Experimental Investigations to Combat Fading in the NR of 5G Applications with Antenna Pattern Diversity

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***Abstract* — This work presents a new design and implementation of an Antenna Array with two different elements, to combat interference and multipath effects that occur in the NR of 5G applications. In fact, communication systems impose severe constraints in terms of channel capacity and transmission quality, while keeping the interference and multipath levels low. In this paper, we propose a new approach to combat fading phenomena without requiring any statistical knowledge of the propagation channel parameters. This new design uses two different elements array that adjust the signal phase shifter to maximize the combined received power proportionally to its gradient magnitude. The proposed architecture was implemented on a Universal Software Radio Peripheral (USRP) to perform experimental measurements and examine the performance of this approach. From the obtained results, we can note a 3 dB improvement over the basic approach that was with two identical antennas.**

Keywords-Antennas; Antenna Array; Fading; Diversity; Multi-path; wireless communication; USRP.

I. INTRODUCTIONH

Mobile communication systems have been evolving steadily in recent years. It has experienced different generations of technology developed from the first generation (1G) to the fourth generation (4G). However, the future looks much brighter for the next fifth-generation (5G) technology, offering better services and supporting more devices with new applications. [1]-[4]. The transmission channel in communication systems is undergoing at the different physical phenomena like scattering, diffusion and diffraction, resulting in interference and multipath effects in wireless communications, while keeping these effects low [5][6]. The fading affects the Quality of Service (QoS) in advanced wireless communication systems. To combat this phenomenon, different approaches have been proposed in the literature, such as increasing the power of emitting or using diversity techniques. Nevertheless, power is expensive, but diversity techniques remain the widely used to improve system performance, which can be divided to space diversity, polarization diversity, frequency diversity and diagram diversity [7][8]. The idea behind these approaches is to modify the different multipath component phases to avoid destructive combinations. The diversity techniques are based on the principle that several versions or statistically independent copies of the transmitted signal arrive at a receiver, each carrying the same information. They are then combined so that the resulting signal will be with less fading [7][8]. Having another antenna in space implies a diversity of space; the different paths phases arriving at the second antenna are different due to the difference in the physical path lengths. By varying the electromagnetic wave polarization (polarization diversity), the direction of the electromagnetic field components is modified; it varies the reflection, diffraction and scattering mechanisms, which result in a difference in the different path components, so different phases. According to change in the electromagnetic waves frequencies (frequency diversity), the wavelength is changed, causing the electrical lengths of the different paths to vary, resulting in different phases. By differentiating the kind of antenna, the electromagnetic waves will undergo different diagrams. To succeed pattern diversity, it is necessary that the shapes of the antenna radiation patterns will be different; i.e., each antenna will therefore capture a maximum of power in different directions and then probably independent. Since signal fading varies according to the direction of arrival, the diagram diversity is easily exploitable and interesting. This technique has been applied and compared to the space diversity with the identical antennas on the base stations in mobile communications. The results showed that two types of diversity give comparable performances in urban areas [7][8]. In general, diagram diversity is usually combined with spatial diversity.

In this work, we present in Section II a new approach based on space and diagram diversity to combat the fading effect based on the improvement of the adaptive algorithm published in [9]. Section 3 explains the system studied which consists of a set of two different elements with a digital phase shift introduced at one of the two antennas of the array to combine the signals received in order to maximize the output power of the array, without the need for channel statistics. Therefore, in section IV, experimental measurements are carried out by implementing the new approach on Universal Software Peripheral Radio (USRP) of National Instruments.

II. THE PROPOSED APPROACH

In order to combat fading effect and improve the received signal quality, the receiver power must be maximized to be exploited. The proposed approach is based on the work presented in [9]. For this aim, a 2-elements array spaced with a distance d is used in a feedback loop that adjusts the phase of one of the two signals based on the proportional adaptive phase-shift system, as shown in Figure 1.

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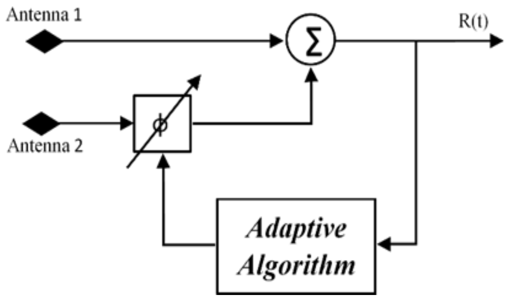


Figure 1. The proposed diversity approach

For simplicity, the same assumptions of [9] are made here and the received signal at antenna 1 is expressed as follows:

$$r_1(t) = A\cos(\omega t + \theta) \tag{1}$$

and the received signal at the antenna 2 is given as follows:

$$r_2(t) = A\cos(\omega t + \theta + \rho) \tag{2}$$

Where A is the amplitude considered here to be constant and the same at the two antennas, ω is the central angular frequency, $\rho = 2\pi d / \lambda$ and θ is a random variable uniformly distributed between 0 and 2π rad.

