser environment.

Multiple access (MA) technique - major building block of the cellular systems.

The users can simultaneously access the physical medium and share the finite resources of the system, such as spectrum, time and power.

MA techniques:

- Time Division Multiple Access (TDMA);
- Frequency Division Multiple Access (FDMA);
- Orthogonal Frequency Division Multiple Access (OFDMA);
- Code Division Multiple Access (CDMA).

There are many factors that determine the efficiency of the MA technique such as spectral efficiency, low complexity implementation, low envelope fluctuations.

MA techniques: Orthogonal and Non-orthogonal MA.

In orthogonal MA techniques, the signal dimension is partitioned and allocated exclusively to the users, and there is no Multiple Access Interference (MAI).

For non-orthogonal MA (NOMA) techniques, all the users share the entire signal dimension, and there is a MAI. Thus, for non-orthogonal transmission, more complicated receiver is required to deal with the MAI comparing to orthogonal transmission.

Non-orthogonal MA is more practical in the uplink scenario because the base station can afford the Multiuser Detection (MUD) complexity. On the other hand, for downlink, orthogonal MA is more suitable due to the limited processing power at the user equipment.

Many non-orthogonal MA techniques have been overlooked due to the implementation complexity. Evidently, the recent advancements in signal processing have opened up new possibilities for developing more sophisticated and efficient MA techniques: **NOMA (low-density spreading); NOMA (sparse code multiple access); NOMA (pattern division multiple access).**

Interleave-division multiple-access (IDMA).

The main difference between IDMA and conventional CDMA is that in IDMA each layer is assigned a layer specific interleaver, whereas in conventional CDMA a layer-specific spreader is applied.

The encoded and interleaved data streams of different layers of the same user are linearly superimposed (preferably with different phases and amplitudes) before transmission.

The data rate can be adapted by superimposing a variable number of layers.

In contrast to other system designs, channel coding is an integral part of the IDMA system design.

A receiver-side separation of the layers can be done iteratively ("turbo processing") by exploiting the different interleavers, the code constraints, and a multi-layer detector.

IDMA inherits many advantages from CDMA, in particular, diversity against fading and mitigation of the worst-case other-cell user interference problem.

IDMA allows a very simple chip by-chip iterative multi-user detection (MUD) strategy.

Experimental studies demonstrate the advantages of the IDMA scheme in terms of both bandwidth and power efficiencies for systems with large numbers of users.

Interleave-division multiple-access (IDMA).

