Massive MIMO Throughput Maximization for Next Generation Wireless Communication Systems Using Convex Optimization Techniques

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Abstract: In the present age, Wireless Telecommunication Systems have gained a huge improvement in both efficiency and cost effectiveness. High data rate and high Quality of Service (QOS) is no more a dream in present Wireless Communication Systems and this rate is increasing quite rapidly with time. Multiple Input Multiple Output (MIMO) Systems are going to make an evolution in the domain of Wireless Communication. MIMO employs the concept of multi Antenna systems deployed concurrently at the transmitter and the receiver sides. Such a system has the capability to communicate with different antennas simultaneously. Nowadays Massive MIMO technology has led to vast improvements in area throughput by increasing the spectral efficiency, while using the same bandwidth and density of base stations as in current networks. In this paper a new method of rate maximization for Massive MIMO Systems using Convex Optimization Techniques has been proposed and implemented. In Massive MIMO Communication, the base stations are equipped with arrays of hundred antennas which enable spatial multiplexing of tens of user terminals. This paper thus explains the basic model for throughput maximization calculation of Massive MIMO systems and provides the implementation related design guidelines for next generation Wireless Communications Systems.

Keywords: Massive MIMO, 5G, Convex Optimization, Array Antenna, Throughput Maximization

I. INTRODUCTION

The Fifth Generation (5G) of wireless mobile communication systems is a technology with a vision, the vision of providing the highest Quality of Service (QOS) with lowest possible end to end latency [1]. The 5G communication systems will have to feed an unprecedented number of mobile devices, expected to approach 50 billion by the year 2020, satisfying their high volume needs of data and voice traffic [1]. To support such a massive number of connected smart devices and their data needs, the 5G systems are expected to provide a 1000 times increase in capacity enhancement with the same power and spectrum resources currently existing in the performing networks[3]. A close proximity insight into the 5G capabilities and its performance indicators reveals that the current available spectrum resources are insufficient to provide the promised user experienced data rates, connection density, end to end latency, mobility and peak data rates [4] Due to inadequate availability of spectrum, it is recommended to design resource allocation algorithms employing reuse of the spectral resource by multiple communication links [1][3]. The deployment of 5G communication systems employing the current network resources rely on highly efficient technologies like (MIMO), cognitive radio (CR) systems, device to device communication and low budget link based cooperative and relay communications[4][5][6]. Massive MIMO, cooperative communication, Cognitive Radio(CR) and compressive sensing are the driving technologies for 5G communication systems to achieve enormously high data rates in order to serve billions of network connected devices and to provide new services like e-Health, Banking, Learning, Vehicle to Vehicle communications (V2V), Device to Device(D2D) [7]. Such explosive data rates cannot be achieved by simply amplifying the transmitter powers, instead such enormous data rates will have to be achieved utilizing the resources of the present networks at a low carrier frequency. It is hence globally accepted fact that the radio resource allocation (bit/joule of energy) is a central design issue for 5G wireless systems [7][8]. Radio resource optimization is a key performance indicator in 5G communication systems. Optimization aims at obtaining the maximum value of a parameter subject to certain real time constraints. Convex optimization technique plays a vital role in obtaining optimal parameter values for enhanced energy efficiency, overall cost per bit, optimal power allocation, transmitter capacity by minimizing the negative sum rate. The resource allocation problems are either concave optimization problems or quasi concave optimization problems and hence do not guarantee optimal solution to the problem. However, by considering the negative sum rate of a concave or quasi concave optimization problem, a less complex closely approaching optimal solution can be obtained. In this paper Convex Optimization Technique has been used to obtain the rate maximization for Massive MIMO Systems at various transmit and receive diversities with and without zero forcing.

The rest of the paper is organized as follows: Section II highlights the related work of the proposed technique. Section

III gives the detailed description of the proposed problem and the problem solution is given in Section IV. Section V represents the system model for Rate Maximization for MIMO Systems. The block diagram and discussion about simulation results is given in Section VI. Finally the paper is concluded in section VII.

