ADAPTIVE BEAMFORMING ARRAY USING MULTI-RATE FILTER BANKS FOR BANDWIDTH-ON-DEMAND APPLICATIONS

Sathish Chandran,
RF Consultants, 32, Jalan S. G. 6/8, Sri Gombak, 68100 Batu Caves, Selangor, Malaysia.
Email: sathish@pc.jaring.my

Abstract: An adaptive beamforming array provides the required coverage to the desired user and spares the undesired user in order to increase the quality of performance of any mobile network. The data rate of radio transmission is not the same for all the communication applications. Therefore the bandwidth associated with each application is of different values. In this work, only one sub-band (after splitting using a multi-rate filter) of the incoming signal bandwidth is subjected to array beamforming in order to save the cost and the circuit complexity of the beamformer. It is shown here that the beamforming performance remains the same for this antenna beamforming array for any fractions of the full bandwidth signal.

Introduction: Adaptive beamforming arrays (ABA) are widely used to enhance the signal to noise ratio in communication systems, by identifying the desired signal and suppressing the undesired signals. These arrays utilize the coherent addition of signals to obtain the required spatial selectivity. Such arrays comprise of antennas, which can be used to steer the beam by providing appropriate delays to each element. This makes the signal emanating from a particular look-direction more desirable to detect, while suppressing the unwanted interference. The antennas are distributed in space and the signals received at each element are delayed versions of the signals generated.

In a mobile communication scenario the needs for high capacity, increase coverage and high quality of voice are of the utmost priority. This in fact, will determine the success of any mobile network in terms of economical engineering execution and of increase in profits. The rate of data transmission can vary from applications to applications, like audio, video etc. Hence it is not necessary to perform the array operation for the entire range of the maximum bandwidth, at each and every time the array senses the relevant radio signal. It would be appropriate, if the operation is carried out after identifying the particular signal of interest. This concept can be employed at the basestations by deploying the ABA with band shaping filters. This application has a great impact in communication applications as the future communication systems demand requirements in downloading the contents from a service provider at a greater speed, when requested by the subscriber. The communication system remains idle when the request has not been initiated by the subscriber and this saves the system power in providing the unnecessary coverage for the non-user.

It has been shown that the error introduced (when compared with the original signal) during the full-band beamforming action can be reduced by processing the received signal bandwidth by dividing it into a number of sub-bands [1]. Sub-banding techniques are generally performed using the Fast Fourier Transform (FFT) filters. Sub-band ABA methods have been introduced using multi-rate filters like Quadrature Mirror Filter (QMF) banks for narrow band signals [2]. This has also been extended to wideband signals [2, 3]. In this work, a novel sub-band ABA hardware configuration is proposed. It is believed that this arrangement would reduce the hardware complexity, the cost and the workload of the earlier version of the QMF sub-band ABA system [3, 4].

Novel sub-band adaptive antenna array structure: The QMF Banks have been previously utilized for ABA and Direction-of-Arrival estimation [5, 6, 7]. Unlike the conventional sub-band ABA, a novel antenna structure is utilized here, as shown in Fig. 1. In earlier applications, for both the lower and the higher sub-bands of the QMF Banks have been optimized to perform the antenna beamforming and for the suppression of the interference [3, 4]. However in here, the same procedures are carried out for the lower sub-band, and then the higher sub-band is further subdivided into the lower and the higher sub-bands. In short, this process is performed only to the lower frequency band of any available video or voice data. The concept used in here, is that the array structure identifies the bandwidth of the incoming signal (by a frequency detector, which is not shown here). It will then, direct that particular signal to the relevant QMF output (lower sub-band), so that only that portion of the signal bandwidth will be optimized for beamforming, rather than the entire frequency bandwidth of the system. This will, in fact save the operational load of the system, time and complexity of the antenna beamforming system.