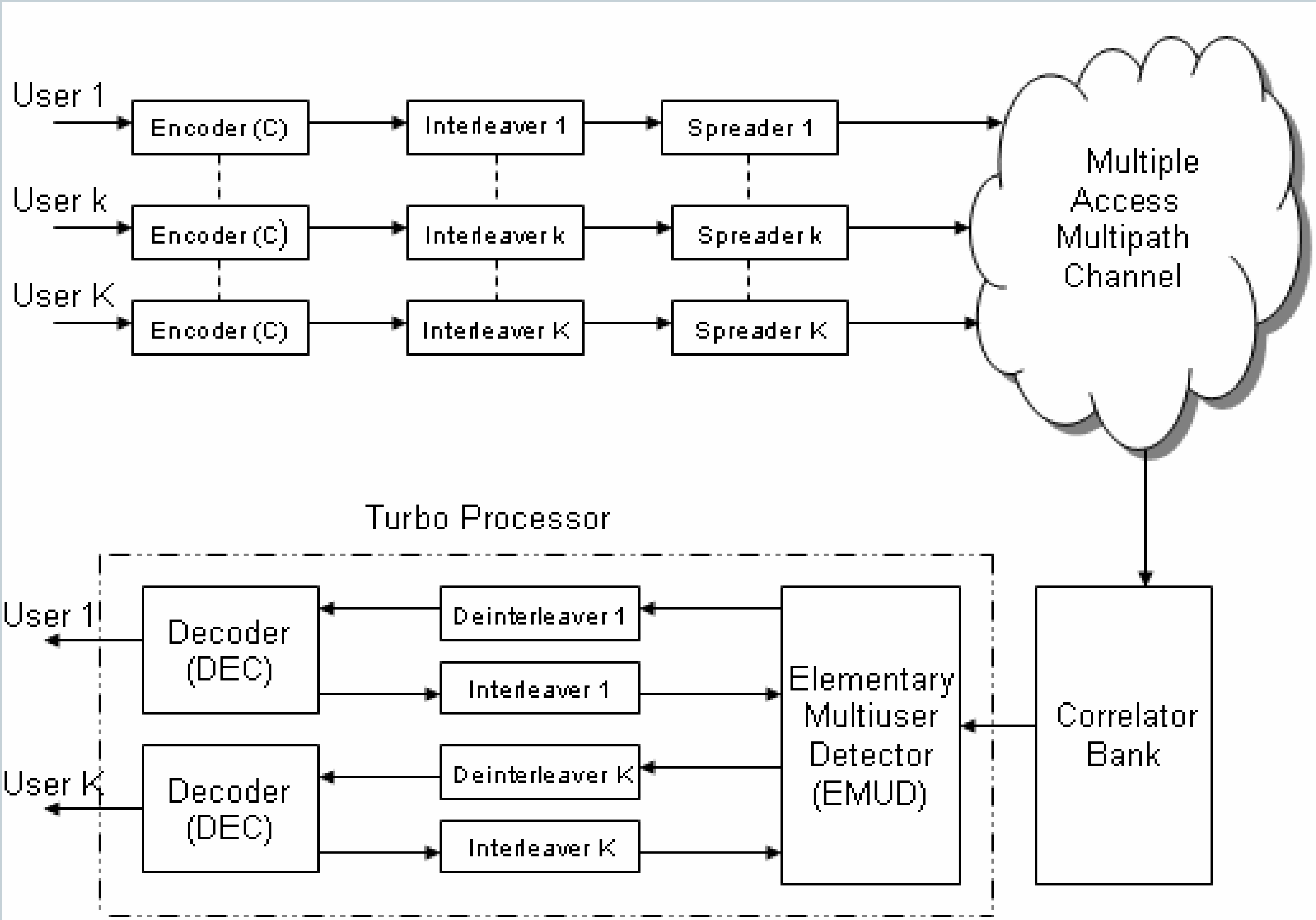

Figure. 3.a. Conventional CDMA

Interleave-division multiple-access (IDMA).

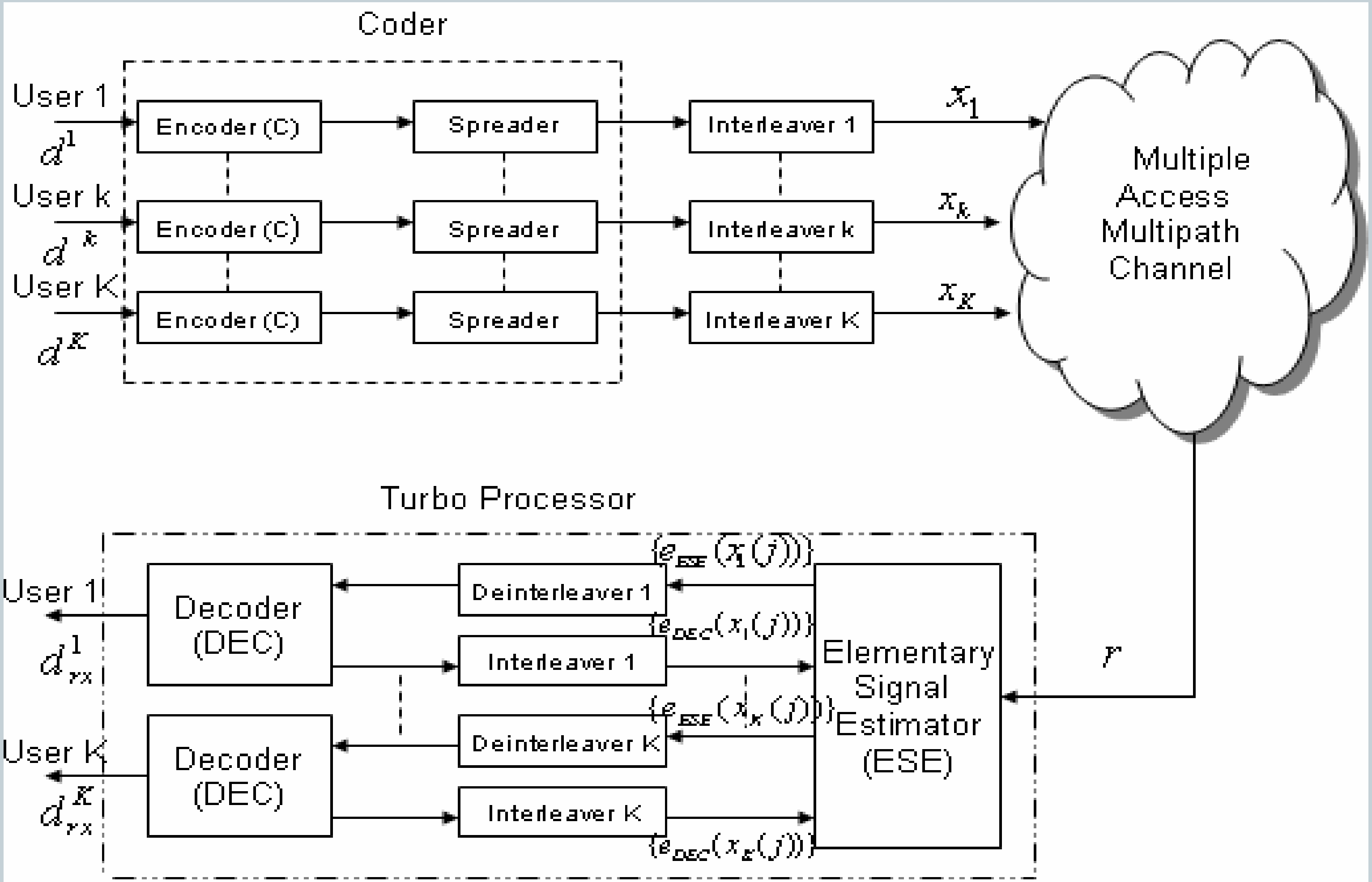

Figure. 3.b. IDMA

1. M. Gabrowska, M. Bossert, and S. Shavgulidze, and S. Schober. “Serially concatenated space time convolutional codes and continuous phase modulation.” IEEE Transactions on Communications, Vol. 56, No. 9, September 2008. P. 1442-1450.

