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Power Allocation Strategies for Non-Orthogonal Multiple Access

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***Abstract*— Non-Orthogonal Multiple Access (NOMA) is considered as a promising downlink Multiple Access (MA) scheme for future radio access. In this paper two power allocation strategies for NOMA are proposed. The first strategy is based on channel state information experienced by NOMA users. The other strategy is based on pre-defined QoS per NOMA user. In this paper we develop mathematical models for the proposed strategies. Also we clarify the potential gains of NOMA using proposed power allocation strategies over Orthogonal Multiple Access (OMA). Simulation results showed that NOMA performance using the proposed strategies achieves superior performance compared to that for OMA.**

***Keywords*— non-orthogonal multiple access; successive interference cancellation and power allocation**

I. INTRODUCTION

The rapid growth in the volume of mobile data such as the data generated from smartphones and new mobile devices, demands new technologies and new technical solutions. The new strategies shall provide higher capacity and higher quality of user experience. The 3rd Generation Partnership Project (3GPP) started discussions on further steps in the evolution of LTE toward the future, i.e., Release 12 and onwards [1]. Furthermore, some initial discussions on the 5th generation (5G) mobile communication systems are taking place in the radio communication sector of the international telecommunications union radio (ITU-R) and are being led by multiple projects and companies [2],[3].

Multiple major 5G technologies such as ultra-densification, millimeter wave, and massive Multiple-Input Multiple-Output (MIMO), have attracted considerable attention in both industry and academia [4]. In addition to these technological implications, physical layer issues such as transmission waveforms and Multiple Access (MA) schemes should be reconsidered. A promising downlink MA scheme which is Non-Orthogonal Multiple Access (NOMA) is considered. NOMA is expected to achieve high spectral efficiencies over Orthogonal Multiple Access (OMA) by combining superposition coding at the transmitter with Successive Interference Cancellation (SIC) at the receivers [5], [6].

Recently, multiple research works have discussed NOMA performance issues and gains achieved over traditional OMA. Some research works proposed Power Allocation (PA) strategies that ensure fairness for the downlink users based on instantaneous or average channel information [7]. Other research works proposed new NOMA scheme which employs intra-beam superposition coding of a multiuser signal [8]. Also some research works addressed SU-MIMO performance besides Modulation and Coding Schemes (MCS) for NOMA [9].Several research works targeted how to allocate power among NOMA cell users [10-12]. The concept of Quality of Service (QoS) and Channel State Information (CSI) based power allocation was introduced without proposing mathematical model for each strategy in [10]. Multiuser scheduling beside users' power allocation algorithms were proposed in [11]. The proposed algorithms were optimal based on water filling, suboptimal algorithm and fixed power allocation. The Pre-defined user grouping was introduced in [12].

The main novelty of this work is proposing detailed concept, mathematical modeling and procedures for two PA strategies for NOMA. The proposed strategies are CSI based power allocation and QoS based power allocation. In CSI based power allocation, power is distributed according to channel conditions experienced by cell users. In contrary to power allocation algorithms proposed in [11] and [12] which allocates power proportional to user's instantaneous CSI, the proposed algorithm in this work assigns power inversely proportional to user's CSI. In the QoS based power allocation, the power is allocated to achieve pre-defined QoS for particular users. We evaluate user's performance in terms of Bit Error Rate (BER) using link level simulations in addition to cell user throughput.

II. NOMA SYSTEM MODEL

A single-cell consisting of one Base Station (BS), and N users is assumed per cell. There are B frequency blocks and the bandwidth of a frequency block is W. The BS groups m_B users per frequency block so that U_i is used to refer to the i-th user ($1 \leq i \leq m_B$). In this paper we assume $m_B = 2$. All terminals are equipped with a single antenna. The BS transmits user’s data using superposition coding technique. The BS has always data to transmit for each user (saturated scenario) and its total available transmitted power per frequency block is equal to P. The assigned power shares per U_i is P_i. All wireless links exhibit independent and identically distributed (i.i.d.) block Rayleigh fading and Additive White Gaussian Noise (AWGN). This means that the fading coefficients h_i (for the $BS \rightarrow U_i$ link) remain constant during one slot, but changes independently from one slot to another according to a complex Gaussian distribution. The AWGN is assumed to be normalized with zero mean and unit variance . Let us define the modulated signal per user per frequency block to be x_i while the received signal per user is y_i. The observed signal per user is given by

