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Minimization of Fading Effect through Novel Method of Beamforming for NGN Wireless Systems

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Abstract—**This paper describes a novel multipath fading effect minimization technique through a novel method of Beamforming algorithm. RMS Delay Spread (RDS) of a channel is highly dependent on beamwidth of deployed antenna systems. Deep fade, which is a bottle neck for high speed wireless networks, causes larger RDS and higher bit error rate (BER). A frequency flat fading channel can trasmit data with smaller RDS and higher bit rate. RDS is reduced if the beamwidth of deployed antenna system becomes narrower. Binomial array and Dolph-Chebyshev array are popular methods of array antenna beamforing, though each of these methods has its own technical limitations. The method of Beamforming described in the paper is technically better which uses a novel concept of Fractional-Powered Binomial coefficients. The method performs better than Binomial and Dolph-Chebyshev array. Superiority of the described method is validated through simulations of realistic antennas and technical analysis of RDS.**

Index Terms— **Antenna radiation patterns; Bit error rate; Channel models; Fading; Next generation networking; Rayleigh channels; Rician channels; Radio propagation;**

I. Introduction

Some of the bottlenecks for next generation networking (NGN) wireless systems (e.g. 5G) are increased number of devices with increased energy consumption, increasingly crowded environment with high rise buildings, requirement of very high speed data channels, shortage of spectrum, and mobility issues. Some goals of 5G systems are:

a. 100 Mbps throughputs;
b. Extremely low latency (1 msec or less), ten times lower than 4G;
c. Data rate at least ten times higher than that of 4G;
d. Use of higher frequencies (30 GHz and above);
e. Wider channel bandwidth (1 to 2 GHz, or even wider).

In a wireless communication system with multipath fading channels, different versions of transmitted signal at the receiver spread in time. This phenomenon is called delay spread. Delay spread can be characterised by Power Delay Profile (PDP) of a channel. PDP is the measure of time distribution of the received signal power when an impulse signal is transmitted through a channel. A time dispersive channel can be characterized by RMS Delay Spread (RDS). RDS is a measure of how the multipath power in a channel is spread over the delay. RDS depends on several factors such as propagation channel, shadowing, types of antennas, polarization, and array signal processing techniques. Channel modelling is required for different purposes of wireless communication systems [1]. Performance evaluation of Long Term Evaluation (LTE) network is done in [2]. Performance evaluation of LTE Rayleigh fading and pedestrian channels are reported in [3]. Another important parameter that describes the channel characteristics is the Rician K-factor. K is the ratio of power through the line of sight (LOS) component to those of other scattered components [4]-[5]. Channels can be classified as Rician or Rayleigh fading channels based on RDS and K-factors [6]-[8]. Rician K depends on several channel factors and beamwidth of antenna system [4]-[5]. Generally higher K-factors and lower RDS represent frequency-flat Rician channels. On the other hand lower K-factors and higher RDS represent frequency selective Rayleigh fading channels. Frequency flat channel is better in terms of higher bandwidth and lower bit error rate (BER).

A channel can be considered as Rician channel if the Rician- $K \geq 0$ dB [9]. Antennas with narrower beamwidth result in higher K-factor [9]. RDS of a channel is also highly dependent on beamwidth of antenna radiation pattern. RDS can be minimized by using high gain antennas [10] with narrower beamwidth. High gain antenna for LTE and 5G system is discussed in [11]. Rician-K of a wireless channel can be expressed [4], [5], [12] as:

$$K \cong F_s F_h F_B K_0 d^{\gamma} \quad (1)$$

where,
F_s is the seasonal factor;
F_h is height factor (meter);
F_B is the beamwidth factor which can be expressed as [4]-[5]:

$$F_B = \left(\frac{B}{17}\right)^{-0.62} \quad (2)$$

B is the beamwidth in degrees;
d is distance in kilometres;
K_0, γ are constants.
The values of K_0 and γ are reported as 10 dB and -0.5 dB in [5].