Space-time codes (STC) aim to achieve diversity gain and coding gain, by using the spatial and the time domain for transmission. The information is transmitted over multiple antennas to provide spatial diversity and over multiple time slots to achieve coding gain.

The radio frequency spectrum is a limited natural resource. Therefore digital satellite communication, digital radio links and digital land mobile radio schemes should use as little bandwidth as possible. For many applications, the power is also a limited resource. Therefore, it is advantageous to have a modulation method, which is both power and bandwidth efficient. A third requirement for many applications is constant amplitude.

Continuous phase modulation (CPM) can be considered as an efficient constant amplitude modulation scheme with memory that simultaneously have narrow mainlobe, low spectral sidelobs and good power efficiency. CPM is a non-linear modulation that is defined by a phase trellis. CPM’s constant envelope provides good power efficiency, and the maintained phase continuity can provide good spectral efficiency.

When CPM is combined with STC good performances may be expected.

The possibility to construct full diversity space time codes based on serially concatenated space-time convolutional codes (STCC) and CPM is investigated. The CPM signals using *Gram-Schmidt* orthogonalization transform were generated in a different Euclidean space with finite energy. Design criteria were derived for an arbitrary number of transmit antennas. The demodulator and the decoder were considered separately at the receiver side. It was shown that the use of an iterative algorithm can improve the performances of the system. The simulations were done for a quasi-static Rayleigh fading channel. An additional gain was achieved using long memory convolutional codes. The complexity of our system model is reduced compared to the complexity of the similar systems known from the literature.

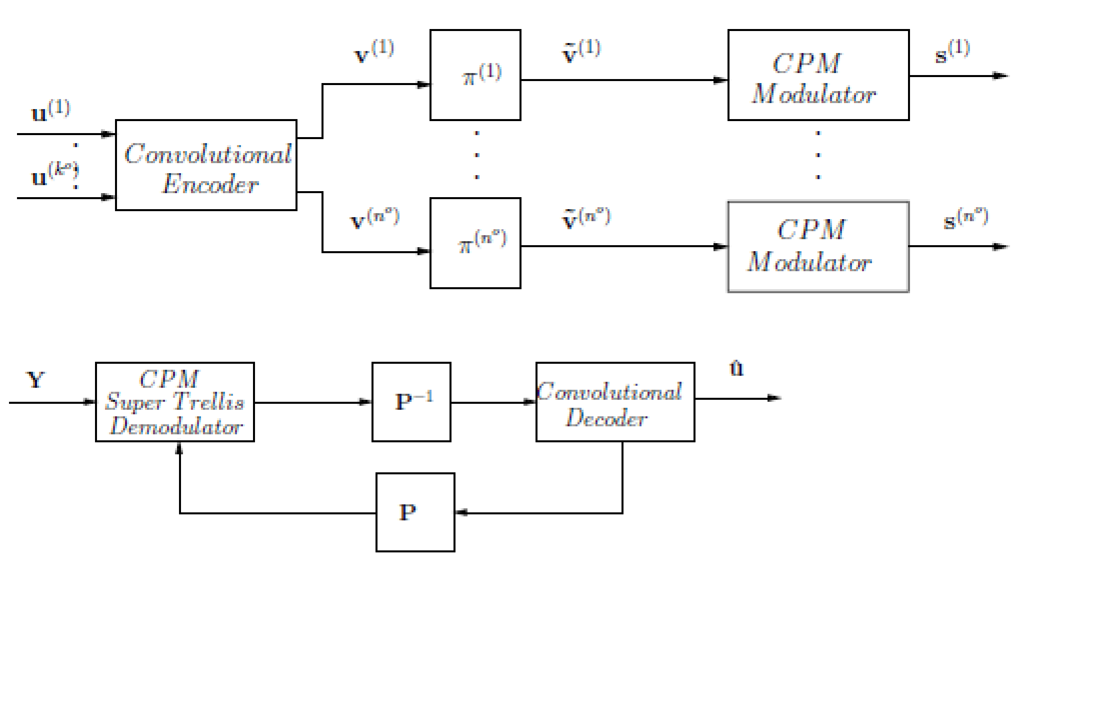

Figure 4. Encoder and Decoder of Serially Concatenated STCC and CPM

2. J. Freudenberger, F. Ghaboussi, and S. Shavgulidze, “New coding techniques for codes over Gaussian integers,” IEEE Transactions on Communications, Vol. 61, No. 8, August 2013. P. 3114-3124.

