OPTIMIZATION OF BEAMFORMING TECHNOLOGY FOR COGNITIVE SPATIAL ACCESS IN MILLIMETRE WAVE

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Abstract: The allocation of 60GHz spectrum for WLAN has made the quests for gigabit data rates delivery to the end users possible in the wireless communication domain. The peculiar propagation characteristics in the millimetre wave can be exploited for improved system capacity. In optimizing beamforming techniques, a weight vector that minimizes a cost function is determined. The most commonly used optimally beamforming techniques or performance measures (cost function) are Minimum Mean Square Error (MMSE), Maximum Signal-to-Noise ratio (MSNR), and Minimum (noise) Variance (MV). A matlab based MVDR (Minimum Variance Distortion Response) and Phase-Shift Beamforming algorithms are proposed in this paper as means for cognitive spatial access in the millimetre wave band to enhance the signal of interest (SOI), with the suppression of interferences. Simulation results reveal that MVDR outperforms the Phase-Shifts in interference limited spatial multiple access (SMA) systems.

1 INTRODUCTION

The formidable growth rate in the wireless technology in the recent times has resulted in new and improved application services at lower cost. Invariably, the increased in demand for airtime by numerous subscribers has led to shortage in the limited frequency spectrum. The most readily practical solution to this problem will be in spatial processing. According to Andrew Viterbi, "Spatial processing remains as the most promising, if not the last frontier, in the evolution of multiple access systems''(Balanis 2005).The wider range and high quality of service required for effective wireless communication by the users that daily increase in exponential rate, can only be realized through the smart antenna technology, and spatial processing is pivotal to this technology. The exponential increase rate of subscribers coupled with limited frequency allocation by FCC, compel wireless system capacity availability a corresponding growth, this has been a huge problem to cope with in communication industry, hence cellular radio system has evolved several techniques through the years. Smart antenna technology among other techniques, with its quality of high interference rejection, will lower the BER thereby providing a substantial system capacity improvement.

The frequency spectrum in the Millimetre wave band has been proven to be the only candidate capable of gigabit throughput delivery required in the multimedia applications. This has received great attentions in research arena for developing ultra-high speed gigabit wireless communication systems for both short ranges such as WPAN as well as WLAN. (Wu, Chiu et al. 2008; Lin, Peng et al. 2011). Nevertheless, the capability of multi-gigabit data rate at 60GHz is faced with a very challenging power budget, this in collision with the propagation conditions of the channel, especially the path loss(Herrero and Schoebel 2010). The major technical challenge of the limited link budget due to high path loss, reflection loss are intended to be optimized for spatial reuse for improved wireless system capacity and quality of service. This was achieved by engaging high gain and high directivity antennas to compensate for the path loss in 60GHz transmission. The short wavelength of 60GHz radio signal necessitates the use of large number of tiny antennas, makes it an ideal wireless interface to support spatial reuse while on the other hand beamforming has emerged as an important

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technology to support high directivity in 60GHz radio transmission to provide high data rates for local users under severe penetration and path loss(Yin, Chiu et al. 2011). The large number of antenna available in 60GHz will be used to serve multiple users while the received SNR to a single user is increased. It is obvious that as spatial reuse in dense environment will lead to CCI among the co-located radio links.

In this work, Optimal Adaptive Beamforming Algorithms (OABA) for cognitive spatial access was used to mitigate the collocated radio links interferences. This was implemented in the digital domain with phased antenna array antenna. A multiple effective antenna is employed to enhance reception to users in the SDMA system, where different users will have different permissible operating regions in order to maintain the SINRs for all users in the SDMA system.