Equation (2) states that Rician-K depends on beamwidth of antenna system. Antennas with lower beamwidth give rise to higher K-factors. Bit rate decreases and inter-symbol-interferences (ISI) increases with increased RDS and decreased K-factors. Fig. 1 shows a plot of F_B vs. beamwidth for different values of beamwidth. It can be inferred from (1), (2) and Fig. 1 that a channel with lower K-factor can be transformed into a channel with higher K-factor by using antennas with reduced beamwidth.

In an antenna system, weightings of antenna elements are adjusted to achieve maximum transmission/ reception in a desired direction by rejecting interfering signals in other directions. In order to ensure a robust and power efficient wireless communication system, propagating signal from antenna should have narrower beamwidth and negligible side lobe levels (SLL). Beamwidth-SLL trade-off can be optimized [13] through optimization of antenna excitation coefficients. There exists different types of power distributions of array antennas. Some of the non-uniform amplitude distributions of array antenna, those can produce lower SLL (at the cost of

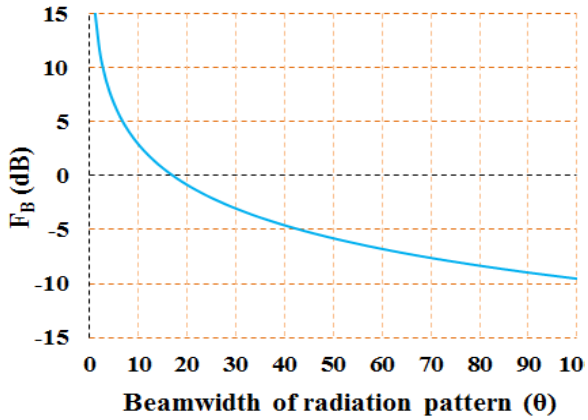

Fig. 1. Beamwidth factor vs. beamwidth of antenna radiation pattern.

wider beamwidth), are Binomial distribution [14]-[15], Dolph-Chebyshev distribution [14], and Gaussian distribution [16]-[17]. Array antenna with Binomial excitation coefficients does not produce any SLL with element spacing 0.5λ or less [14]-[15]. Coefficients of an N-element Binomial array can be calculated as [14]-[15]:

$$1, N-1, \frac{(N-1)(N-2)}{2!}, \ldots\ldots\ldots\ldots.. \quad (3)$$

This paper describes a minimization technique of multi-path fading effects through a novel concept of Fractional-Powered Binomial Array (FPBA) [15]. The novel FPBA is better than popular Dolph-Chebyshev or Binomial array from the perspective of beamwidth-SLL trade off [15]. The paper is organized in the following way. Section II compares the radiation parameters of Binomial array, Dolph-Chebyshev array and FPBA considering different number of isotropic antenna elements and different set of excitation coefficients. Section III analyses the radiation parameters of FPBA with realistic antennas (e.g. microstrip patches). Section IV describes the effect of frequency flat and frequency selective fading channels on RDS. Finally, section V concludes the paper.

II. Analysis of Excitation Coefficients and Radiation Patterns For Different Array Distribution

In this section a comparative analysis of radiation patterns for Binomial array, Dolph-Chebyshev array and the proposed FPBA [15] is made by using different set of excitation coefficients and number of antenna elements. Effect of different main beam steering angle on radiation patterns is also investigated. Binomial and Dolph-Chebyshev array antennas have some limitations. Beamwidth of Binomial array is the widest. Widest main beam will result in maximum power loss in some wireless applications. Magnitudes-variation of Binomial array is also too wide which can lead to an impractical implementation of power amplifier at the output stage of transmitter. Too wide variation of amplifier output causes non-linearity of the system. Though element spacing of $\leq 0.5\lambda$ increases mutual coupling effects, Binomial array does not produce any SLL when element spacing of $\leq 0.5\lambda$ is used [14]. Another problem with Binomial array is the increase of SLL when element spacing becomes higher than $0.5\ \lambda$. Mutual coupling effects can be minimized with element spacing of $\geqslant 0.6\lambda$ and will be discussed further in section III.

