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Investigations on spectral efficiency of multi-cell networks using hybrid beamforming

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ABSTRACT

Millimeter wave communication systems with antenna beamforming facilitates practical solutions to the capacity crunch issues in the upcoming 5G wireless networks. Multi-cell dense networks are prone to three major interferences-inter-cell, intra-cell and Inter layer interference-the most dominating being the inter-cell interference. This paper focuses to alleviate inter-cell interference using hybrid beamforming (HBF) approach, leveraging coordinated multipoint (CoMP) technique, thereby improving the SE of 5G networks. Simulation results show HBF peforms in par with optimal weights, making it a suitable candidate for 5G networks. As the number of data streams is increased from Ns=1 to 4 for 0 dB signal to noise ratio (SNR) with Nt=64 and Nr=16, the SE increases from 9.5557 bits/s/Hz to 26.423 bits/s/Hz for optimal weights and from 9.1885 bits/s/Hz to 19.763 bits/s/Hz and hybrid weights, respectively. The second set of experiments are conducted to study the effect of number of transmit antennas on spectral efficiency (SE). The results show that as the number of transmit antennas is increased from Nt=16 to 64 for 0 dB SNR, with Nr=16 and Ns=4, the SE increases from 17.735 bits/s/Hz to 26.423 bits/s/Hz and 13.750 bits/s/Hz to 19.763 bits/s/Hz for optimal weights and hybrid weights, respectively.

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1. INTRODUCTION

The need to address the bandwidth requirements of multitude of users in the upcoming 5G networks, and to solve the capacity crunch issues owing to the ever-increasing wireless user data traffic, has been the root-cause for exploring the spectral region beyond the 6 GHz frequency band. In the recent years, extensive research has been done to investigate the deployment of millimeter-wave systems in 5G networks. The millimeter waves span a wider spectral region from 30 GHz to 300 GHz and occupy the spectral region between microwaves and infrared radiation (IR) waves. The high frequencies incorporated by millimeter waves and their propagation characteristics make them suitable to transmit enormous data and finds its application in cellular-based communications and in radar community. Millimeter-wave systems can achieve humongous data rates and poses practical and reasonable solutions to the afore-mentioned issues of bandwidth shortage and capacity crunch problems. Thus, mmWave communication systems have transpired as the most prominent technology for next generation 5G networks. Spectrum being the most important resource, should be efficiently utilized to ensure that its potential benefits are exploited to the fullest for the social and economic welfare of any nation. The tremendous growth of mobile telecommunications indicates the significance of frequency spectrum. Beamforming using multiple antennas is a key element for effective utilization of millimeter wave spectral band. Multiple antennas at the transmitting and receiving ends can achieve multiplexing, diversity or high antenna gains.

Multi-cell dense networks are subjected to a major challenge–inter-cell interference, which has to be solved. Two approaches for alleviating inter-cell interference in multi-cell, dense networks include; i) power control and ii) antenna beamforming. Antenna beamforming proves to be a more suitable approach for mm-wave systems owing to the fact that antenna arrays deployed at both ends of a communication link can compensate for free space path loss during signal propagation. The three beamforming techniques are: analog, digital and hybrid beamforming. The beamforming techniques have been analyzed and explored in the literature earlier and these works [1]-[7] highlights the significance of hybrid beamforming (HBF) for mmWave systems. Hybrid beamforming can support multitude of users with maximized data rate and reduced interference and is highly desirable for multi-user, multi-stream millimeter wave communications [8]-[10]. The factors such as improper phase adjustments and amplitude variations, phase shifter loss, noise and non-linearity in analog beamforming and the drawbacks of high-power consumption, increased hardware cost and complexity with digital beamforming is overcome with hybrid beamforming. Schwarz and Rupp [11] explored extensively on multi-cell analysis using base station (BS) coordination and interference suppression which focused on fully digital beamforming technique. The authors have proposed four different analog and digital beamforming schemes for multi cell networks [12]. Wei and Liao [13] focuses on maximizing the network utility in multi-cell networks through cooperative scheduling. In this work, the user equipment performs side interference cancellation.