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$$y_i = h_i \sum_{k=1}^{m_B} \sqrt{P_k}\, x_k + \sigma^2 \, . \quad (1)$$

Users' data multiplexing is performed in the power domain. The BS transmits a linear superposition of N data flows by allocating P_i to the i-th data flow. The sum of assigned power shares for all users sharing the same frequency block shall not exceed P.

$$\sum_{i=1}^{m_B} P_i = P \, . \quad (2)$$

The instantaneous downlink Signal-to-Interference-plus-Noise Ratio (SINR) γ_i per U_i is given by

$$\gamma_i = \frac{|h_i|^2 P_i}{|h_i|^2 \sum_{k=i+1}^{m_B} P_k + \sigma^2} \, , i = 1, \ldots, m_B \, , \quad (3)$$

where $|h_i|^2 \sum_{k=i+1}^{m_B} P_k$ represents other users interference. The achievable NOMA downlink throughput per user is given by

$$R_i^{NOMA} = W \log_2(1 + \gamma_i) \, . \quad (4)$$

III. Power Allocation Strategies

In this section, two alternative power allocation strategies are proposed that can be used for NOMA. The proposed techniques are power allocation based on channel state information and power allocation based on pre- defined quality of service per user.

Fig. 1 shows the algorithm used for both proposed power allocation strategies. The BS groups users into groups. Each users' group is served by a frequency block. Users grouping strategy differs from one technique to another which will be illustrated later in each technique. Users' signals are multiplexed at the BS according to selected power allocation algorithm. The BS shall send the power allocation matrix to users over control channels in downlink. Users' power shares are sorted into the matrix in descending order. All users sharing the same frequency block shall decode the messages which include power allocation matrix. Each user will determine how to decode his data by whether performing successive interference cancellation (SIC). The user who has bigger power share will decode his data directly without performing SIC considering. In this case, this user will consider less power user as interference. The user who has smallest power share will decode highest share user data. The user will extract his data from received data using SIC.

A. CSI Based Power Allocation

In this strategy, the power coefficients are determined based on the channel state information experienced by every user. The BS allocates power coefficients based on the reports sent from NOMA users over control channels. The BS will group users together so that one user with good radio condition will be grouped with another user with bad radio condition. Then each group of users will be assigned to a frequency block. Users' signals will be multiplexed together using assigned powers and transmitted to users so that the total transmitted power per resource block shall not exceed P.