The combined signal is then:

$$R(t) = r_1(t) + r_2(t) \tag{3}$$

$$R(\mathrm{t}) = A\cos(\omega t + \theta) + A\cos(\omega t + \theta + \rho - \phi) \tag{3.1}$$

The output power can then be written as:

$$P_R = E\{R^2(t)\} = A^2 + A^2\cos(\rho - \phi) \tag{4}$$

$$= A^2(1 + \cos(\rho - \phi)) \tag{5}$$

where $E\{\}$ represents the mean value. To maximize the power P_R, it must be maximized $\cos(\rho - \phi)$ implies that $(\rho - \phi) = 0$.

On the other hand, for large phase shifts between $r_1(t)$ and $r_2(t)$ (i.e., when $\rho - \phi = \pi$ or close to this value), the received power is around zero 0, causing important fading. Therefore, to maximize the received power, the phase shifter must provide a phase shift that makes the signals from two antennas in-phase.

Consequently, to maximize the received power PR applying the iterative algorithm of all or nothing, to the two-antenna network to adjust the phase, so one can write:

$$\emptyset(i+1) = \emptyset(i) + \vartheta * sign[(d P_R(t))/dt] \tag{6}$$

Where $\emptyset(i+1)$ and $\emptyset(i)$ are the phase shift at the $(i+1)^{th}$ and i^{th} iterations, respectively and ϑ is a weighting coefficient.

The key aspect of this algorithm is that it does not depend on the level of the received power and offers a good performance in terms of convergence speed. In [9], the phase adjustment is done sequentially by incrementing or decrementing the phase shift with a constant step according to the gradient sign of the combined received power with the same antenna.

Therefore:

$$\text{If } sign[(dP_R(t))/dt] > 0 \Longrightarrow \emptyset(i+1) = \emptyset(i) + \vartheta \tag{7}$$

$$\text{If } sign[(dP_R(t))/dt] < 0 \Longrightarrow \emptyset(i+1) = \emptyset(i) - \vartheta \tag{8}$$

To apply this algorithm in a two-element antenna array, a single phase-shifter is used at antenna 2, as shown in Figure 1.

This approach has proven to be able to improve the received power but with limited performance. This limitation is due to the fact that the two antennas are identical so, for a deep fading in a given direction of radiation, the two antennas will be affected by its effect which will be able to weaken the received power by the system, and even if there will be power compensation will always be weak.

To overcome this problem, it is proposed to use two different antennas, implying two different patterns, which makes the probability of having both signals received in the same direction or at the same time small and insignificant.

III. IMPLEMENTATION

To test experimentally the proposed approach, the algorithm has been implemented on two pairs of Universal Software Radio Peripheral (USRP 2921 and 2932) platforms from National instruments [10]. These platforms are software programmable radio transceivers, programmable with NI LabView software and are suitable for physical layer communication systems prototyping. These modules have the ability to transmit and receive RF signals across the bands [0.4GHz - 4.4GHz] and [4.9GHz - 5.9GHz]. The clock synchronization aspect between the two platforms is carried out using wire synchronization, where two identical monopole antennas are used to acquire RF signals in two different frequencies of the Operating Bands in FR1 of 5G applications (ex : 2.5 GHz and 5.88GHz) transmitted from a Network Analyzer (as shown in Figure 2).

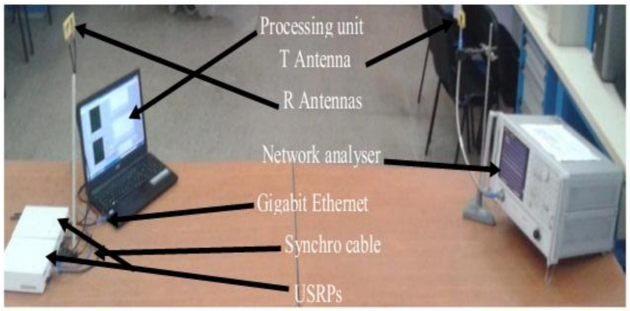


Figure 2. The adaptive dual-antenna array with the communication chain.