1.1 Related Work

Quite a few number of works have been done on millimetre wave band beamforming using phased array antenna.(Lin, Peng et al. 2011) proposed a MMSE based switched beamforming code selection algorithm for mixed analog/digital beamforming structure to enhance interference mitigation and spatial reuse capability in the presence of CCI. The disadvantage of Switched Beam(SB) is that the fixed beam required the user to be in the centre of the beam for the placement of the desired signal at the maximum of the main lobe; otherwise, an interferer can be enhanced instead. Also SB is unable to fully reject the interferers. Hence we chose to use adaptive array system to customise an appropriate radiation pattern for individual user in simulated wireless system in our work.(Liu 2007) Used NLMS algorithm with the replacement of the delay-lines (TDLs) in the traditional broadband beamforming by sensor delay-lines to determine the effectiveness of the adaptive broadband beamforming with spatial only information. Beamforming algorithm with the suppression of interference was proposed by (alias Jeyanthi and Kabilan 2009) using matrix Inversion-Normalised Least Mean Square adaptive beamforming with minimum Bit Error Rate (BER). NLMS is characterised by computational complexity and low convergence, It also requires a reference signal.
In this paper, An empirical analysis of a typical wireless network deployed in millimetre wave band was conducted to determine the QoS and reliability of the channels in a spatial multiple access (SMA) system. We adopted Phase Shift and MVDR adaptive beamforming techniques algorithms in a digital domain transmission. A matlab based simulation was implemented for digital beamforming structure to achieve an optimal adaptive beamforming (OAB) for an enhanced signal of interest (SOI) and suppression of non-signal of interest (NSOI) to improve system capacity in a dense spatial reuse environment. Moreover, a comparison of the two beamforming algorithms was done for better and effective performance. Our simulation results showed that the proposed algorithms are able to provide interference mitigation while the beamforming capability in the millimetre wave is optimized in the dense spatial reuse scenario with multiple service users for effective utilization of frequency spectrum. The rest of this paper is organised as follows: section two discussed the Array Signal Processing and adaptive beamforming, while section three discussed the challenges in the millimetre wave frequency band, with empirical analysis in a real world scenario. Section four proposed and implemented the beamforming algorithms targeting at the optimization of cognitive spatial access system for improved system capacity. The results of the simulations and discussions were presented in section five. The conclusion was presented in section six.

2 ARRAY SIGNAL PROCESSING

This is one of the major areas of signal processing with wide applications in radar, sonar, communications e.t.c. The technology involves multiple sensors at different locations in space to process received signals arriving at different directions. (Matsuo, Ito et al. 2011). The three major areas of ASP are: Detecting the presence of an imping signal and determine the signal number, finding the direction of arrival angles of the impinging signals, and enhancing the signal of interest from known/unknown directions and suppress the interfering signals(Liu and Weiss 2010).This work is based on the third category: we developed an algorithm using the ASP technique to mitigate co-location interference in wireless access network for the improvement of the communication network system.

2.1 Adaptive Beamforming

This is a technique geared towards forming a multiple beams towards desired users while nulling the interferers at the same time through the adjustment of the beamformer's weight vectors. It is the process of altering the complex weight on-the-fly to maximize the quality of the communication channel. Smart Antenna which is pivotal in adaptive beamforming is a system of antenna with smart signal processing algorithms. These algorithms are used to identify the spatial signature like direction of arrival (DOA) of the signal as well as to determine the beamforming vectors, which is used to track and locate the antenna beam on the mobile terminal (Park 2011). The figure 1 below depicts the process involved in adaptive beamforming

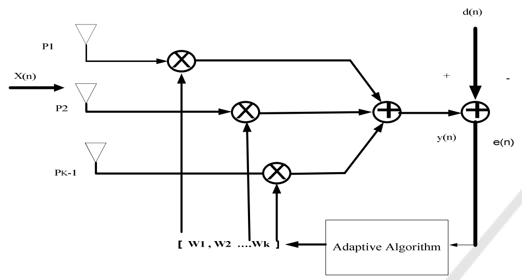

Figure 1: .Block diagram of Adaptive beamforming

Figure 2: 60GHz Transmission Measurement set up

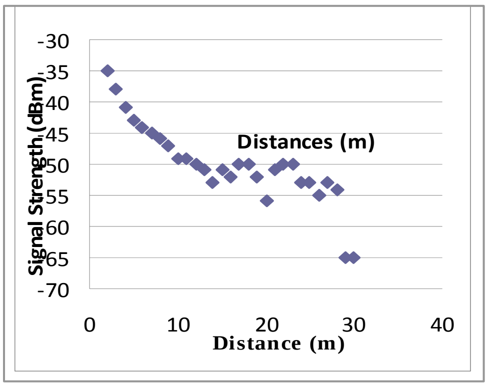

Figure 3: 60GHz Transmission at MSc Lab Beam Steering.