II. Related Work

Several works have already been carried out on the efficient radio resource allocation schemes for 5G communication systems. In [3], Xin Liu, Yanan Liu, discussed the Non orthogonal multiple access (NOMA), MIMO and relaying technologies to attain much higher data throughput and improved spectral efficiency without the requirement for increased bandwidth and redundant base stations. In [4], the authors presented cooperative and coordinated multi-cell resource allocation methods for 5G ultra reliable low latency connection, considering the typical indoor environment. Moreover [2][9][10], presents various other resource allocation schemes for 5G networks with application to device to device (D2D) and machine to machine(M2M) communications. Efficient resource allocation for MIMO and OFDM in 5G is a non-convex optimization problem [11]. A less complex closely approaching optimal solution for such problems can be generated by considering the negative sum rate of the optimization objective function using the convex optimization routine in MATLAB. Massive MIMO, cooperative communication etc. are promising technologies for the 5G communication systems. In massive MIMO, a large array of high directive/gain antennas are employed at both the base station terminal and the mobile station terminal multiplexed spatially for highly directed beam-forming to efficiently allocate the channel resources and to support the spectrum reuse. For MIMO and OFDM based wireless system architectures, the resource allocation scheme is a non-convex optimization problem and hence do not guarantee the optimal solution of the problem. In this paper we introduce a duality counterpart for obtaining the solution of the non-convex optimization problems by minimizing the negative sum rate of the objective function. The convex optimization techniques form the basis for the efficient resource allocation like energy efficiency, spectrum reuse, bit error rates etc. the optimal solutions for all the convex optimization problems related to judicious allocation of network resources can be generated by minimizing the objective function or cost function subject to certain real time constraints (inequality or equality constraints).

III. Problem Description

Massive MIMO, cooperative communication etc. are promising technologies for the 5G wireless communication systems. In massive MIMO, a large array of high directive/gain antennas are employed at both the base station and the mobile station multiplexed spatially for highly directed beam-forming to efficiently allocate the channel resources and to support the spectrum reuse. For MIMO and OFDM based wireless system architectures, the resource allocation scheme is a non-convex optimization problem and hence do not guarantee the optimal solution of the problem. In this paper we introduce a duality counterpart for obtaining the solution of the non-convex optimization problems by minimizing the negative sum rate of the objective function. The convex optimization techniques form the basis for the efficient resource allocation like energy efficiency, spectrum reuse, bit error rates etc. the optimal solutions for all the convex optimization problems related to judicious allocation of network resources can be obtained by minimizing the objective function or cost function subject to certain real time constraints(inequality or equality constraints)

IV. Problem Solution

For optimum resource allocation in MIMO and multicarrier (OFDM,FBMC) based 5G wireless communication systems, we formulate mathematically and analytically the various optimization parameters like MIMO rate optimization[14][15], OFDM rate optimization, optimal MIMO-OFDM power allocation and optimization problems related to effect of multiple antennas in cooperative communication. In this section we first introduce the concept of typical convex optimization problem and then we will analyze various optimization parameters using the convex optimization approach and LaGrange’s function. Note that the number of Lagrangian coefficients is always equal to number of the constraints.

A. *Convex function and convex optimization:*

If the domain of the optimization function g(x) is a convex set, i.e. $x, y \epsilon$ dom g, the function g(x) is a convex function satisfying the following inequality.

$$g(\alpha x + (1-\alpha)y) \leq \alpha g(x) + (1-\alpha)g(y) \quad ; 0 \leq \alpha \leq 1 \qquad (1)$$

Any convex optimization problem will have the form

$$\begin{aligned} &\text{Minimize} \quad g_0(x) \\ &\text{Subject to} \quad g_i(x) \leq 0, \quad i = 1,2,\dots,m \\ &\qquad\qquad\quad h_i(x) = 0, \quad i = 1,2,\dots,n \end{aligned}$$

This describes a convex optimization problem for finding the values of the variable x that minimizes $g_0(x)$ $\forall x$ satisfying the constraints

$g_i(x) \leq 0, \quad i = 1,2,\dots,m$ and $h_i(x) = 0, \quad i = 1,2,\dots,n$.

The variable $x \in R^n$ is termed as the optimization variable and the function $g_0 : R^n \rightarrow R$ the optimization function or cost function. The inequalities $g_i(x) \leq 0$ are inequality constraints corresponding to inequality constraints functions $g_i: R^n \rightarrow R$. The equality constraint $h_i(x) = 0$ corresponds to the equality constraint functions $h_i: R^n \rightarrow R$. If there are no constraints, the optimization problem is called unconstrained.