Beamwidth of Binomial array can be reduced further by using excitation coefficients according to FPBA [15]. Instead of using Binomial coefficients of (3), following FPBA excitations coefficients can be used [15]:

$$1^{\beta}, (N-1)^{\beta}, \left[\frac{(N-1)(N-2)}{2!}\right]^{\beta}, \quad (4)$$

β in (4) is a variable within the range $0 < \beta < 1$.

Coefficients of (4) can reduce beamwidth and 'wide-variation of excitation coefficients of convention Binomial array'. FPBA becomes Binomial array when β is set to 1. Following sub-sections describe radiation patterns of FPBA, Binomial array, and Dolph-Chebyshev array for different cases of number of antenna elements, main beam steering angle, and different sets of excitation coefficients. Isotropic element spacing for all cases was chosen as 0.6λ (for 60 GHz system).

A. Excitation Coefficients and Radiation Patterns for 25-elements Array (MSLL=20 dB)

Fig. 2 shows the relative excitation coefficients (dB) for Binomial array, 20 dB Dolph-Chebyshev array, and FPBA ($\beta = 0.07$). The number of elements for each of these three distributions was 25. Fig. 2 shows that reverse tapering occurs in case of Dolph-Chebyshev array which may lead to technical difficulties. Fig. 3 shows the radiation patterns for the respective distributions.

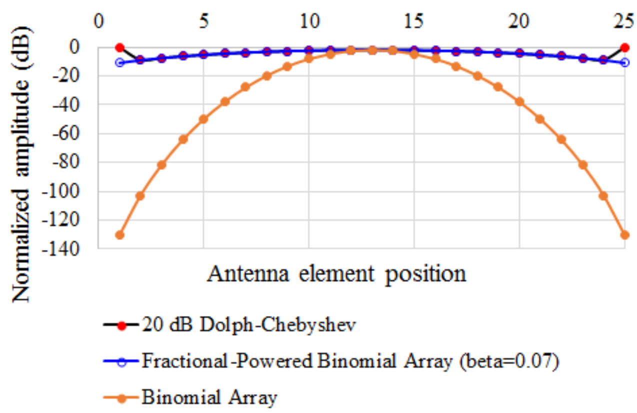

Fig. 2. Excitation coefficients of 25 antenna elements for 20 dB Dolph-Chebyshev, Binomial, and Fractional-powered-Binomial array (**$\beta = 0.07$**).

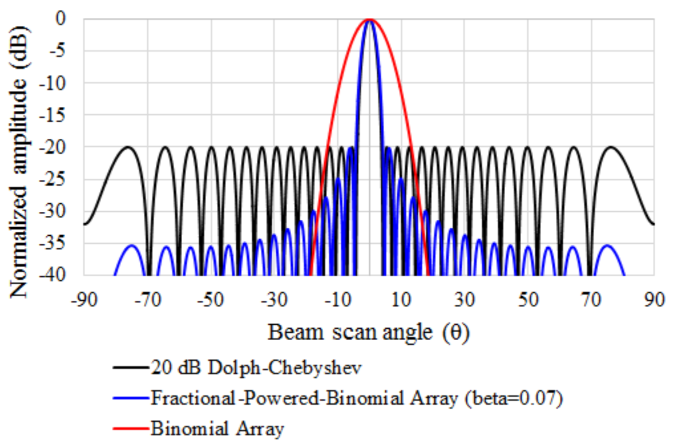

Fig. 3. Radiation patterns of 20 dB Dolph-Chebyshev array, Binomial array and FPBA at **0°** beam steering angle (respective excitation coefficients are shown in Fig.2.)

Fig. 3 shows that the main beamwidth is the highest in case of Binomial array. First Null Beamwidth (FNBW) are same in case of Dolph-Chebyshev array and FPBA ($\beta = 0.07$). Maximum SLL (MSLL) are also same in case of Dolph-

Chebyshev array and FPBA (-20 dB in this case). Though other SLLs of FPBA are lower than those of Dolph-Chebyshev array. Fig. 4 shows the radiation patterns for the respective distributions and at 30° beam steering angle. FPBA also shows the best performance along this 30° direction.