Gaussian integers are a subset of the complex numbers such that the real and imaginary parts are integers. Codes over Gaussian integers can be used for coding over two-dimensional signal spaces, e.g. using quadrature-amplitude modulation (QAM).

This work considers codes over finite sets of Gaussian integers. We have shown that OMEC codes, product codes, and Plotkin codes can be constructed for Gaussian integer fields as well as for rings. Gaussian integer rings extend the possible complex signal constellations for codes over Gaussian integers. Moreover, binary information vectors can easily be encoded.

We have demonstrated that set partitioning for Gaussian integers is possible. The partitioning of rings does not alter the algebraic properties of the set. The set partitioning enables multilevel code constructions. We have constructed simple codes that illustrate the code construction. Multiple error correcting codes can be constructed when all partition levels are protected by outer codes.

We think that this is a promising direction for further research.

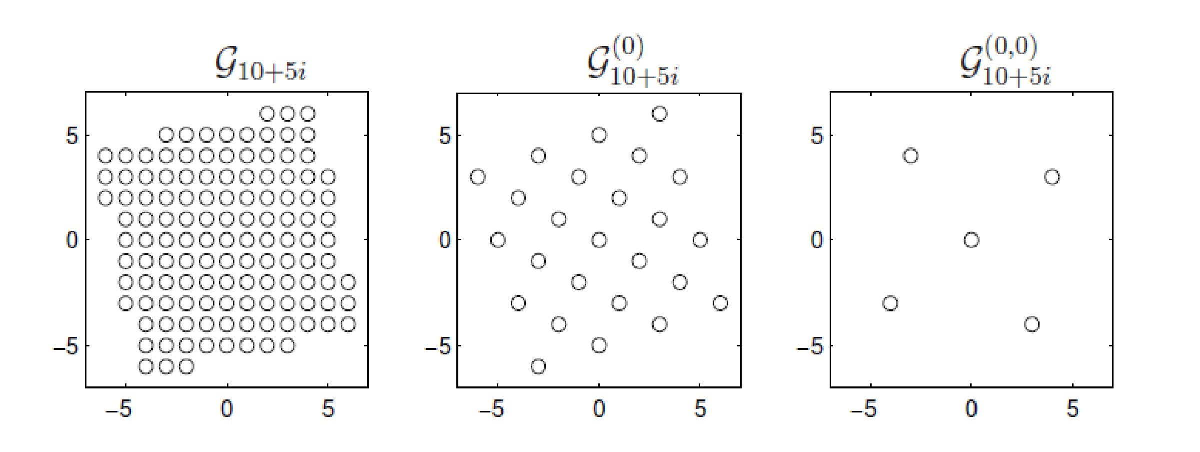

Figure 5. Complex constellation of the Gaussian integer ring G_{10+5i} and two subsets at the first and second partitioning level.

Most previous publications on codes over Gaussian integers considered only hard-input or optimum maximum-likelihood decoding.

However, maximum-likelihood decoding is only feasible for small signal constellations and short codes. We have shown that low-complexity soft-input decoding is possible by using a Chase-type algorithm.

Furthermore, we have presented a soft-input decoding algorithm for OMEC codes that has lower complexity than maximum likelihood decoding.

A Gaussian integer is a complex number whose real and imaginary parts are both integers.

Likewise a Lipschitz integer is a quaternion whose components are all integers. Based on the modulo function for Lipschitz integers it is possible to define residual class rings (quotient rings) of Lipschitz integers that have a finite number of elements. Coding over such quotient rings of Lipschitz integers has recently attracted some attention.

Some of these code constructions are generalizations of coding techniques developed for Gaussian integers.

Other examples for codes over quaternions are the constructions for Hurwitz integers and codes over quaternions, where the elements are from the commutative ring of even integers.

Forney and Wei proposed the *constellation figure of merit (CFM)* to compare signal constellations of different dimensions. The CFM is the ratio of the minimum squared Euclidean distance and the average energy per two-dimensions. Two constellations that have the same CFM have similar error probabilities for high signal to noise ratios (SNR). Gaussian integers and Lipschitz Integers can be compared by means of the CFM.

3. J. Freudenberger and S. Shavgulidze, “New four-dimensional signal constellations from Lipschitz integers for transmission over the Gaussian channel,” IEEE Transactions on Communications, Vol. 63, No. 7, July 2015. P. 2420-2427.

This work investigates the performance of Lipschitz integer constellations for transmission over the AWGN channel. A construction of sets of Lipschitz integers that leads to a better CFM compared to ordinary Lipschitz integer constellations and Gaussian integer constellations is presented.