Graphically a convex function represents a chord passing through two points $(x, g(x))$ and $(y, g(y))$ from x to y. An optimization function g is strictly convex, if strict inequality holds i.e. whenever $x \neq y$ and $0 \leq \alpha \leq 1$. If g is concave then $-g$ is convex and g is strictly concave if $-g$ is strictly convex. This is a generalized fact that an optimization functions like a MIMO rate optimization function, OFDM rate optimization function, optimal MIMO-OFDM power allocation functions and optimization problems related to effect of multiple antennas in cooperative communication are concave optimization problems but the negative sum rate of these functions are convex functions. The convex optimization techniques can now be employed to obtain the optimal values of the said functions.

V. System Model for MIMO Rate Optimization

In this section we will consider a standard MIMO system consisting of $'t'$ transmit antennas at the base station side and $'r'$ decentralized receive antennas. The MIMO channel can be equivalently modelled as:

$$\bar{Y} = H\bar{X} + \bar{N} \quad (2)$$

where $\bar{Y} = [y_1 y_2 y_3 \dots y_r]$ is the $'r'$ dimensional receive vector at the MIMO receiver, $\bar{X} = [x_1 x_2 x_3 \dots . x_t]$ is a't' dimensional transmit vector with each symbol transmitted through each transmit antenna [16]. $\bar{H} = [h_{11} h_{12} h_{13} h_{31} \dots h_{rt}]$ is the $r \times t$ channel coefficient vector and $\bar{N} = [n_1 n_2 n_3 \dots n_r]$ is the $'r'$ dimensional noise vector. The subscripts to the parameters y, x, h, n corresponds to the antenna numbers at transmit and receive sides of the MIMO channel.

The MIMO system introduced represents the parallelization of the MIMO channel with $'t'$ symbols transmitted in parallel and spatially multiplexed. The signal power received at the receiver corresponding to each MIMO channel is given as:

$$\sigma_i^2 \{E|\bar{X}|^2\} \quad (3)$$

where σ_i represents the singular values of the channel coefficient matrix $\bar{H}$ [13] of the MIMO channel. The SVD of $\bar{H}$ is given below:

$$H = U \Sigma V^H \quad (4)$$

Where the matrices U, Σ V are $r \times t$, $t \times t$ and $t \times t$ dimensional respectively [12]

The noise power received at the receiver corresponding to each MIMO channel is given by σ_n^2 computed as the value of the covariance of the noise matrix. Therefore the signal to noise ratio at the input of the receiver is given as:

$$SNR = \frac{\sigma_i^2 \{E|\bar{X}|^2\}}{\sigma_n^2} \quad (5)$$

From the above SNR expression for the i^{th} channel, the Shannon capacity C_i of the channel can be derived as given below:

$$C_i = log_2\left(1 + \frac{P_i \sigma_i^2}{\sigma_n^2}\right) \quad (6)$$

The optimal MIMO power allocation problem can now be formulated as:

$$\text{maximize.} \sum_{i=1}^{t} log_2\left(1 + \frac{P_i \sigma_i^2}{\sigma_n^2}\right) \quad (7)$$

$$\text{subject to} \sum_{i=1}^{t} P_i \leq P$$

Where P is the total transmit power.

The above optimization problem with the given inequality constraint is a non-convex optimization problem and hence the convex optimization techniques cannot be applied directly to obtain the optimal solution for the MIMO power allocation problem. A non-convex optimization problem is transformed into a convex optimization problem by taking the negative sum rate of the non-convex optimization expression. The optimal MIMO power allocation problem can further be modified and formulated as a convex optimization problem by taking the negative sum rate of $\sum_{i=1}^{t} log_2\left(1 + \frac{P_i \sigma_i^2}{\sigma_n^2}\right)$ as under:

$$\text{Minimize} - \sum_{i=1}^{t} log_2\left(1 + \frac{P_i \sigma_i^2}{\sigma_n^2}\right)$$

$$\text{subject to} \sum_{i=1}^{t} P_i \leq P \quad (8)$$

To solve the above convex optimization problem a series of steps are followed as under