3 CHALLENGES IN 60GHz BAND

The peculiar characteristics of the millimetre wave such as limited emitted power, high temperature noise, and high oxygen absorption has confined its propagation to within the rooms or open areas in the

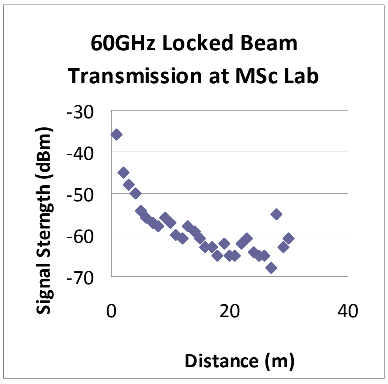

Figure 4: 60GHz Transmission at MSc Lab Locked Beam

close proximity of the antennas. There is unacceptable strong interference occurrence in these scenarios as a result of reuse of resources which attracts broadband mobile telecommunication. It was shown by (Flament 1999; Flament 1999) that the Signal-to- Interference ratio can drop from 15dB to 0dB within a few centimetres. .Likewise, a human influence on the path of transmission can attenuate the signal by 15dB or more, hence complete breakage of link.(Yang and Park 2009). The importance of antenna design in an indoor environment at 60GHz cannot be overlooked, since each room/small coverage area is a single cell with its own antenna, full coverage as well as lack of signal spill across rooms must be guaranteed. In case of coverage areas overlap results in co-channel interference(Voigt, Hubner et al. 1999; Xia, Qin et al. 2007). Adaptive Beamforming is method where antenna array are used to improve system capacity through interference reduction and also mitigates multipath fading. This was demonstrated in this work through matlab simulations and the results are depicted in the graphs.

3.1 Empirical Measurements Setup of Millimetre Wave Access Networks

The setup for source and sink transceivers for the radiation pattern measurements of 60GHz is shown in figure 2. The SiBeam P5 HDMI reference kits contain two host MCUs. One host is on the SK9200DB debug board and the other host is on the

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module board. The SBAM2 (SiBeam Applications Manager) software is installed on a PC with XP operating system to monitor status, set configuration and control other parameters of the WiHD transceiver modules. The SK9200DB Boards (Source and Sink) are connected to the PC through the USB cable, The source is connected to the DVD player via an HDMI cable, both source and sink are connected to monitors separately for monitoring signal transmitted and received.

3.2 Data Acquisition and Processing

The transmission measurement was carried out at the MSc laboratory of the University of Essex, Colchester campus. The total distance 30m was covered at a step distance of 10m.The recorded received signals at different locations were processed through the excel software to generate the graphs 3 and 4 above.

4 BEAMFORMING ALGORITHMS FOR OPTIMIZATION OF COGNITIVE SPATIAL ACCESS SYSTEM

The Normalized Least Mean Square (NLMS) and Recursive Least Square (RLS) are the classes of adaptive algorithms and cost functions used for wideband beamforming when a reference signal is available and are characterised with computational complexity. Linearly constrained Minimum Variance Beamforming and Minimum Variance Distortion less Response (LCMV and MVDR) beamforming can be better options when a reference signal is not available but the DOA angle of the signal of interest and the range of their bandwidth is known. Some constraints can be imposed on the array coefficients to adaptively minimize the variance or power of the beamformer output such that the SOI impinging on the array from specific directions are preserved by a specified gain and phase response while all other contributions from NSOI from other directions are suppressed.(Liu and Weiss 2010).Taken a transmitted signal with a frequency of ω and DOA angle of θ, then the beamformer's response can be expressed as follows:

$$P(\theta,\omega) = W^H d(\theta,\omega) \tag{1}$$

Where $d(\theta,\omega)$ is the steering vector for wideband Beamformer with corresponding elements of complex exponentials expressed as :

$$d(\theta,\omega) = \begin{bmatrix} e^{-j\omega\tau_0} \dots e^{-j\omega\tau_{M-1}}\ e^{-j\omega(\tau_0+T_s)} \\ \dots e^{j\omega(\tau_{M-1}+T_s)} \\ \dots e^{j\omega(\tau_0+(J-1)T_s)} \\ \dots e^{j\omega(\tau_{M-1}+(J-1)T_s)} \end{bmatrix}^T \tag{2}$$