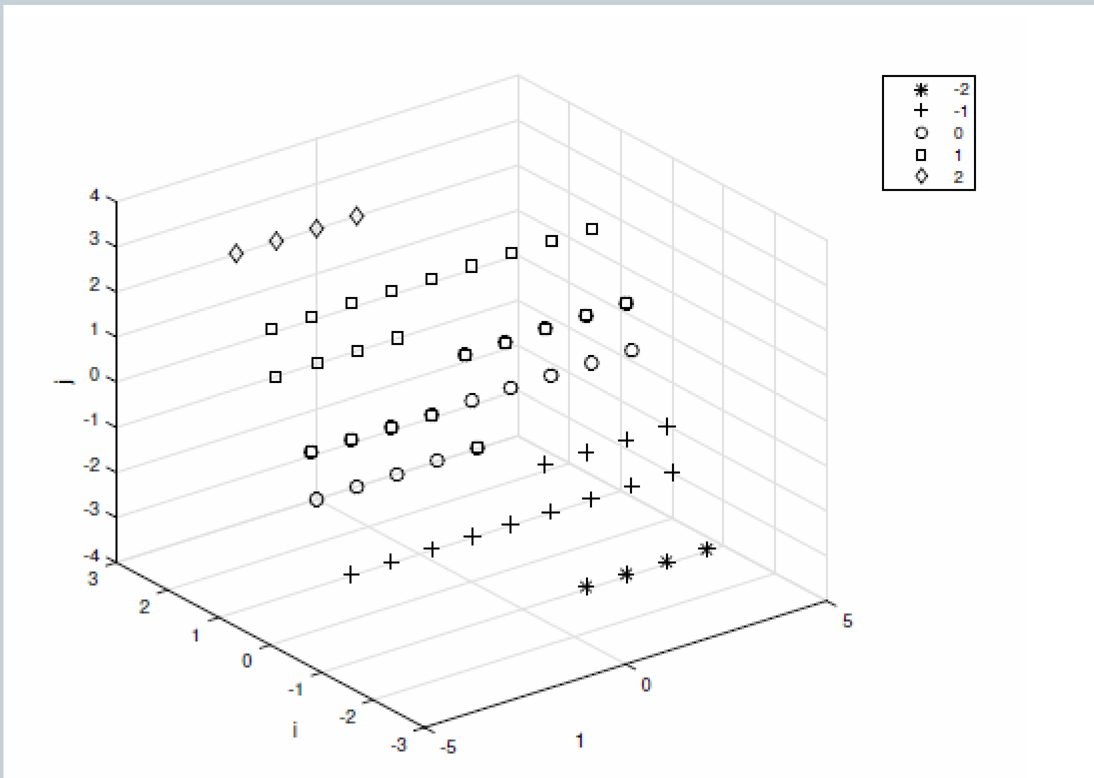

Figure 6. Visualization of the set $L_{6+3i+2j+2k}$ with 53 elements.

We proved, that minimum Euclidean distance in the partitions of new Lipschitz integer constellations is always larger than in original set. We present the multilevel code constructions and multi-stage decoding. This performance was obtained with a simple multi-stage decoding algorithm using hard-input syndrome decoding for the outer code. Such a coding scheme might be attractive for communication systems that require low decoding complexity or low decoding latency. On the other hand, the performance of these codes can potentially be improved using more sophisticated decoding methods.