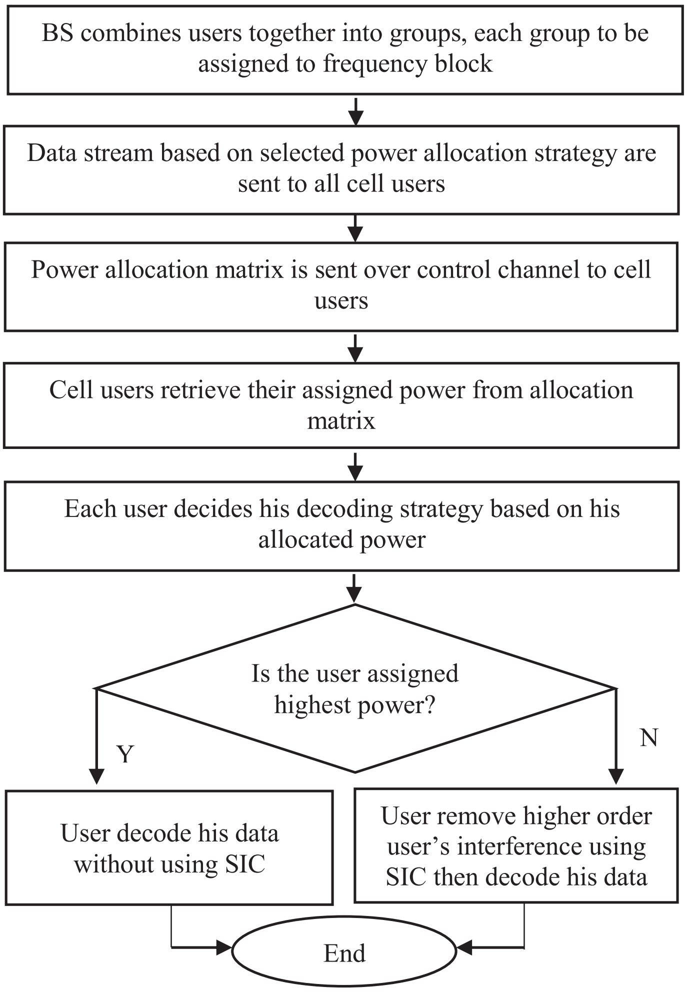

Fig. 1. Proposed NOMA power allocation algorithm

In contrary to what proposed in [11], which propose water filling technique to calculate users' power, the relation between power share per user P_i and its channel h_i is assumed to be inversely proportional, thus it can be given by

$$P_i \propto \frac{1}{|h_i^2|} \, . \quad (5)$$

This means that BS will assign highest power share to user which experiences worst channel conditions while less power share to user which experiences better channel conditions which is usually called channel inversion. From equation (5), the power allocation coefficient of i-th user is given by

$$P_k = \frac{|h_i|^2}{|h_k|^2} P_i \, , i \neq k \, . \quad (6)$$

Substituting equation (6) into equation (2) we get

$$P_i \left(1 + \frac{|h_i|^2}{|h_k|^2} + \cdots + \frac{|h_i|^2}{|h_{m_B}|^2} \right) = P \, . \quad (7)$$

This will lead to

$$P_i = \frac{P}{|h_i|^2 \sum_{k=1}^{m_B} \frac{1}{|h_k|^2}}. \tag{8}$$

Equation (8) emphasizes the assumption used for equation (5) which is the inverse proportionality between power allocated and channel coefficients and $\sum_{k=1}^{m_B} \frac{1}{|h_k|^2}$ is the proportionality constant.

B. QoS Based Power Allocation

In this strategy, the power coefficients are determined based on pre-defined QoS per user. In the proposed strategy, users are assumed to be divided into classes based on their importance. Two types of users are assumed which are high priority users and low priority users. Using users' grouping, the BS shall guarantee pre-defined QoS for high priority users while no QoS limitations is defined for less priority users. BS starts to pair one high priority and less priority over same frequency blocks and start assigning required power for high priority user. The remaining power will be allocated to the less priority user. The maximum transmitted power per frequency block shall not exceed *P*. Users' signals will be multiplexed together using assigned powers and transmitted to users.

Using eq. (4), it can be assumed that the required SINR to achieve guaranteed downlink throughput for high priority user can be given by

$$\gamma = 2^{\frac{R^{NOMA}}{W}} - 1 = \frac{P_h |h_h|^2}{P_l |h_h|^2 + \sigma^2}, \tag{9}$$

where, P_h and P_l are the power allocation coefficients for high priority and low priority users respectively and $|h_h|^2$ is high priority user's channel coefficient. Using eq. (2), we can define the relation between power coefficients of high priority and low priority users to be

$$\sum_{i=1}^{m_B} P_i = P_h + P_l = P. \tag{10}$$

Substituting equation (9) into equation (10) we can get

$$\gamma = \frac{P_h |h_h|^2}{|h_h|^2 (P - P_h) + \sigma^2}. \tag{11}$$

Simplifying and organizing equation (11), the power allocation coefficients for high priority user is given by

$$P_h = \frac{\gamma(|h_h|^2 + \frac{1}{\rho})}{|h_h|^2 \,(\gamma + 1)} \, P, \tag{12}$$

where, ρ is the transmit Signal to Noise Ratio (SNR) and is given by

$$\rho = \frac{P}{\sigma^2}. \tag{13}$$

The remaining power budget that shall be assigned to the low priority user is given by

$$P_l = P - P_h. \tag{14}$$

Substituting equation (12) into equation (14) we get

$$P_l = \frac{(|h_h|^2 - \frac{\gamma}{\rho})}{|h_h|^2 \,(\gamma + 1)} \, P. \tag{15}$$

IV. Simulation Results

In this section, we present simulation results for NOMA when applying the proposed power allocation strategies which are CSI and QoS based power allocation strategies. We assume in our Link Level Simulations (LLS) a single cell with one BS. The system will be simulated for two and four users per cell. Two NOMA users will be assigned for every frequency block ($m_B = 2$).