A. *Finding the Lagrangian cost function* $f(\bar{P}, \mu)$

It is important to note that the number of Lagrangian multiples is equal to the number of constraints- inequality of equality constraints. The Lagrangian cost function $f(\bar{P}, \mu)$ for the given optimization problem can be formulated as under:

$$f(\bar{P}, \mu) = \sum_{i=1}^{t} log_2\left(1 + \frac{P_i \sigma_i^2}{\sigma_n^2}\right) + \mu\left(P - \sum_{i=1}^{t} P_i\right) \quad (9)$$

B. Finding the maxima of the Lagrangian cost function:

Differentiating the above obtained Lagrangian cost function $f(\bar{P},\mu)$ with respect to power associated with the i^{th} MIMO channel P_i and setting the result equal to 0, we get:

$$\frac{\partial}{\partial x} f(\bar{P},\mu) = 0$$

$$\Rightarrow \frac{\frac{\sigma_i^2}{\sigma_n^2}}{1+\frac{P_i\sigma_i^2}{\sigma_n^2}} - \mu = 0 \quad (10)$$

C. Finding the optimal P_i using KKT conditions:

The kurush Kuhn tucker (KKT) conditions states that if $\frac{\partial}{\partial x} f(\bar{P},\mu) = 0$ then there exist local minima P^* for a unique value of the Lagrangian multiple μ as μ^* subject to $\mu^* \geq 0$. Solving the above differential equation $\frac{\partial}{\partial x} f(\bar{P},\mu) = 0$ yields

$$\frac{\frac{\sigma_i^2}{\sigma_n^2}}{1+\frac{P_i\sigma_i^2}{\sigma_n^2}} - \mu = 0 \quad (11)$$

$$\Rightarrow \frac{\sigma_i^2}{\sigma_n^2}\frac{1}{\mu} = 1 + \frac{P_i\sigma_i^2}{\sigma_n^2} \quad (12)$$

$$\Rightarrow P_i = \left(\frac{1}{\mu} - \frac{\sigma_n^2}{\sigma_i^2}\right)^+ \quad (13)$$

P_i Represents the power associated with the i^{th} MIMO channel, the function $\left(\frac{1}{\mu} - \frac{\sigma_n^2}{\sigma_i^2}\right)^+$ always accounts for the positive value of the channel powers, because channel powers cannot be negative. $P_i = \left(\frac{1}{\mu} - \frac{\sigma_n^2}{\sigma_i^2}\right)^+$ is positive if $\frac{1}{\mu} \geq \frac{\sigma_n^2}{\sigma_i^2}$ and 0 otherwise. P_i Can now be formulated as a piecewise optimization function as under:

$$P_i = \begin{cases} \left(\frac{1}{\mu} - \frac{\sigma_n^2}{\sigma_i^2}\right)^+, & x \geq 0 \\ 0, & x < 0 \end{cases} \quad (14)$$

D. Finding the Lagrangian multiplier 'μ' for optimal P_i:

The power allocated to the i^{th} MIMO channel is directly dependent on user defined function σ_i^2. Increasing the σ_i will increase the power allocated to the i^{th} MIMO channel coefficient. Thus the resulting power allocation will result in the water filling phenomenon subject to the constraint $\sum_{i=1}^{t} P_i \leq P$. Employing the same constraint will yield the value of 'μ' for optimal power allocation to the i^{th} MIMO channel.

$$P_i = \left(\frac{1}{\mu} - \frac{\sigma_n^2}{\sigma_i^2}\right), \quad \forall \frac{1}{\mu} \geq \frac{\sigma_n^2}{\sigma_i^2} \quad (15)$$

Solving the above expression for 'μ' we get

$$\mu = \frac{\sigma_i^2}{P_i\sigma_i^2 + \sigma_n^2} \quad (16)$$

For optimal P_i, the Lagrangian multiplier 'μ' should be minimum subject to the condition $\sum_{i=1}^{t} P_i\sigma_i \leq P$.

VI. RESULTS AND DISCUSSION

Figure 1 represents the block diagram of the proposed technique. An input data (random signal) is generated and system parameters are defined accordingly. The channel matrix from secondary user to primary user and primary user to secondary user is defined. The singular value decomposition (SVD) of the channel matrix is defined and rate maximization for Massive MIMO Systems is calculated for three respective cases: without zero forcing, with zero forcing and third being with zero forcing and interference. The interference is externally added to the signal.