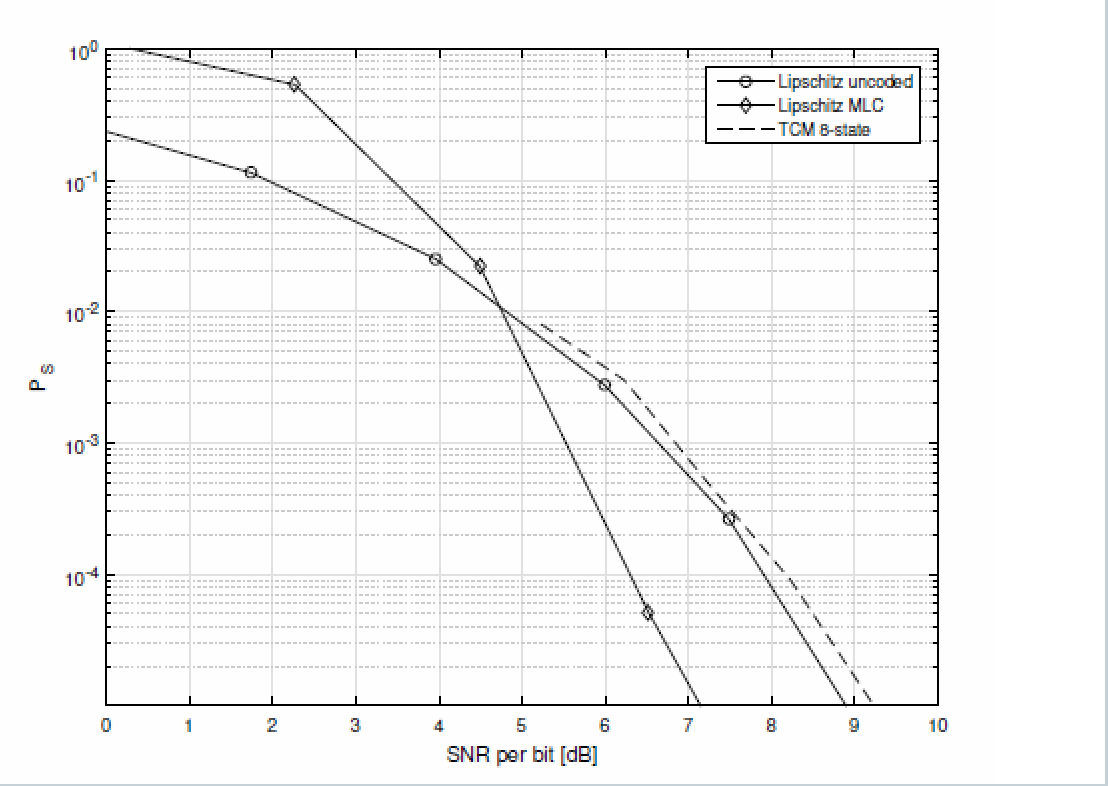

Figure 7. Symbol error rates for transmission over the AWGN channel (N=65).

Spatial Modulation (SM) is a recently proposed modulation scheme for multi-antenna systems exploiting the space domain as well as the signal domain to modulate the information.

In this scheme, an amplitude-phase modulation technique is combined with the space shift keying (SSK) to send the information over a multi-input multi-output (MIMO) channel. In the SSK, each data symbol is associated to one specific transmit antenna such that in each transmit interval, to transmit a particular symbol, only the corresponding transmit antenna is active.

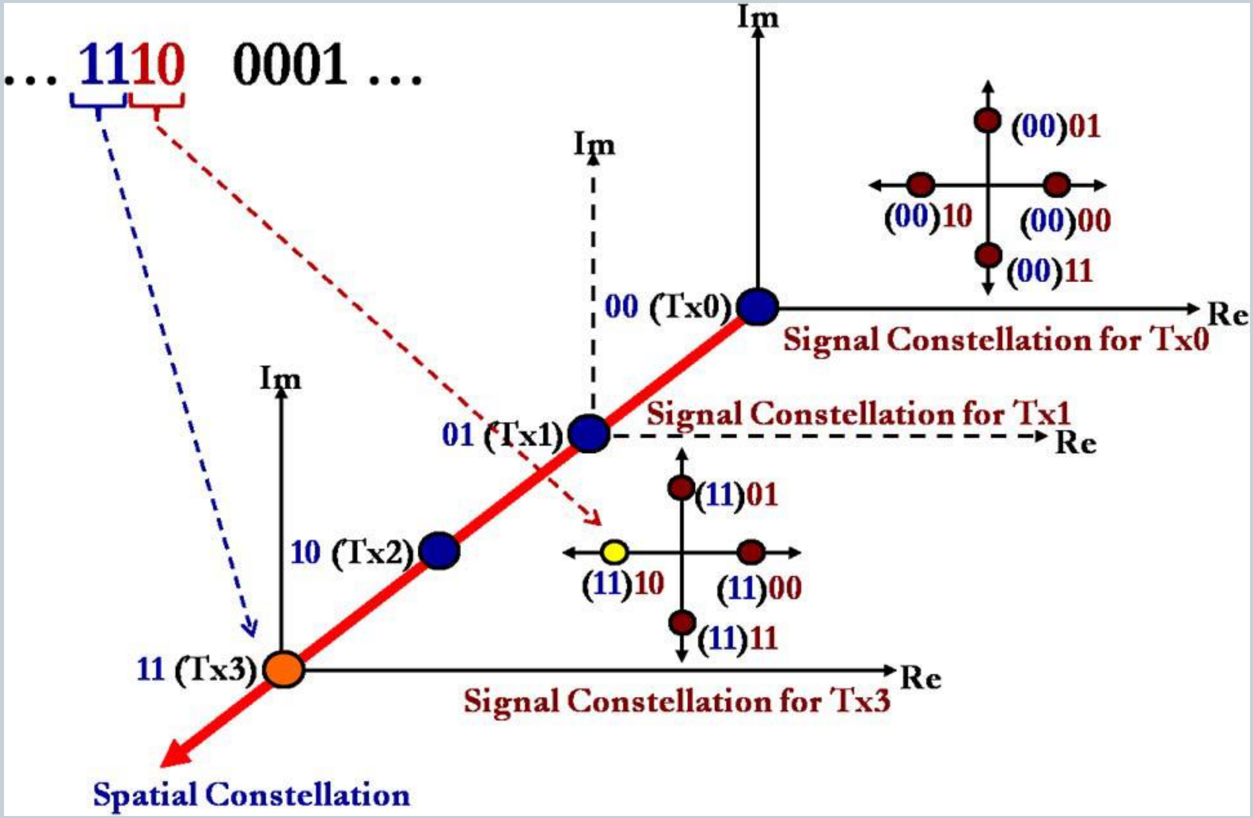

Figure 8. Illustration of the 3-D encoding of SM (first channel use).

Several benefits of SSK and SM transmission and their advantages over traditional MIMO transmission schemes have been addressed in the literature.