BS transmit user's data using quadrature phase shift keying (QPSK) modulation over AWGN and Rayleigh fading channel. Minimum Mean-Squared Error (MMSE) equalization is used at the receiver [13].

Before proceeding to the simulation results, let us define normalized bandwidth factor of β_i $(0 < \beta_i < 1)$ for OMA user such that

$$\sum_{i=1}^{m_B} \beta_i = 1. \tag{16}$$

thus β_i is given as

$$\beta_i = \frac{1}{m_B}. \tag{17}$$

The achievable OMA downlink throughput per user assuming equal power allocation among users in this case is given by

$$R_i^{OMA} = \frac{W}{m_B} \log_2 \left(1 + \frac{|h_i|^2 P}{m_B \sigma^2}\right). \tag{18}$$

A. CSI Based Power Allocation

In this sub section, we verify CSI based power allocation strategy for two users only in the cell and comparing NOMA performance using the proposed power allocation strategy against OMA performance.

Fig. 2 shows the achievable downlink throughput per user using proposed CSI based power allocation against achievable downlink throughput of OMA and NOMA when N=2. NOMA achievable total system throughput and achievable throughputs for NOMA users is greater than achievable total system throughput and user throughput for OMA users. This gain in throughput in accompanied by BER performance degradation as shown in Fig. 3. The BER for both NOMA users slightly deteriorated than equal power OMA because of inter user interference. It worth mentioning that performance of both NOMA users is nearly equal due to the fact of assigning suitable power per user according to channel conditions. The percentage of increase for achievable throughput for NOMA versus OMA is around 30% at 15 dB SNR as shown in Fig. 4.

Fig. 5 and Fig. 6 are showing the achievable throughput and BER performance for NOMA and OMA in case of $N = 4$ respectively. In this part of simulation, two frequency blocks were used ($B = 2$). As shown in Fig. 5, the achievable rate per NOMA and OMA users in case of ($N = 4$) is less than the achievable rate in case of ($N = 2$) as more users are now