The communication chains implemented at the USRP's both start with an amplifying stage where the gains are adjusted to get signals of the same strength of the two antennas. The phase shift is performed directly at the RF side, and not the IF, using a Virtual Instrument of LabView.

Furthermore, to ensure that the measurement setup fulfills the far field condition, the transmitter is separated by a distance greater than *D2/λ*, where *D* is the largest dimension of the antenna and *λ* is the signal wavelength. The measurements have been done indoor a Lab room of 10 x 5 meters with a lot of equipment inside.

Two different measurement setups have been used. In the first one, the reception is done with the same antenna (monopole). In the second setup, the reception is done with a different antenna (monopole radiate horizontally and Vivaldi radiate vertically upwards). These antennas are simulated with CST (Computer Simulation Technology) [11] software and then designed and fabricated shown in Figure 8. We present in the next paragraph theirs performance:

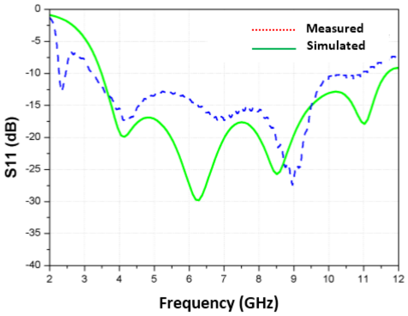


Figure 3. The S11 parameter of realized Vivaldi antennas.

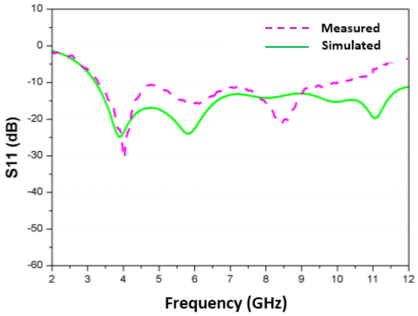


Figure 4. The S11 parameter of realized Monopole antennas.

The two antennas: Vivaldi and Monopole are ULB antennas that cover virtually the same band as shown in Figure 3 and Figure 4. These antennas are designed with a minimum of mutual coupling or the S12 and S21 parameters are identical to see the isolation and they are less than -15 dB over the operating frequency band as shown in Figure 5.

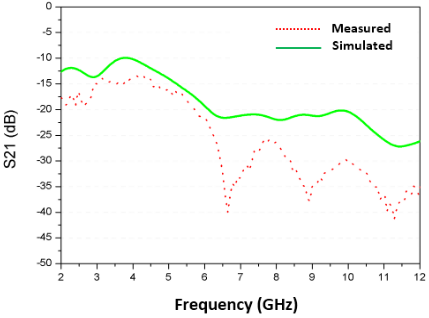
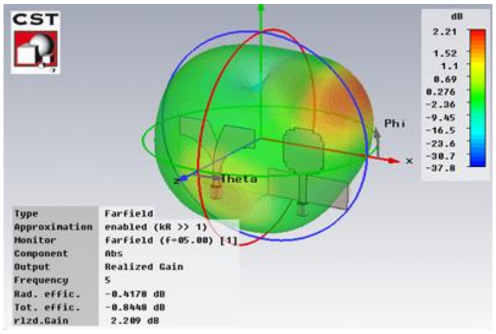
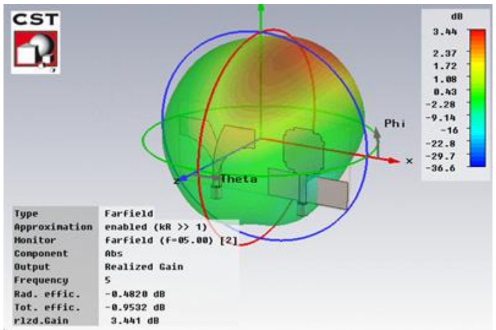


Figure 5. The S11 parameter of realized Monopole antennas.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=05.00) [1]
Component	Abs
Output	Realized Gain
Frequency	5
Rad. effic.	-0.4178 dB
Tot. effic.	-0.8448 dB
rlzd.Gain	2.209 dB

Figure 6. Radiation patterns of Vivaldi antenna.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=05.00) [2]
Component	Abs
Output	Realized Gain
Frequency	5
Rad. effic.	-0.4820 dB
Tot. effic.	-0.9532 dB
rlzd.Gain	3.441 dB

Figure 7. Radiation patterns of Monopole antenna

The radiation of the two antennas are shown in Figure 6 and Figure 7.