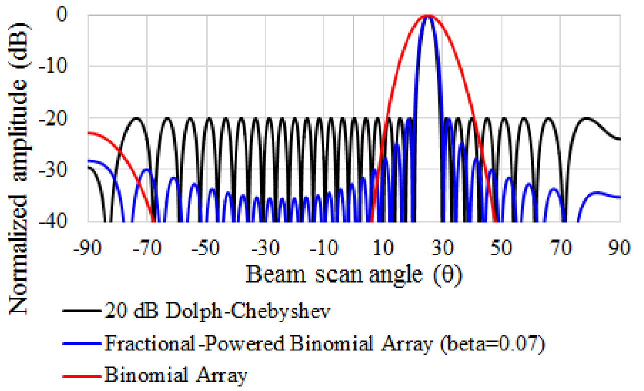

Fig. 4. Radiation patterns of 20 dB Dolph-Chebyshev array, Binomial array and FPBA($\boldsymbol{\beta = 0.07}$) at **30°** beam steering angle (respective excitation coefficients are shown in Fig.2.)

B. *Excitation Coefficients and Radiation Patterns for 45-elements Array (MSLL =40 dB)*

Fig. 5 shows the excitation coefficients for 45-element Dolph-Chebyshev array (40 dB), and 45-element FPBA ($\beta =$ 0.11). Fig. 6 shows the corresponding radiation patterns. In this case, main beam direction was at 35° from array broad side. Fig. 5 and Fig. 6 show that FPBA is also technically better than Dolph-Chebyshev array for higher number of antenna elements with lower MSLL. It was shown in [15] that GL appears with 8-element FPBA/Dolph-Chebyshev array when main beam angle is greater than 25°. Therefore number of antenna elements is a deciding factor for larger beam steering angle without any GL.

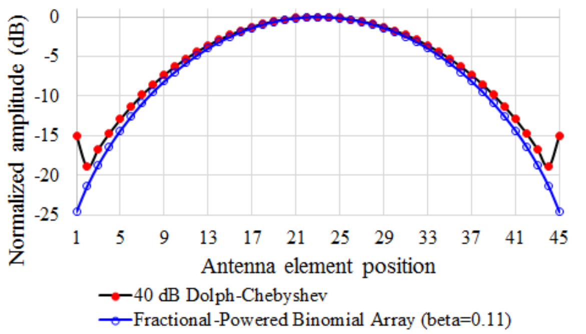

Fig. 5. Excitation coefficients of 45 antenna elements for 40 dB Dolph-Chebyshev array and FPBA ($\boldsymbol{\beta = 0.11}$). Respective radiation patterns are shown in Fig. 5.

From the above analysis of radiation patterns it is evident that FPBA is better than Dolph-Chebyshev array when SLL and excitation coefficients are compared. FPBA does not produce any reverse tapering. It is technically difficult to implement reverse tapering. Though Binomial array does not produce any SLL in some cases, the main beamwidth is the widest in this case. Directivities of FPBA are also higher than those of Dolph-Chebyshev arrays. The reason of these higher directivities are the lower SLL of FPBA. Higher directivities imply higher received power and lower RDS. Table I summarizes the radiation parameters for Dolph-Chebyshev array and FPBA.

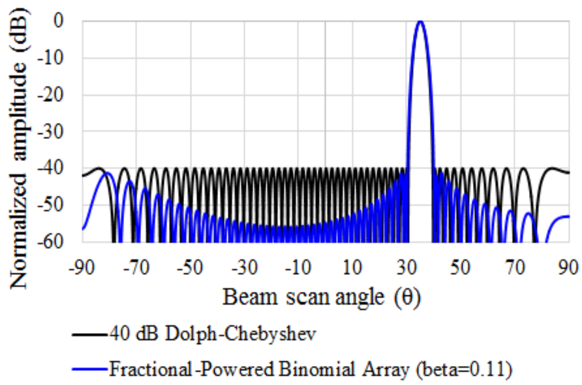

Fig. 6. Radiation patterns of 40 dB Dolph-Chebyshev array and FPBA ($\boldsymbol{\beta = 0.11}$) at **35°** beam steering angle (respective excitation coefficients are shown in Fig.5.)