For any signal with frequency ω_0 and DOA angle θ_0 to
Pass through the beamformer, with a specified response, a
Constraint is set as follows:

$$W^H d(\theta,\omega) = G_0 \tag{3}$$

The power output is given by:

$$E\{|y[n]|^2\} = W^H R_{XX} \tag{4}$$

$$R_{XX} = E\{XX^H\} \tag{5}$$

The LCMV beamforming problem follows equation Below:

$$W = argmin W^H R_{XX} W \tag{6}$$

These constrains determines the response of the beamformer to signal coming from specified direction and at specified frequencies. The resultant beamformer is called the minimum variance distortion less response (MVDR) beamformer.

Table 1: Simulations Parameters.

SOI angle	35
Interfering signals angles	45 and 55
SNR 1	4dB
SNR 2	40dB
Element number	10
Carrier Frequency	60GHz
Element spacing	lambda/2

5 SIMULATION RESULTS AND DISCUSSION

In this part we provided simulation results of the proposed algorithms. There are 10 sensors aiming at enhancing SOI at 35dgrees and adaptively suppress two wideband interfering signals arriving at 45 and 55 degrees respectively. SNR is 4dB and 40dB.A set of 500 channel iterations was generated using 60GHz NLOS multipath channel model.

Figure five is the magnitude plots of two antennas out of the array of ten to depict the transmission of the SOI and some thermal noise modelled as complex Gaussian distributed random numbers. Figure six depicts the output of a phase shift beamformer used to suppress signals from all directions other than the desired signal direction. The SOI becomes stronger than the noise as a result of the 10-array multiplicative power to give a gain of 10. The output response of this beamformer is shown in figure seven, where the mainlobe of the beamformer is pointing to the SOI direction (35degrees) as desired. A challenging scenario for the phase shift beamformer is depicted in figure eight. Interference signal from neighbouring transmitter masked antenna array and the SOI fell to the side lobe, therefore an adaptive MVDR Beamformer was used for the suppression of the interference at 45 and 55 degrees. This is depicted in figure nine; the output response of these beamformer for comparison is depicted in figure ten. The two nulls in the graph shows the suppression of interfering signals. It also shows the outperformance of the MVDR Beamformer over the phase shift beamformer for optimization of beamforming technology in spatial access system.

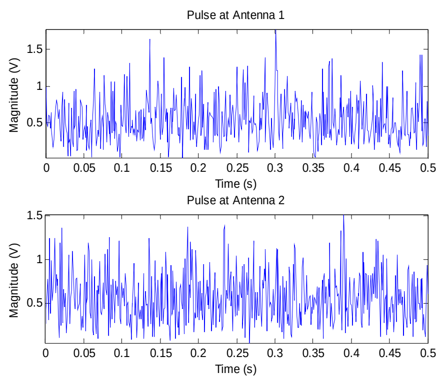

Figure 5: Magnitude plots of the first two channels.

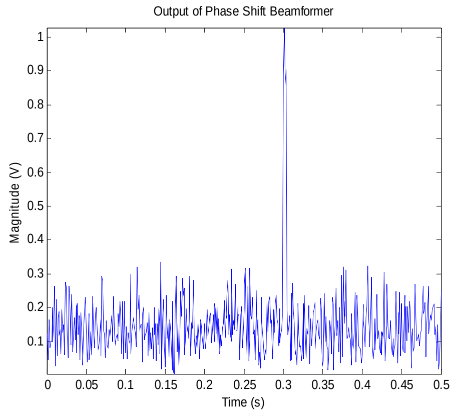

Figure 6: Output of the phase shift beamformer.