•The low transmission/reception complexity of these transmission techniques makes them a suitable candidate for future wireless systems especially when the number of antennas at the transmitter is large. For example, SSK/SM can be considered as a technique applicable to massive MIMO communication to support high dimension modulation.
•Having many antennas at the transmitter, enables modulating information via space which can increase the rate significantly while only using one RF chain at the transmitter to avoid complexity.
•SM is capable of dispensing with the requirement of multiple Radio Frequency (RF) chains, therefore relaxing the Inter-Antenna-Synchronization (IAS) specifications, whilst mitigating the Inter Antenna Interference (IAI) of conventional MIMO techniques. Additionally, the single-RF design is capable of reducing the total power consumption.
•Only a single power amplifier is needed for implementing SM-MIMO systems, which is typically responsible for the vast majority of power dissipation at the transmitter.
• It may be flexibly configured for diverse transmit and receive antenna constellations, especially for the challenging scenario of asymmetric/unbalanced MIMO systems.

On-going Research:
Signal Constellation Design for SM. Coded SM. A Low-complexity Detection scheme for SM. High rate spatial modulation for multiuser systems.

4. J. Freudenberger and S. Shavgulidze, “Signal constellations based on Eisenstein Integers for generalized spatial modulation,” IEEE Communications Letters, Vol. 21, No. 3, March 2016. P. 556-559.

This letter introduces signal constellations based on multiplicative groups of Eisenstein integers, i.e., hexagonal lattices. These sets of Eisenstein integers are proposed as signal constellations for generalized spatial modulation.

The algebraic properties of the new constellations are investigated and a set partitioning technique is developed. This technique can be used to design coded modulation schemes over hexagonal lattice. We consider Eisenstein constellations which omit the zero element. The resulting constellations are commutative groups under multiplication.

We demonstrate that the proposed hexagonal constellations can have advantages compared with other signal constellations that were proposed for generalized spatial modulation. We exploit the algebraic properties of the Eisenstein constellations, in order to derive a set partitioning method. Set partitioning of Gaussian integer constellations was proposed.

We present results of Monte Carlo simulations, which were obtained using Rayleigh fading. In the simulations, symbol vectors were randomly generated and transmitted over the channel, ML detection was performed using the received noisy signal samples, assuming perfect channel state information at the receiver.

We compare the performance of the proposed signal constellations with the enhanced spatial modulation (ESM) scheme, where we consider sets of signal vectors with similar cardinality.