III. Radiation Patterns of FPBA With Realistic Patch Antenna Elements

Radiation patterns of isotropic antennas [15] and those of realistic antennas are not the same due to some technical reasons. In this section analysis of radiation patterns of FPBA is done considering realistic antenna elements. Both rectangular and circular Microstrip patch elements were considered for the analysis of the radiation patterns, directivities, and the mutual coupling effects. Different inter-element spacing within the range 0.25 cm~0.37 cm (0.5λ~0.74λ) was considered for 60 GHz arrays. Antenna elements were placed along the X-axis (Fig. 7) in PCAAD simulation software. Effects of both X-axis polarization and Y-axis polarization were investigated. Fig. 8 shows the directivity versus 'inter-element spacing' graphs of rectangular and circular patch arrays. Total number of antenna elements was 8 in each case. It is noteworthy to mention here that in [15] only the isotropics cases of 8-element FPBA were investigated.

It is well known that the directivity decreases with the increased mutual coupling effect. On the other hand, directivity increases with increased inter-element spacing. Graphs of Fig. 8 also verify that the directivity increases with increased inter-element spacing of realistic antennas. Fig. 9 shows the radiation patterns of 8-element array (β=0.68) with different polarization. Some of the parameters of patch elements and radiation patterns are summarized in Table II. It is noteworthy to mention here that the Half-Power Beamwidth (HPBW) and MSLL for the FPBA (β=0.68; element spacing 0.6λ) were respectively 16° and – 50 dB when isotropic elements were considered (not shown in the figure). Simulation results show that circular patch array (both X and Y polarizations) is better than rectangular patch array in terms of directivity, HPBW and SLL. Results of Table II also suggest that the mutual coupling effect is less in case of circular patches. Radiation parameters of Table II verify that the FPBA is better than Binomial or Dolph-Chebyshev array even when practical antenna shapes are considered.

IV. RMS Delay Spread vs. Fading Channels

Results of sections II-III show that FPBA is better than Binomial or Dolp-Chebyshev array, particularly in terms of directivity, SLL, and beamwidth. It was discussed in previous

TABLE I
COMPARISON OF RADIATION PARAMETERS FOR DOLPH-CHEBYSHEV AND FRACTIONAL-POWERED BINOMIAL ARRAYS (ISOTROPIC CASE)

Types of excitation	Number of elements	Element spacing	Directivity (dB)	FNBW (deg.)	MSLL (dB)
Dolph-Chebyshev array	25	0.6 λ	14.16	8.8	-20
	45	0.6 λ	16.60	8	-40
FPBA	25	0.6 λ	**15.10**	8.8	-20
	45	0.6 λ	**17.11**	8	-40

TABLE II
COMPARISON OF DIFFERENT RADIATION PARAMETERS OF FRACTIONAL-POWERED BINOMIAL ARRAY (FPBA) WITH RECTANGULAR AND CIRCULAR PATCH ELEMENTS (TOTAL ELEMENTS = 8).

Patch Type	Dimensions	Element spacing (cm)	Polarization	Directivity (dB)	HPBW (deg.)	MSLL (dB)
Rectangular	0.2×0.2 cm^2	0.31	X	15.1	15.43	-48
		0.31	Y	15.1	15.44	-48.3
Circular	Radius = 0.2 cm	0.31	X	**16.2**	**14.82**	**-53**
		0.31	Y	**16.7**	**15.23**	**-50.7**

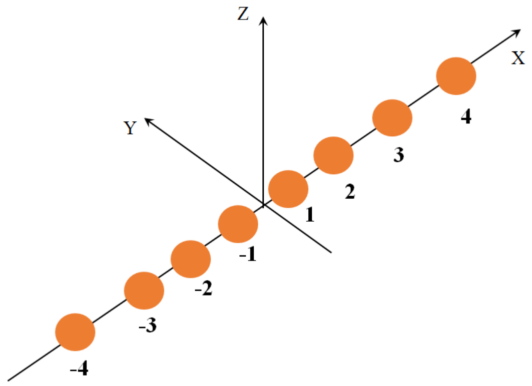

Fig. 7. Element position (x) of array antenna.