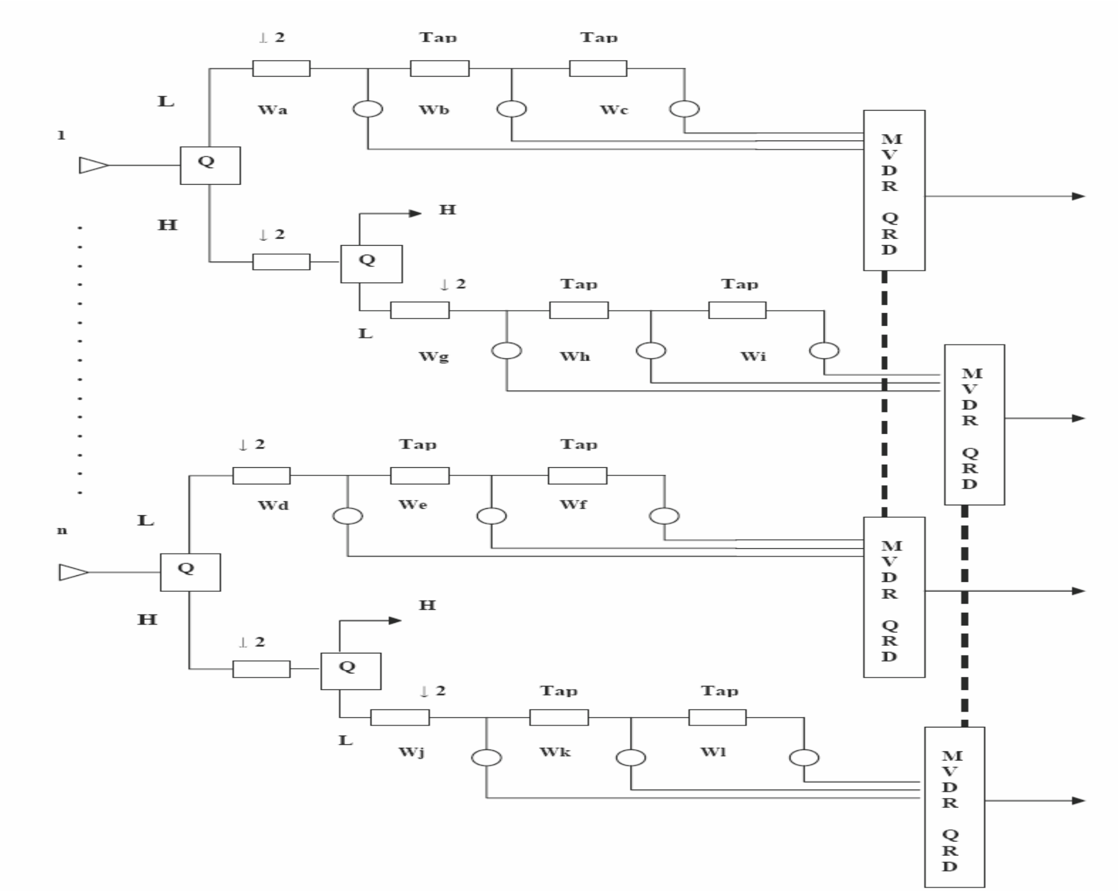

Fig 1: Schematic diagram of the novel sub-band antenna adaptive beamforming array.

Wa to Wl - weights of the associated taps, Q - Quadrature Mirror Filter (QMF), L - Lower sub-band of the QMF output, H - Higher sub-band of the QMF output, ↓2 - Decimation by 2, n – Number of Antennas, MVDR QRD – The MVDR QRD Optimizer

Simulation results: The performance of the ABA is evaluated for the lower sub-bands for different signal bandwidths. In a linear array structure, two consecutive antenna elements are placed at a distance $\lambda/2$, where λ is the wavelength of the carrier signal. In this case, the sub-banding is carried out consecutively for three levels and each time only the lower sub-band is considered for optimization for the desired signal. This method is opted after taking into consideration the lower bandwidth requirements for any communication systems. Two taps are connected for the lower band after dividing the bandwidth of the incoming signal into two sub-bands. In this paper the output of only three QMF banks are considered. The intermediate frequency is chosen arbitrarily and in this study it is fixed at 10 MHz. The frequency of interest at the output of the second and third QMF bank is 5.0 and 2.5 MHz respectively. The sampling rate is chosen to be four times the IF frequency. The received signal is assumed to be TDMA signal with BPSK modulation. It is also assumed that each antenna element contains zero mean thermal noise and they are uncorrelated with each other. The interference to noise ratio (INR) is assumed as 40 dB. The interference comes from -30˚, while the desired signal direction is from boresight of the antenna array (0˚). An 8 taps FIR-QMF band is used to split the band into two sub-bands [8]. The decimation factor is made equal to the number of the sub-bands, i.e., 2.

Fig. 2 shows the radiation responses of the lower sub-band ABA for the incoming signals with different bandwidths. It is noted the radiation responses show 0 dB amplitude at boresight (0˚), which is the direction of the desired signal. Deep suppression is observed at 30˚, which is the direction of the undesired signal, for all three bandwidths. This clarifies that the beamforming actions for the desired signal are the same, regardless of whatever bandwidths are used for the operation. The same applies to the nulling of any other undesired signal from any other directions too.