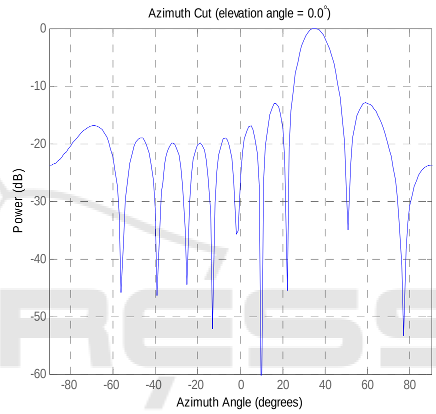

Figure 7: Beam pattern response of the beamformer.

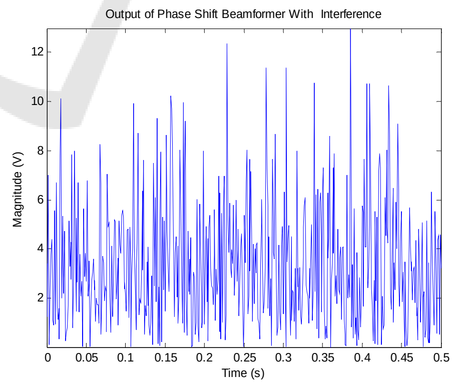

Figure 8: Response of the Phase shift beamformer with interference.

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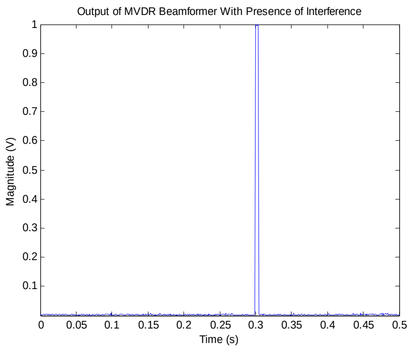

Figure 9: Response of the MVDR beamformer in the presence of interference.

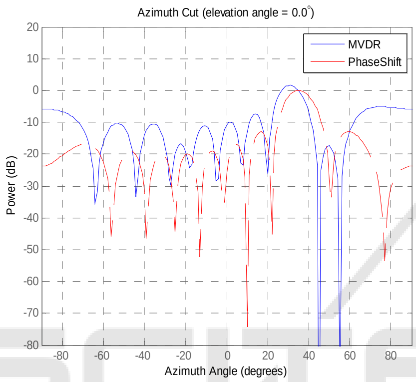

Figure 10: Beam pattern response of the beamformers.

5.1 Discussion

Fig 6 shows the desired signal is stronger than the noise. The SNR here is 10 better than for the single antenna shown in fig 5. Fig 7 shows the beam pattern response of the beamformer with the applied weights. The main beam of the beamformer is pointing to the set desired direction for the received signal (35). While fig8 shows the response of the beamformer when interference was introduced. The SNR is increased to 40dB to reflect the presence of interference. The interring signals are set to arrive at angles 45 and 55 degrees. It is obvious that phase shift beamformer cannot handle the challenge of interference; hence another beamformer called MVDR was used to retrieve the desired signal in this condition as depicted in fig 9. Fig. 10 shows the beam pattern response of the beamformers. While the phase shift fails to null the interferences; the MVDR does totally suppress the interferences and enhances the signal of interest.

6 CONCLUSION

Considering the effects of oxygen absorption and related technical challenges in 60GHz, it is obvious that the availability of large chunk of spectrum in it may not satiate the quest for high throughput as well as quality of service with high reliability required in the wireless network and multimedia applications. The confinement of transmission to a small area requires many access points to reasonably provide a wider coverage for users in the SMA systems, and consequently, a co-located interference is inevitable. An MVDR and Phase Shift beamforming algorithms are proposed to achieve improved system capacity and quality of service through interference suppression and enhanced SOI in a spatially dense transmission scenario. The simulation results demonstrated effective gigabits throughputs in the MMW band.

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