Hefnawi [14] works on Hybrid beamforming for heterogeneous networks. In this work, maximal ratio transmission (MRT)/maximal ratio combining (MRC) scheme is employed and near-optimal performance is achieved with less computational complexity. Ayach *et al.* [15] computes the spatially sparse precoding and combining weights via orthogonal matching pursuit (OMP) algorithm. Precoders/combiners with reduced hardware cost can be developed but the direct optimization of the precoding and combining weights is a major concern. Four hybrid beamforming schemes were presented in [16] based on coordinated multipoint (CoMP) techniques to mitigate inter-cell interference in multi-cell, millimeter-wave networks. The spectral efficiency comparisons of the four schemes were illustrated and investigated using two channel model-3rd generation partnership project (3GPP) and New-York University (NYUSIM). Nauryzbayev and Alsusa [17] worked on interference cancellation to enhance multiplexing gain in multi-cell networks using interference alignment (IA) technique. Dai and Clerckx [18] develop hybrid precoders based on rate splitting (RS) transmission strategy to mitigate high hardware cost in mmWave systems. The previous research provide insights on CoMP transmission and reception in long term evolution (LTE)-advanced networks and study of 3GPP on the deployment scenarios and operational challenges of such systems [19]-[21]. Sun *et al*. [22] concludes that CoMP based on maximizing signal to leakage noise ratio (SLNR) improves the spectral efficiency by 67% compared to non-CoMP case. The 5G channel models-3GPP and NYUSIM were investigated and compared in the works [23]-[25].

Though mm-wave systems undoubtedly offer significant benefits for the upcoming 5G cellular networks but poses few technical challenges which needs to be addressed. A combination of high frequency and wider bandwidth requires close attention to linearity, frequency response, phase noise and power dissipation. Millimeter waves are attenuated due to two reasons: i) free-space path loss and ii) shadowing. However, the shorter wavelength of mm-wave provides greater antenna gain. It provides narrow beam which limits the coverage area. So, multi-beam or beam-steering techniques need to be adopted with next generation cellular networks. This paper focuses on to reduce inter-cell interference in multi-cell, dense networks using hybrid beamforming approach, leveraging CoMP technique. CoMP based on maximizing SLNR is employed and the spectral efficiency performance of 5G millimeter wave system is measured. A comprehensive analysis on: i) the effect of number of data streams and ii) the number of transmit and receive antennas on spectral efficiency is performed and the spectral efficiency obtained using both optimal weights and hybrid weights is compared. The paper is organized as follows: section 2 presents an overview of analog and digital beamforming techniques and describes elaborately about hybrid analog-digital beamforming type with its architectures, its system design including computation of hybrid weights, leveraging OMP algorithm.

This section briefs about the different CoMP techniques and discusses the channel models available for evaluation of next generation 5G networks. In section 3, the simulation results for the effect of number of data streams (Ns) and the effect of number of transmit (Nt) and receive (Nr) antennas on spectral efficiency are illustrated with their corresponding beam pattern response and the results are tabulated. Section 4 presents the analysis and conclusions on the effect of data streams (Ns) and the effect of transmit (Nt) and receive (Nr) antennas on spectral efficiency.

2. METHOD

Hybrid beamforming works with the foremost objective of achieving massive data rates, low delay and an energy-saving implementation. The power constraints and hardware complexities with fully digital beamforming technique is overcome with hybrid beamforming, which is essentially an integration of analog phase shifters with the digital circuitry. The hybrid beamforming architecture satisfies the two major requirements for hardware implementation in an ideal millimeter wave environment, such as: i) a separate radio frequency (RF) chain (ADCs and DACs) is not required behind each antenna element and ii) no multipath reflections. Hybrid beamforming architecture is broadly classified as: i) fully array hybrid beamforming and ii) sub array or partially connected hybrid beamforming. Every antenna element has a separate RF chain in fully connected structure, whereas the sub-array configuration has a set of array elements connected with each RF chain. The fully connected beamforming architecture (Figure 1), works as follows: i) initially, digital precoding of the user signal is done, ii) processing of the precoded signal by RF chain, and iii) once processing is complete, transmission of the processed data by means of the antenna array using a common analog beamforming unit.