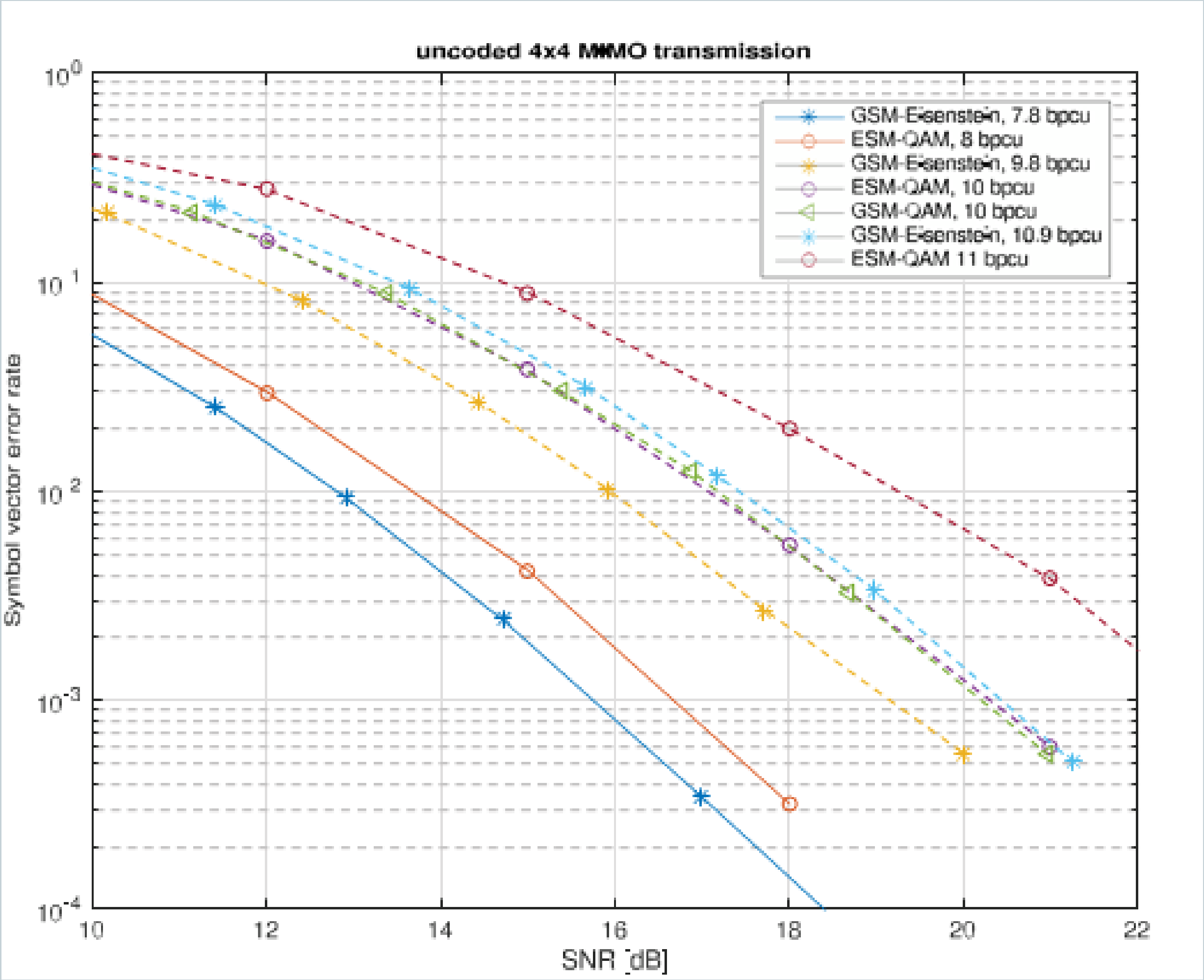

Figure 9. Simulation results for different spatial modulation schemes.

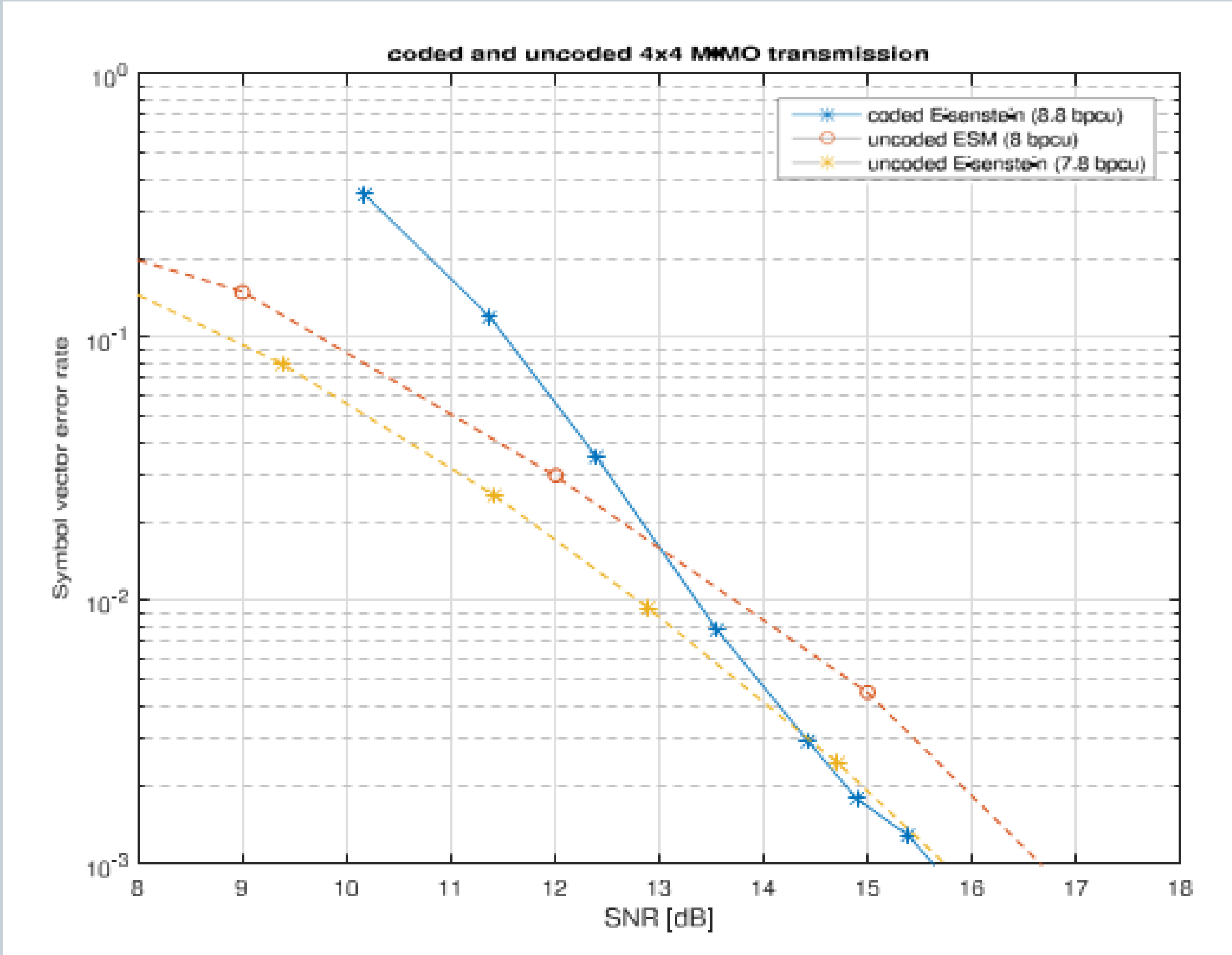

Figure 10. Simulation results for proposed encoded spatial modulation scheme.