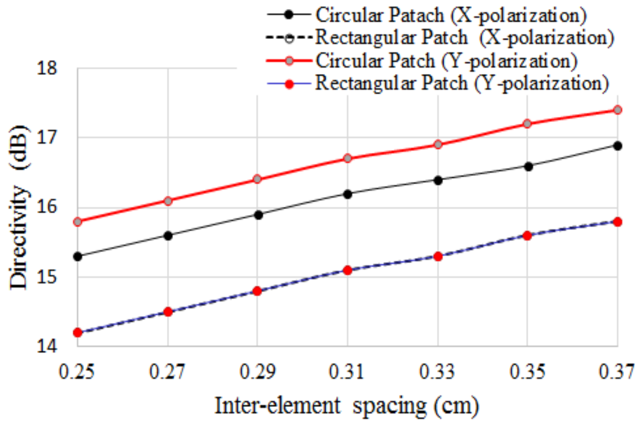

Fig. 8. Directivities of FPBA (β = 0.68) with rectangular and circular patch elements and for different polarization.

sections that narrorwer beamwidth of antenna radiation pattern gives rise to lower RDS (higer Rician-K) in a multipath fading channels [12]. The effect of fading on RDS will be investigated in this section. RDS of a channel can be defined as [12], [18]:

$$RMS\ delay\ spread\ (RDS)\ ,\ \sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \qquad (5)$$

$$\text{where } \bar{\tau} = mean\ ecess\ delay\ = \frac{\sum_k^N a_k^2 \tau_k}{\sum_k^N a_k^2} = \frac{\sum_k^N P(\tau_k)\tau_k}{\sum_k^N P(\tau_k)} \qquad (6)$$

$$\text{and} \quad \overline{\tau^2} = \frac{\sum_k^N a_k^2 \tau_k^2}{\sum_k^N a_k^2} = \frac{\sum_k^N P(\tau_k)\tau_k^2}{\sum_k^N P(\tau_k)} \qquad (7)$$

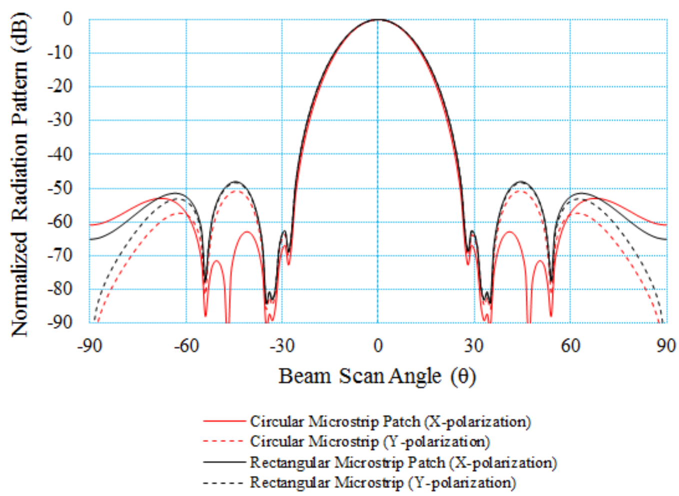

Fig. 9. Radiation patterns (E-θ plane) of FPBA (β = 0.68) with different polarizations and patch shapes (element spacing 0. 31 cm).

In (6),(7), and (8):
N: Total multipath components;
$P(\tau_k)$: power of the k-th multipath component;
τ_k: time of arrival of the k-th multipath component;

Delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$. Equations (6)-(8) do not rely on absolute power level of $P(\tau)$, but only on the relative amplitudes of multipath components with in $P(\tau)$. Delay spread is highly dependent on beamwidth of antenna radiation pattern [12]. About 6 ns RDS is found in a residential environment, though it can be reduced to 1 ns by using high gain antennas [10], [12].