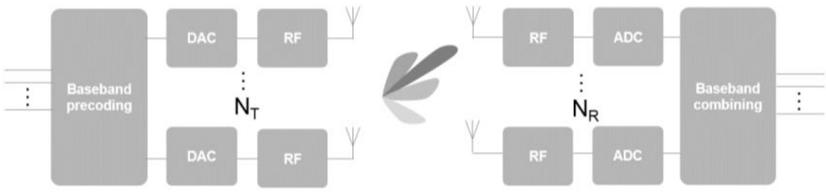


Figure 1. Fully-connected beamforming structure

The sub-connected beamforming architecture (Figure 2) works the same way as the fully connected beamforming architecture with the only difference that the signal transmission is done with a set of array elements that forms the sub-array. Although the wavelength of millimeter wave band is smaller, it is exorbitant and less practical for each element to have an individual transmit-receive (TR) module. Therefore, a single TR module is often connected to a set of array elements. This concept is the base for sub-array configuration. This configuration illustrates that TR switches, N_{TRF}, on transmit side, counts lesser than the antenna elements N_T. In this way, greater flexibility can be achieved. A similar configuration is deployed at the receiver side. The digital weights, in this configuration, are applied at each RF chain and not on each antenna element. The analog phase shifters, capable of beam steering, are used to change the phase of the signal. Thus, in this approach, beamforming is performed in both analog and digital platforms and is therefore referred to as hybrid beamforming.

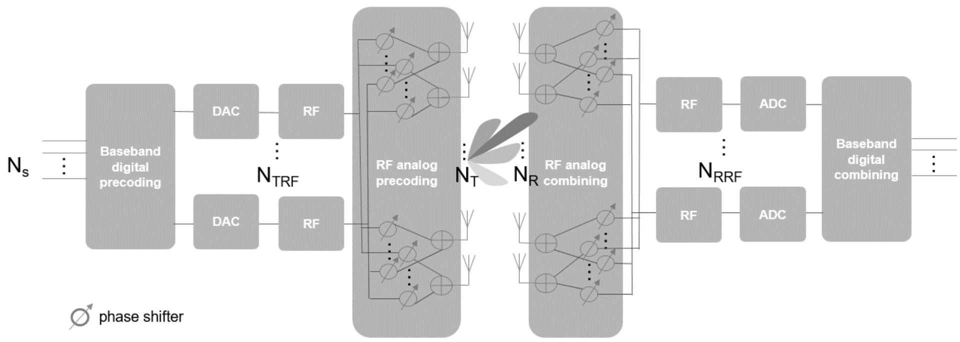


Figure 2. Sub-array configuration

2.1. System design

In fully digital beamforming system, the process can be mathematically expressed as (1):

$$|Y = (X * F * H + N) * W| \tag{1}$$

where X is an N_s-column matrix; F is an $N_s\ x\ N_t$ matrix which represents precoding weights, W is an $N_r\ x\ N_s$ matrix–representing the combining weights, N is an N_r-column matrix whose columns are the receiver noise at each element, and $Y$is an N_s-column matrix representing data streams that are recovered. Digital weights, when applied to incoming data streams, convert these streams as inputs at each RF chain. On applying analog weights containing phase shifts, the signal at each RF chain is converted to radiated signal. This can be expressed mathematically as:

$$F = F_{bb} * F_{rf} \tag{2}$$

$$W = W_{bb} * W_{rf} \tag{3}$$

where F_{bb} is an $N_s x N_{tRF}$ matrix, F_{rf} is an $N_{tRF}\ x\ N_t$ matrix, $W_{bb}$is an$N_{rRF}\ x\ N_s$ matrix and W_{rf} is a $N_r\ x\ N_{rRF}$ matrix. Achieving better spectral efficiency serves to be the main goal of the system and the computation of precoding and combining weights is therefore considered to be an optimization problem. In identifying the optimal precoding and combining weights, a few additional constraints come into effect as both F_{rf} and W_{rf} can be used to change only the phase of the signal. Ideally, the product of $F_{bb}\ x\ F_{rf}$ and $W_{bb}\ x\ W_{rf}$ can therefore be considered as approximations of F and W, without any additional restrictions. Orthogonal matching pursuit (OMP) algorithm is used for computing the sub-optimal weights since optimization of all four matrix variables (F_{bb}, F_{rf}, W_{bb}, and W_{rf}) is a tedious task. The OMP algorithm is first used for deriving the precoding weights. After computing the precoding weights, the corresponding combining weights are then obtained using the result.

2.2. Orthogonal matching pursuit (OMP) algorithm

The orthogonal matching pursuit (OMP) algorithm as shown in Algorithm 1 and 2 proposed in paper [15] is used for computing the hybrid weights. It first computes the precoding weights and then the result is used for computing the combining weights. This algorithm derives the sub-optimal solution to the problem of sparse signal representation. This method is used for sparse-signal recovery. The term “sparse” refers to a signal with fewer non-zero entries. The OMP algorithm is an iterative one that selects the best fitting column of the sensing matrix at each step. Best-fitted column is then added to the set of columns selected. The observations are projected onto the linear subspace comprises of the selected columns; the algorithm is then iterated. The simplicity of the OMP algorithm and its implementation speed are the major advantages thrown by this algorithm compared to other methods.