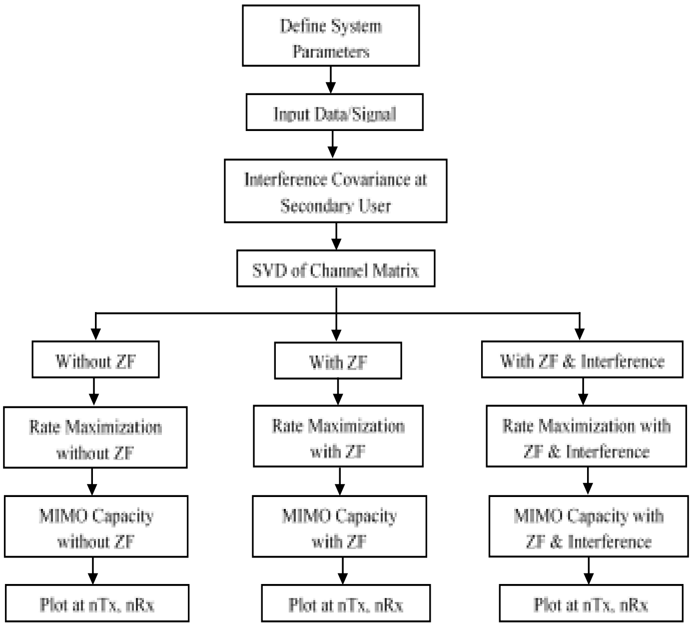

Figure1. Block Diagram of the Proposed Technique

The figures from 2-7 represents the capacity (Mbps) associated with the i^{th} MIMO channel as a function of the corresponding power of the same channel with and Without Zero-forcing and with Zero forcing and Interference. From the obtained graphs it is clearly visible that with ZF technique capacity increases with the increase in power, resulting in water filling phenomenon.