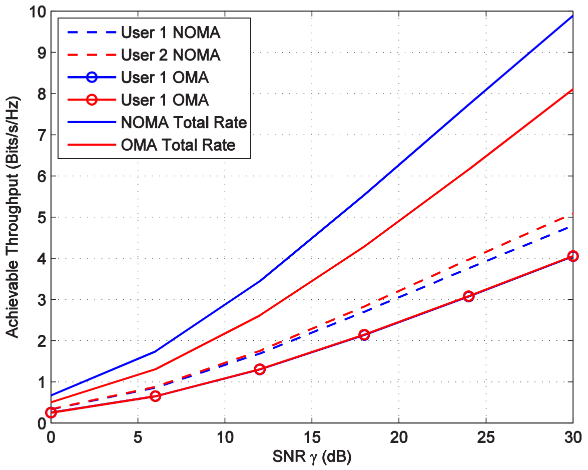

Fig. 2. CSI based NOMA and OMA achievable throughput, N=2

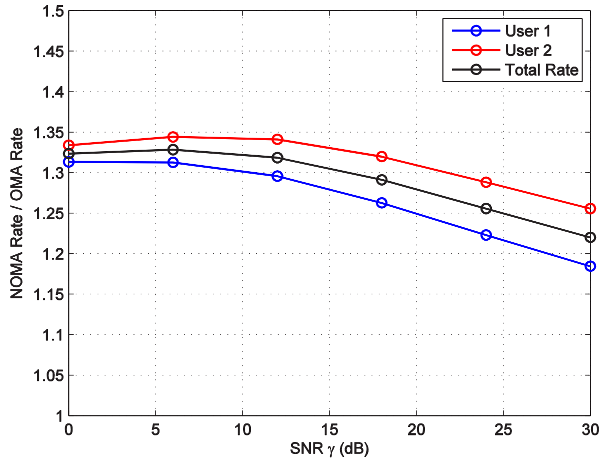

Fig. 4. CSI based NOMA Rate and OMA rate ratio, N=2

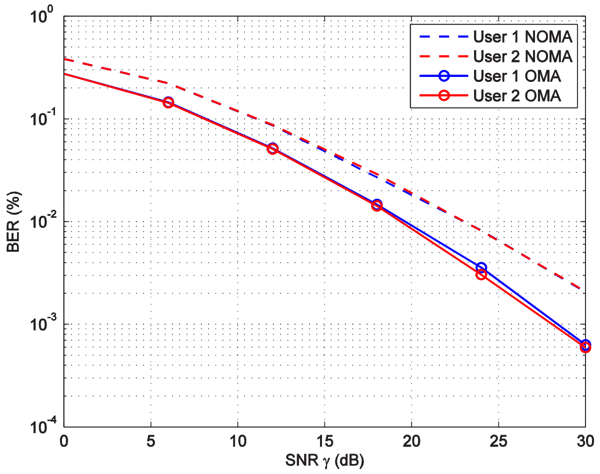

Fig. 3. BER performance of CSI based NOMA and OMA, N=2

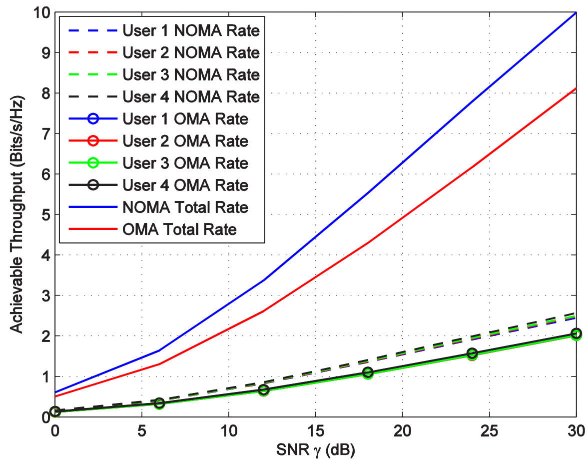

Fig. 5. CSI based NOMA and OMA achievable throughput

sharing same bandwidth but the overall achievable rate for NOMA technique is still the same for both cases. On the other hand, Fig. 6 shows the BER performance for the 4 users which is deteriorated than OMA BER performance as mentioned earlier in case of two users.

B. QoS based Power Allocation

In this sub section, we verify QoS based power allocation strategy for four users only in the cell of $(N = 4)$ and comparing NOMA performance using the proposed power allocation strategy against OMA performance. Before going deeper in simulation results and analysis, Lets defined the guaranteed bit rate that shall be provided for a high priority user as

$$R_i^{NOMA} \geq C_i * R_i^{OMA}\,, \tag{19}$$

where, C is scaling factor . The BS will guarantee throughput for high users according to equation (19) and C shall be determined by network operator. In this simulation, a single BS will be simulated with $N = 4$. The first and third users will be considered as high priority users with pre-defined QoS requirements while the second and fourth users will be considered low priority users. We will simulate the NOMA so that first user achieves 50% throughput increase than that in case of OMA or C_1=1.5 while the third user shall achieve 30% throughput increase than in case of OMA or C_3 =1.3. As mentioned before the four users will be assigned to two frequency blocks. Each block shall serve one high priority user and one low priority user.

As shown in Fig. 7, the overall NOMA system throughput is less than overall achieved system throughput achieved by CSI based technique. Low priority user's achievable throughput may be less than OMA throughput but the overall achievable throughput by NOMA is still higher than overall OMA throughput. First and third user's achievable throughputs are higher than those of second and fourth user's achievable throughputs which were equal in case of CSI based NOMA. This inequality in throughput will also be reflected in BER performance for the four users which is shown clearly in Fig. 8. The BER performance of high priority users which are the first and third users is better than low priority users' BER performance. This is because of assigning on average highest power share to high priority users in order to achieve the pre-