Algorithm 1. RF and baseband precoding via orthogonal matching pursuit (OMP) [15]

Require: F_{opt}

1. F_{RF} =Empty Matrix
2. $F_{res} = F_{opt}$
3. for i≤ $N_t^{RF} do$
4. $\psi = A_t^* \ F_{res}$
5. k = arg $max_{l=1,\dots,N_{cl}N_{ray}}(\psi\psi^*)_{l,l}$
6. $F_{RF} = [F_{RF}|A_t^{(k)}]$, $F_{BB} = (F_{RF}^* F_{RF})^{-1} F_{RF}^* F_{opt}$, $F_{res} = \frac{F_{opt} - F_{RF}F_{BB}}{||F_{opt} - F_{RF}F_{BB}||_F}$
7. end for
8. $F_{BB} = \sqrt{N_s} \frac{F_{BB}}{||F_{RF}F_{BB}||_F}$
9. return F_{RF},F_{BB}

Algorithm 2. RF and baseband combining via orthogonal matching pursuit (OMP) [15]

Require: W_{MMSE}

1. W_{RF} =Empty Matrix
2. $W_{res} = W_{MMSE}$
3. for i ≤ $N_t^{RF} do$
4. $\psi = A_r^* E[yy^*] \ W_{res}$, k = arg $max_{l=1,\dots,N_{cl}N_{ray}}(\psi\psi^*)_{l,l}$
5. $W_{RF} = [W_{RF}|A_r^{(k)}]$, $W_{BB} = (W_{RF}^* E[yy^*] W_{RF})^{-1} W_{RF}^* E[yy^*] W_{MMSE}$
6. $W_{res} = \frac{W_{MMSE} - W_{RF}W_{BB}}{||W_{MMSE} - W_{RF}W_{BB}||_F}$
7. end for
8. return

2.3. Coordinated multi-point technique (CoMP)

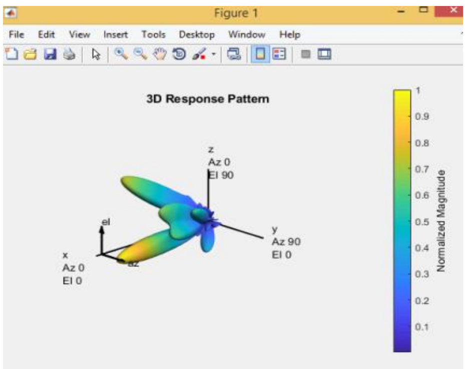
Coordinated multi-point is a downlink/uplink technique to procure effective network performance by improving throughput at cell edges and overall capacity of system. The conceptual aspects of beamforming and multiple-input multiple-output (MIMO) are used in this technique to not only improve system capacity but also data rate and reliability of link. When the mobile is located in an area with interference, the cell performance is improved between cells operating in the same frequency band by the use of CoMP technique. Three different CoMP strategies in downlink direction are entailed with different complexity levels and requirements: i) coordinated scheduling/beamforming (CS/CB), ii) dynamic point selection (DPS)/muting, and iii) joint transmission (JT). CoMP based mechanisms for uplink direction are: i) joint reception (JR) and ii) coordinated scheduling (CS/CB). Phase synchronization is required among transmission point/eNodeBs (TPs/eNBs) for joint transmission and DPS mechanisms (in downlink) and JR mechanism (in uplink). Four hybrid beamforming schemes have been explored in the literature-one with no coordination among transmission points and three of them based on CS/CB [8], namely: i) no tp coordination among cells (baseline case), ii) leakage-suppressing and signal-maximizing precoding (LSP), iii) SLNR-based precoding, and iv) generalized maximum-ratio pecoding. The next HBF scheme that works based on CS/CB is the generalized maximum-ratio pecoding (GMR) based precoding. This scheme is the same as SLNR-based approach with respect to RF and baseband precoding and combining process. It is to be noted that this scheme holds good only if $N_T^{RF}=N_S$ and doesn't work well in other cases due to mismatch in matrix dimensionality. From literature it is evident that that SLNR scheme improves the SE by 67% compared to non-CoMP case. So, the CoMP technique leveraging SLNR based precoding is preferred for improving the spectral efficiency of 5G mmWave multi-cell networks.