The nature (Rayleigh or Rician) of a fading channel can be predicted from RDS and K-factor of the respective channel [9], [12]. Higher RDS with lower K-factor suggests that the channel is a Rayleigh channel; on the other hand lower RDS with higher K-factor suggests that the channel is a Rician channel [9], [12]. IEEE 802.11b Task Group has adopted an indoor channel model that follows an exponential power delay profile [12]. Fig.

10 and Fig. 11 show the simulation results of average channel power distributions and frequency response of an IEEE 802.11 channel model for two different values of RDS [12]. Maximum amplitude-variation in Fig. 11 is 25.38 dB (RDS= 42ns). Fig. 11 suggests that a channel can be considered as frequency-flat Rician channel when then RDS of the channel becomes 12.5 ns. On the other hand a channel can be considered as frequency-selective Rayleigh fading channel with RDS of 42 ns. These results agree well with those of [9]. Larger RDS corresponds to deep fade and vice versa. Deep fade of a channel can be minimized by implementing antenna system with narrower beamwidth (e.g. FPBA). It is noteworthy to mention here that FPBA can be implemented in any frequency range.

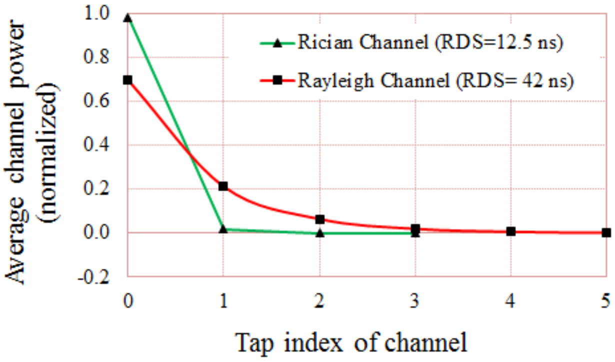

Fig. 10. Channel powers of IEEE 802.11 indoor channel model for two different values of RMS Delay Spread (RDS).

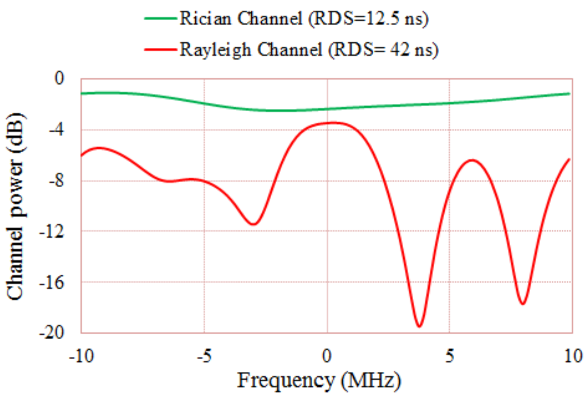

Fig. 11. Frequency spectra of IEEE 802.11 indoor channel model for two different values of RMS Delay Spread (RDS).

V. Conclusions

Next generation State of the Art (SOA) wireless networks will require very high speed wireless communication channels with lower bit error rate (BER), lower RMS delay spread (RDS), and higher values of Rician-K factors. Lower RDS and higher K-factors of a wireless channel can be achieved if an antenna system with narrower beamwidth can be implemented. This paper compares the radiation patterns of array antenna considering Binomial Array, Dolph-Chebyshev Array, and novel Fractional Powered Binomial Array (FPBA) [15]. It is seen that FPBA outperforms Binomial Array and Dolph-Chebyshev array from the technical perspectives. FPBA can achieve better radiation pattern with lower side lobe level (SLL) and narrower beamwidth. Narrower beamwidth and lower SLL of FPBA can enhance received power and reduce RDS of a wireless channel. Since RDS is a function of beamwidth. Narrower beamwidth of FPBA is also helpful in mitigating deep fade of a multipath channel. Large number of antenna elements at higher frequencies (e.g. within mm-range) can be deployed with novel FPBA Beamforming for next generation wireless system.

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