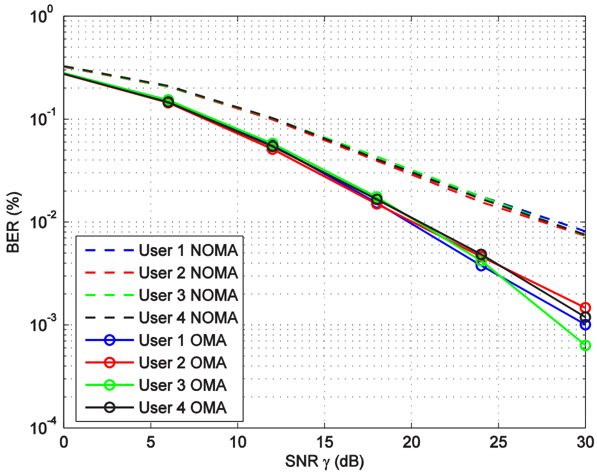

Fig. 6. BER performance of CSI based NOMA and OMA

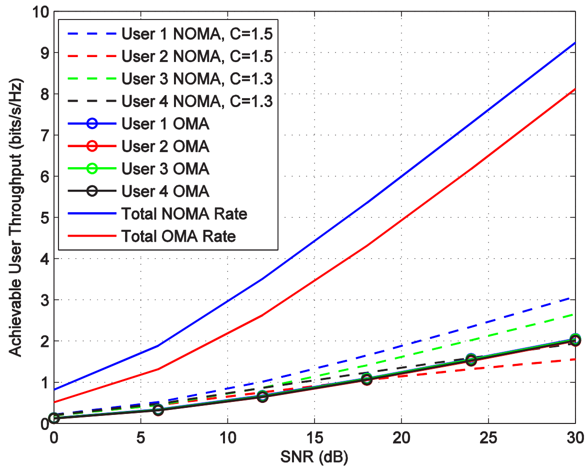

Fig. 7. QoS based NOMA and OMA achievable throughput

defined QoS. Also, high priority users' BER performance outperforms OMA users' BER performance. This is because of assigning higher power by the BS to high priority users to achieve the pre-defined QoS. This power increase was not possible in case of OMA which limited to fixed transmitted power. Fig. 9 shows that first and third users' throughput is successfully maintained as needed using C_i.

V. Conclusion

In this paper, two power allocation strategies were proposed and simulated for NOMA. The simulation showed that NOMA provides better performance than OMA with more spectral efficiency. The first PA strategy was based on CSI and around 30% increase for overall system throughput was achieved using this strategy. The other proposed strategy was based on pre-defined QoS for high priority users. This proposed strategy can successfully provide high priority NOMA with higher rates than provided in OMA. The main results of this work show that NOMA can ensure better capacity requirements through appropriate PA and is a promising multiple access scheme for

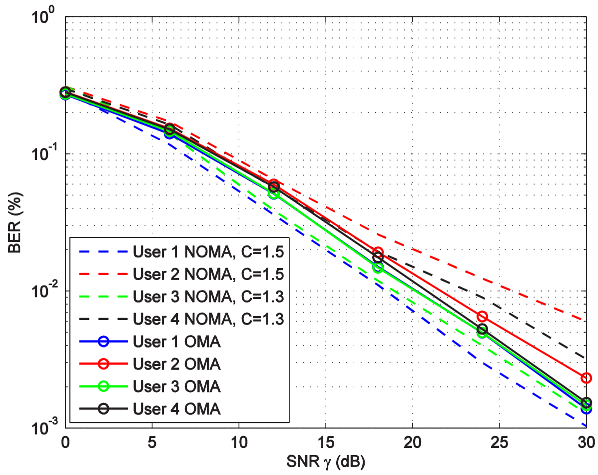

Fig. 8. BER performance of QoS based NOMA and OMA

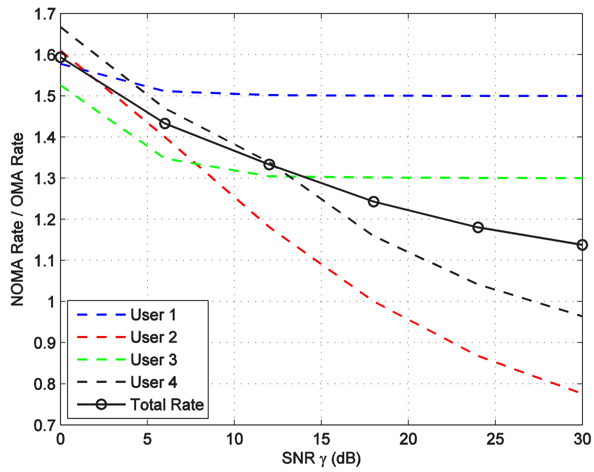

Fig. 9. CSI based NOMA Rate and OMA rate ratio

future communication systems.

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