2.4. Channel model

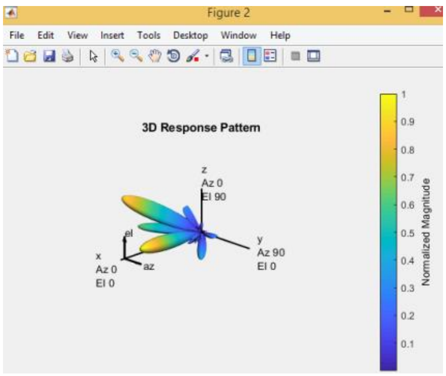
The choice of a particular channel model is essentially a tradeoff between the fidelity of the model and its computational efficiency. Two of the channel models contemplated to be the most promising and popular models for the next generation 5G communication systems are 3GPP TR 38.901 release 14 channel model and NYUSIM model developed by New York University. These two models differ in their modeling approaches including path loss, line of sight (LOS) probability and clustering. NYUSIM channel model generates results extensively based on the statistical data obtained from real-time measurements in New York and is not an open-access model. Therefore, this paper focuses on the standardized TR 38.901 release 14 channel model developed under 3rd generation partnership project (3GPP). Simulations are performed based on the 3GPP model to examine the spectral efficiency achieved using SLNR based CoMP technique and system-level performance of 5G mmWave wireless system is evaluated. Sun *et al*. [22] explained the SLNR based scheme achieves 67% higher spectral efficiency compared to non-CoMP case.

3. RESULTS AND DISCUSSION

For 5G system, spectral efficiency is a significant performance metric. As discussed earlier, a comprehensive analysis is conducted to understand the effect of N_s and N_t on the spectral efficiency of 5G mmwave multi-cell networks. The simulation is carried out using optimal weights and hybrid weights. This simulation is carried out with the antenna array connected in sub-array configuration. The number of RF chains, N_{tRF} and N_{rRF} is assigned to be 4 and this model assumes the scattering environment with scattering clusters, N_{cl}=6 and the number of rays or scatterers per cluster is taken to be N_{ray}=10. Figure 3 shows the beam pattern response obtained. Figures 3(a) and 3(b) illustrates that for constant values of N_t=64 and N_r=16, the radiation pattern using hybrid weights is highly directional (desirable) compared to that of optimal weights for (N_s= 4).



(a)



(b)

Figure 3. Beam pattern obtained for Nt=64 and Nr=16 is (a) using optimal weights and (b) using hybrid weights

3.1. Effect of varying the number of data streams on spectral efficiency

In the first set of analysis, the $N_t$and N_r is kept constant, whereas the number of data streams is varied from 1 to 4 and its effect on spectral efficiency (SE) is observed. Table 1 shows the observations obtained for optimal weights and hybrid weights. For both cases, the SNR is varied from -40 dB to 0 dB with a step increase of 5 dB. The simulated results indicate that as the number of data stream (Ns) increases (with Nt and Nr constant), the spectral efficiency increases for increasing values of SNR. Comparing the results, it is observed that the hybrid weights produce results in par with optimal weights in terms of Spectral Efficiency. Thus, hybrid beamforming is a preferred choice since optimal results are obtained with reduced hardware.

Table 1. Spectral efficiency obtained using optimal weights and hybrid weights for N_t=64, N_r=16

SNR (dB)	Spectral Efficiency (bits/s/Hz) using Optimal Weights				Spectral Efficiency (bits/s/Hz) using Hybrid Weights			
	Ns=1	Ns=2	Ns=3	Ns=4	Ns=1	Ns=2	Ns=3	Ns=4
-40	0.0842	0.0599	0.0518	0.0499	0.1066	0.0870	0.0725	0.0616
-35	0.2646	0.1932	0.1548	0.1575	0.3220	0.2705	0.2268	0.1925
-30	0.6671	0.5436	0.4616	0.4574	0.8173	0.7730	0.6763	0.5896
-25	1.5105	1.4429	1.2644	1.2614	1.7420	1.9230	1.8155	1.6563
-20	2.6848	2.9474	2.7702	2.8681	2.9972	3.8648	4.0371	3.8865
-15	4.2797	5.5692	5.6670	5.6425	4.6316	6.7281	7.7540	8.1353
-10	5.8842	8.5735	9.4779	9.5100	6.2306	9.8291	12.147	13.595
-5	7.5597	11.741	13.844	14.076	7.9255	13.076	16.967	19.775
0	9.1885	15.063	18.706	19.763	9.5557	16.432	21.951	26.423