IV. EXPERIMENTAL VALIDATION

To evaluate the performance of the proposed approach, experimental measurements are carried out according to situations. The first one considers two identical antennas similar to the work published in [9] and the second adopts two different antennas (designed and fabricated in this work). Figure 9 illustrates the different received measured powers for the two identical and different antennas, respectively. As we can see, the received signals undergo the fading phenomenon. This is due to the multipath propagation, imposing destructive combinations of the received signal.

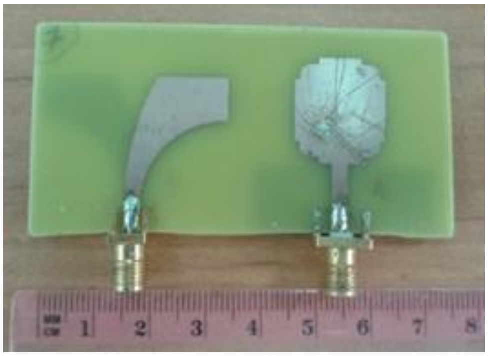


Figure 8. Photo of the fabricated antenna array.

The power levels for antenna 1 and antenna 2 are low because they are on average of -71dBm with deep-fad

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reaching -80dBm. As we can see in Figure 9, the proposed approach performance exceed those obtained with two identical antennas, such that we have, respectively, average values of -62dBm and -65dBm, as maximum values -60 dBm and -63 dBm and -66.5 dBm and -71 dBm as minimum values. So the proposed approach enormously improve the original approach by means of 3 dB, which itself improves the power [9].

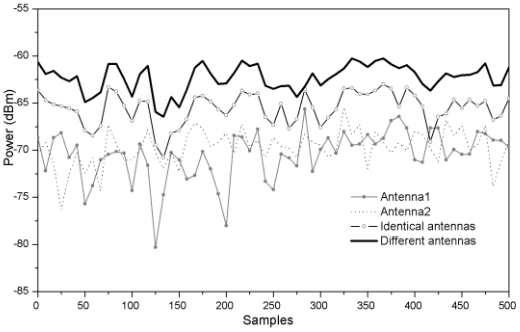

Figure 9. Measured received powers.

However, the first approach behaves well in conditions where the two signals are uncorrelated; it can be observed that it achieves performance closer to those of the new approach. Nevertheless, the new approach results always surpass the other by an average value of 3 dB.

TABLE I. DIFFERENT POWER VALUES

Feature (dBm)	Min value	Means value	Max value
Reception with antenna 1	-80.2	-71.9	-65.9
Reception with antenna 2	-76.45	-70.4	-65.8
Reception with identical antenna	-71.30	-65.8	-62.9
Reception with different	-65.41	-62.2	-60.2
Comparison	-5.89	3.6	2.7

Another performance criterion that can be used to compare the two approaches is the Cumulative Distribution Function (CDF), it gives the cumulative probability that the received power level is less than a given value. Figure 10 illustrates the CDF for antenna 1, antenna 2 and the applied algorithm in both cases of identical and different antennas.

As we can see in Figure 10, the algorithm with the proposed approach outperforms all the other ones.

For example, at -66 dBm, with the proposed approach, only 5% of the signal is below this value (95% of the signal is greater than this power level) while with the original approach 30% of the signal is lower at this value. For another reading, for example, the power level corresponding to 10% probability (90% of the signal is greater than this power level) is -64dBm for the algorithm with two different antennas and -67dBm with two identical antennas that gives about 3 dB difference.

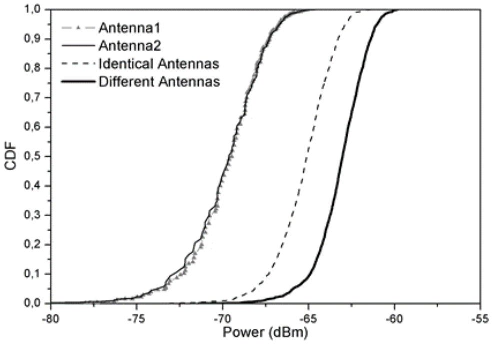

Figure 10. Measured received powers.

V. CONCLUSION

In this paper, a new approach with an adaptive algorithm to combat fading phenomenon has been proposed with a two different (02)-element array. This technique allows adjusting the phase of one of the two antennas in proportion to the variation of the received power by the two different diagrams combined to maximize this power. To evaluate its performance, an experimental measurement was carried out to measure the power received and calculate the CDF in order to compare the results obtained with our approach that uses two different antennas with the two identical antennas. All the results show clearly that the approach used with enormously improves the received power making it recommended generally for advanced wireless communications and particularly for NR of 5G applications.

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