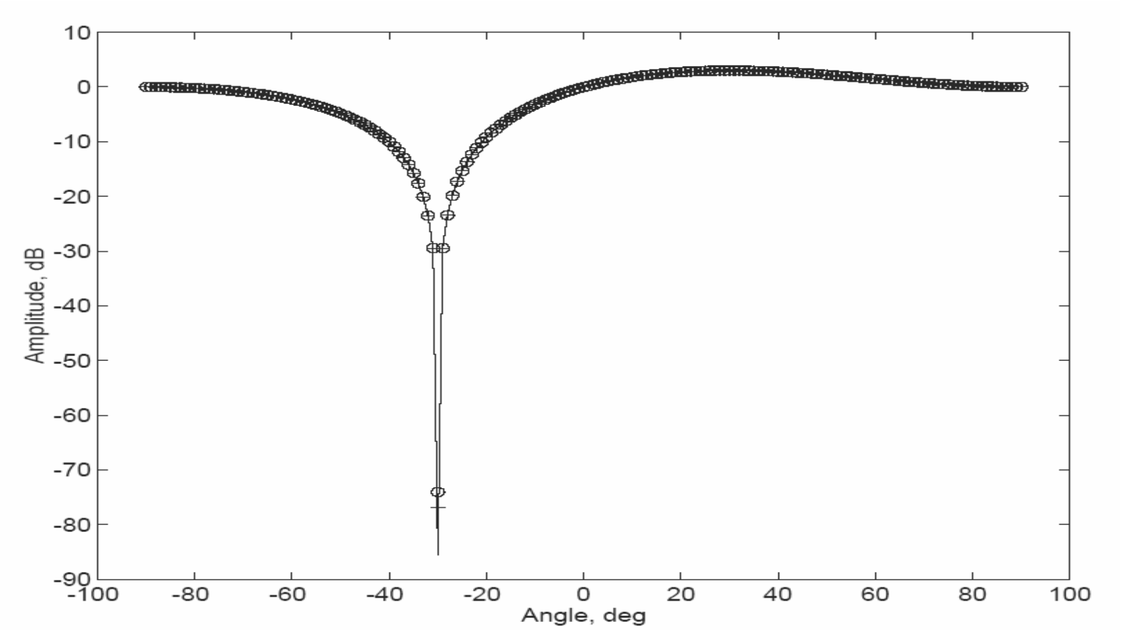

Figure 2: Radiation patterns showing the desired (wanted) and interference (unwanted) signals for the sub-band adaptive beamforming array. (Line) 10 MHz bandwidth (o) 5 MHz bandwidth (+) 2.5 MHz bandwidth

Fig. 3 illustrates the mean square errors (MSE) of the lower sub-band ABA. They show almost the same values centred around -80 dB for all three bandwidths, from the beginning of the optimization. These characteristics ensure satisfactory beamforming performances, guaranteeing deep nulling performances throughout the operations of the sub-band ABA.

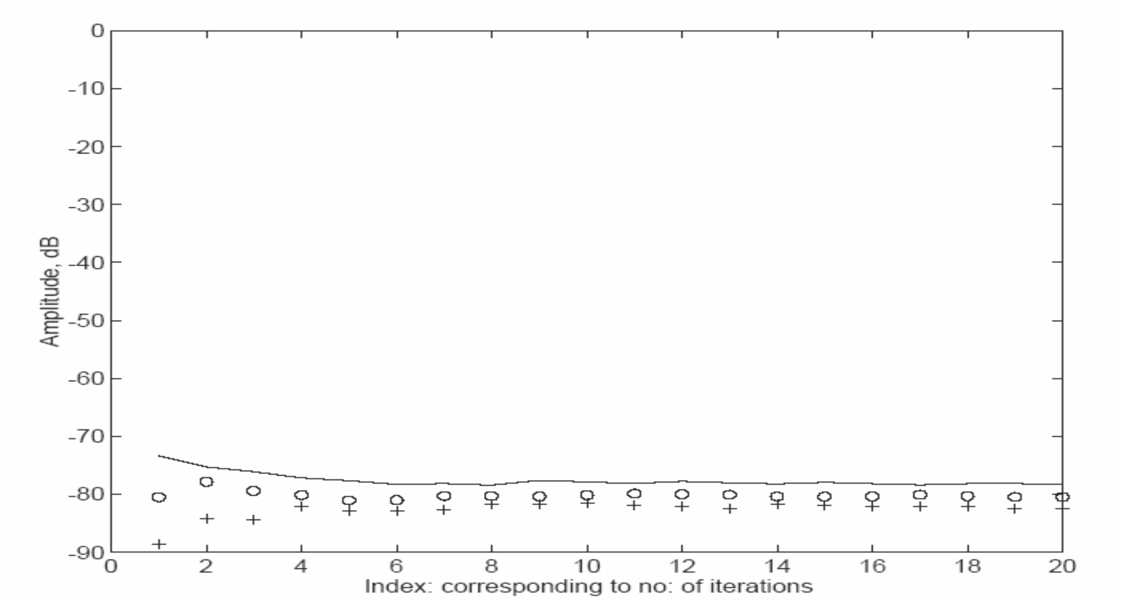

Figure 4: The mean square errors (MSE) the for sub-band beamformers for the sub-band adaptive beamforming array. (Line) 10 MHz bandwidth (o) 5 MHz bandwidth (+) 2.5 MHz bandwidth

Conclusion: The system configuration of a novel Quadrature Mirror Filter (QMF) sub-band adaptive beamforming array has been proposed. It has been demonstrated that for the data transmission of any given signal bandwidth, only the lower sub-band of the input signal bandwidth is needed to be used for the array beamforming. The sharp cut-off characteristics of the QMF banks are the main reason for employing those filters for subdividing the bandwidth of the signal into two. Only the lower sub-bands of the QMF banks are used for array beamforming, since it results in the total operational bandwidth to be smaller than the same, if the higher sub-band is used. The beamforming at the desired direction and the deep nulling at the undesired direction are observed for all the three cases of bandwidths. The sub-band adaptive antenna array is, thus capable of performing for applications like the bandwidth-on-demand features. This type of array beamforming arrays would reduce the extra processing, the cost and the circuit complexity.

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