Comparing the spectral efficiency obtained using optimal weights for 0 dB SNR, it is observed that spectral efficiency increases from 9.5557 (bits/s/Hz) to 26.423 (bits/s/Hz) when the number of data streams is increased from Ns=1 to Ns=4. Similar comparison shows that using hybrid weights for 0 dB SNR, the spectral efficiency is increased from 9.1885 (bits/s/Hz) to 19.763 (bits/s/Hz) when the number of data streams is varied from N_s=1 to N_s =4. This effect of data streams on spectral efficiency is depicted in Figure 4. For all the four cases it is observed that hybrid weights produce results closer to optimal weights and a significant improvement in Spectral efficiency is achieved by increasing the number of data streams.

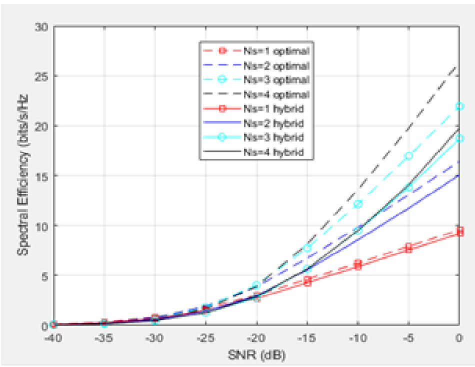


Figure 4. Effect of number of data streams on spectral efficiency for N_s= [1, 2, 3, 4]

3.2. Effect of increasing the number of transmit antennas on spectral efficiency

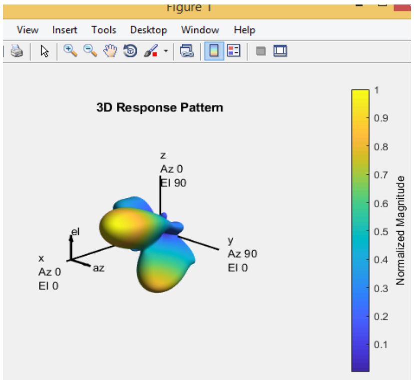
In the second set of analysis, the effect of the number of transmitting antennas on spectral efficiency is studied. Initially the number of receiving antennas N_r is fixed as 16 and the number of transmitting antennas is increased to study the effect of transmitting antennas on spectral efficiency (SE). The SNR is varied from -40 dB to 0 dB and the corresponding spectral efficiency obtained using optimal weight for two casese N_t=16 and N_t=64 is recorded in Table 2. Observations are made for four different values of N_s (1,2,3,4). When the number of transmit antennas is increased from 16 to 64 for 0 dB SNR and Ns=4, the spectral efficiency significantly increases from 17.735 (bits/s/Hz) to 26.423 (bits/s/Hz) for optimal weights. The simulations are repeated using hybrid weights and the results obtained are recorded in Table 3. From the table it is clear that, when the number of transmit antennas is increased from 16 to 64 for 0 dB SNR and Ns =4, the spectral efficiency significantly increases from 13.750 (bits/s/Hz) to 19.763 (bits/s/Hz) for hybrid weights. Thus, it is observed that when the number of transmitting (N_t) antennas is increased (with fixed N_r), the spectral efficiency increases significantly. Figure 5 shows the beam pattern obtained using optimal weights. Figure 5(a) shows the beam pattern obtained using optimal weights with 16 transmit antennas and 16 receive antennas [N_t=16, N_r=16] N_s=4. Figure 5(b) shows the beam pattern obtained using optimal weights with 64 transmit antennas and 16 receive antennas [N_t=64, N_r=16] for N_s=4. From the figures, it can be clearly observed that the beam pattern is highly directional for N_t=64 compared to N_t=16. Thus, increasing the number of transmit antennas increases the directivity of the beam pattern in turn. Figure 6 shows the beam pattern obtained using hybrid weights. Figure 6(a) shows the beam pattern obtained using hybrid weights with 16 transmit antennas and 16 receive antennas [N_t=16, N_r=16] for the number of data streams, N_s=4.