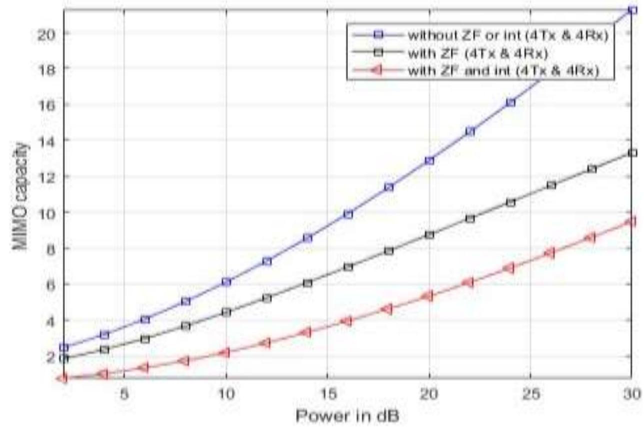

Figure. 2: Capacity (Mbps) vs. Power (dB) for 4x4 MIMO systems

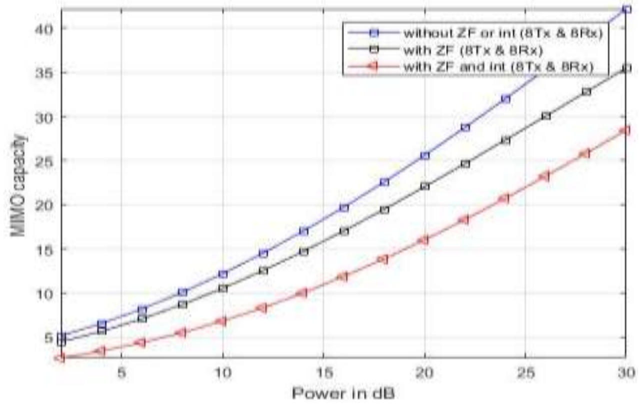

Figure 3: Capacity (Mbps) vs. Power (dB) for 8x8 MIMO systems

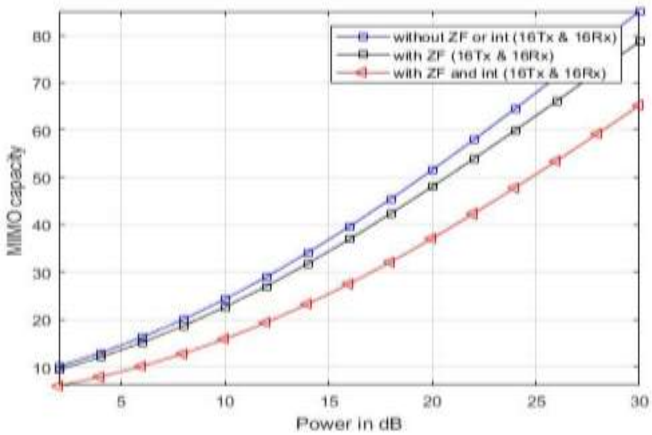

Figure 4: Capacity (Mbps) vs. Power (dB) for 16x16 MIMO systems

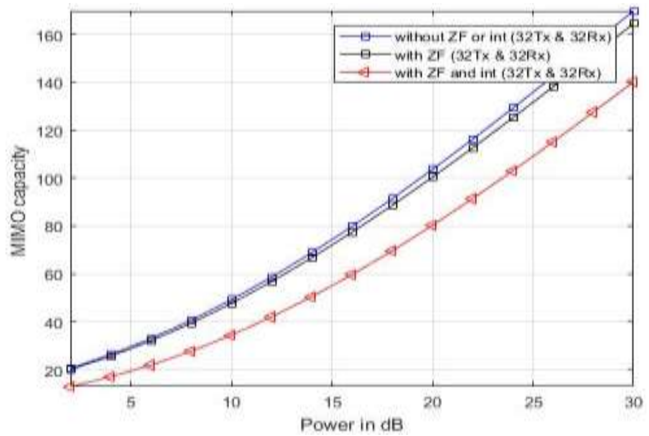

Figure 5: Capacity (Mbps) vs. Power (dB) for 32x32 MIMO systems

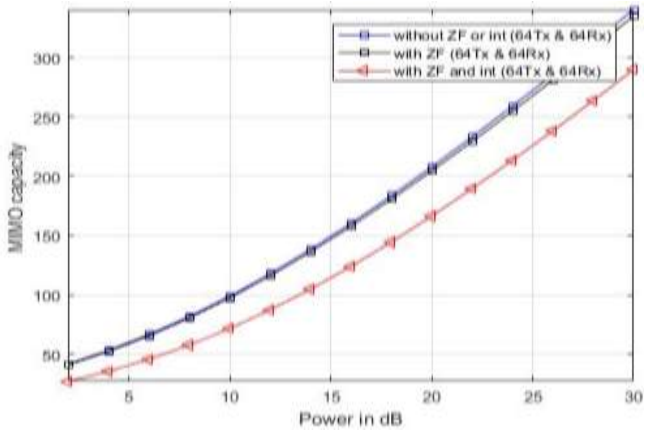

Figure 6: Capacity (Mbps) vs. Power (dB) for 64x64 MIMO systems

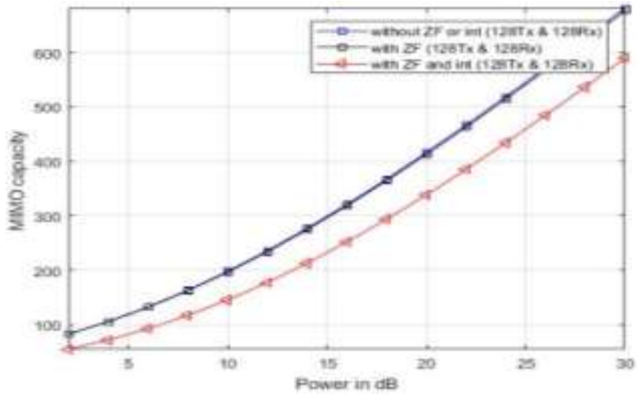

Figure 7: Capacity (Mbps) vs. Power (dB) for 128x128 MIMO systems

VII. CONCLUSION

In this paper number of iterations has been done to evaluate the performance of proposed MIMO system with ZF technique using convex optimization method. The iteration method was based on applying negative sum rate of non-convex optimization. The sum rate maximization of proposed ZF technique is dealt via CVX toolbox. The optimal values for power allocation coefficient and Lagrangian coefficient obtained in the proposed technique result in water filling phenomenon as depicted from our plots. The proposed ZF technique performs better as compared to non-ZF at higher power levels for higher MIMO order configurations due to lesser interference and noise limited environment. With diversity order more than 100, the MIMO system capacity approaches the Shannon limit.

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