Table 2. Spectral efficiency obtained using optimal weights

SNR	Spectral Efficiency (bits/s/Hz) for N_t=16, N_r=16				Spectral Efficiency (bits/s/Hz) for N_t=64, N_r=16			
(dB)	N_s=1	N_s=2	N_s=3	N_s=4	N_s=1	N_s=2	N_s=3	N_s=4
-40	0.0415	0.0304	0.0224	0.0176	0.1066	0.0870	0.0725	0.0616
-35	0.1315	0.1003	0.0740	0.0579	0.3220	0.2705	0.2268	0.1925
-30	0.3837	0.3012	0.2268	0.1794	0.8173	0.7730	0.6763	0.5896
-25	0.9164	0.8256	0.6514	0.5237	1.7420	1.9230	1.8155	1.6563
-20	1.8562	1.9671	1.6571	1.3863	2.9972	3.8648	4.0371	3.8865
-15	3.3573	4.1661	3.9055	3.4665	4.6316	6.7281	7.7540	8.1353
-10	4.8292	6.8073	7.1610	6.8757	6.2306	9.8291	12.147	13.595
-5	6.5840	10.0883	11.505	11.826	7.9255	13.076	16.967	19.775
0	8.1846	13.3999	16.331	17.735	9.5557	16.432	21.951	26.423

Table 3. Spectral efficiency obtained using hybrid weights

SNR	Spectral Efficiency (bits/s/Hz) For N_t=16, Nr=16				Spectral Efficiency (bits/s/Hz) For N_t=64, Nr=16			
(dB)	N_s=1	N_s=2	N_s=3	N_s=4	N_s=1	N_s=2	N_s=3	N_s=4
-40	0.0336	0.0221	0.0166	0.0150	0.0842	0.0599	0.0518	0.0499
-35	0.1101	0.0729	0.0553	0.0508	0.2646	0.1932	0.1548	0.1575
-30	0.3152	0.2154	0.1630	0.1529	0.6671	0.5436	0.4616	0.4574
-25	0.7742	0.5974	0.4703	0.4295	1.5105	1.4429	1.2644	1.2614
-20	1.6214	1.4875	1.2084	1.1397	2.6848	2.9474	2.7702	2.8681
-15	3.0622	3.3508	2.9100	2.7215	4.2797	5.5692	5.6670	5.6425
-10	4.5333	5.7572	5.4789	5.2128	5.8842	8.5735	9.4779	9.5100
-5	6.2574	8.9510	9.3061	8.9812	7.5597	11.741	13.844	14.076
0	7.8547	12.1836	13.872	13.750	9.1885	15.063	18.706	19.763



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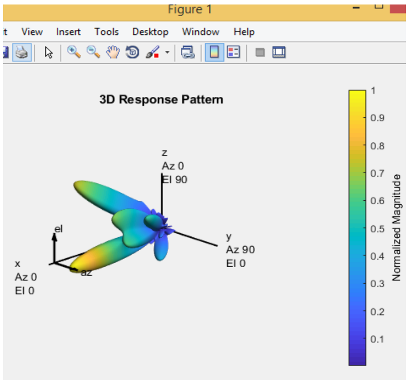
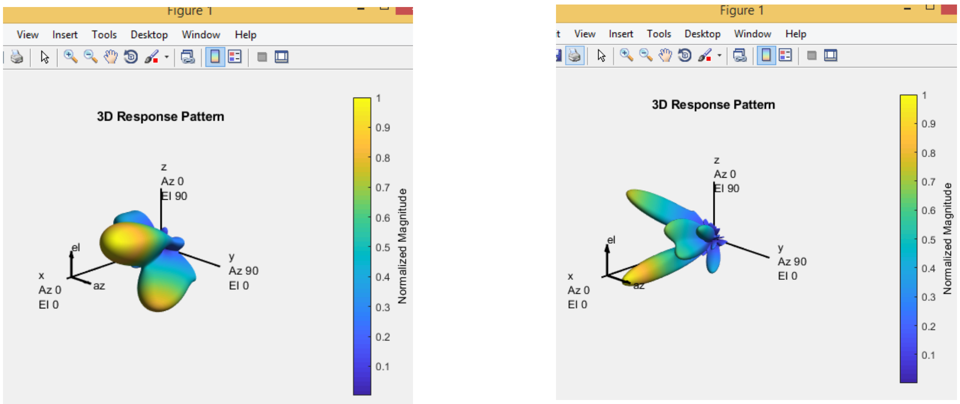


(b)

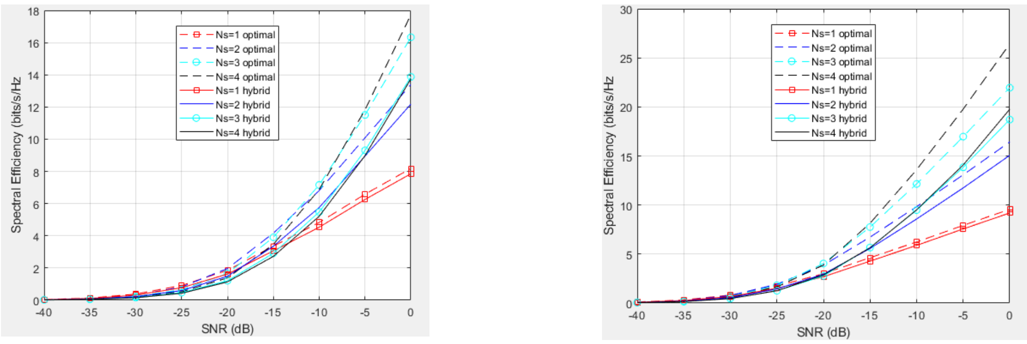
Figure 5. Radiation pattern obtained using optimal weights: (a) N_t= 16; N_r=16 and (b) N_t= 64; N_r=16

Figure 6(b) shows the beam pattern obtained using hybrid weights with 64 transmit antennas and 16 receive antennas [N_t=64, N_r=16] for N_s=4. From the beam patterns obtained, it can be clearly observed that the beam pattern is highly directional for N_t=64 compared to N_t=16. Thus, increasing the number of transmit antennas increases the directivity of the beam pattern in turn for both optimal weights and as well as hybrid weights. Figure 7 depicts the spectral efficiency curves obtained using optimal weights and hybrid weights. Figure 7(a) shows the spectral efficiency obtained with 16 transmit antennas and 16 receive antennas [N_t=16 & N_r=16] for 4 different values of $N_{s=}$[1,2,3,4]. Figure 7(b) shows the spectral efficiency curves obtained using optimal weights and hybrid with 64 transmit antennas and 16 receive antennas [N_t= 16 & N_r=16] for 4 different values of N_s=[1,2,3,4]. The following observations are made from the figure: i) spectral efficiency obtained hybrid weights is in par with the spectral efficiency obtained using optimal weights. Thus, using hybrid beamforming comparative results are obtained with reduced hardware making it a preferred choice, ii) The second observation that can be observed is that as the number of data streams is increased the spectral efficiency also increases.



(a) (b)

Figure 6. Radiation pattern obtained using hybrid weights: (a) Nt=16; Nr=16 and (b) Nt= 64; Nr=16



(a) (b)

Figure 7. Spectral efficiency obtained using optimal weights and hybrid weights with: (a)Nt=16 and Nr=16; and (b) Nt= 64 and Nr=16

4. CONCLUSION

In this paper, we have made a comprehensive analysis on the significance of hybrid beamforming in alleviating inter-cell interference-the most dominant one in multi-cell networks. Two significant analyses are carried out viz, i) the effect of number of data streams (Ns) on spectral efficiency and ii) the effect of transmit antennas (N_t) antennas on spectral efficiency. Based on the the observed results the following inferences are made: i) With the increasing number of data streams, the spectral efficiency displays a significant improvement for increasing values of SNR (with $N_t$and N_r kept constant). No significant changes are observed in the beam pattern response for both optimal and hybrid weights as N_t and N_r does not vary in this case. The count of data streams is varied from Ns=1 to Ns=4 with N_t and N_r being constant (N_t =64, N_r=16), the spectral efficiency increases from 9.5557 bits/s/Hz to 26.423 bits/s/Hz and from 9.1885 bits/s/Hz to 19.763 bits/s/Hz for optimal weights and hybrid weights, respectively, for 0 dB SNR; and ii) The second observation reveals that when the number of transmit antennas are increased the spectral efficiency obtained also increases for both optimal and hybrid weights. A highly directional beam pattern response is observed for the different antenna configurations on transmit and receive side. When the count of transmit antennas is increased from N_t =16 to N_t=64 for 0 dB SNR, with N_r=16 and N_s=4, the spectral efficiency increases from 17,735 bits/s/Hz to 26,423 bits/s/Hz and 13,750 bits/s/Hz to 19,763 bits/s/Hz for optimal weights and hybrid weights, respectively, which implies that the performance of hybrid weights is closer to that of optimal weights with reduced hardware. It can be noted from the above two observations that the spectral efficiency has a direct relationship with the signal to noise ratio (SNR). More sophisticated algorithms can be investigated for the computation of hybrid beamforming weights in the future.

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