BEAMFORMING FOR WIRELESS COMMUNICATION SYSTEMS

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ABSTRACT

This report discusses our submission idea for ICASSP 2020 Five-Minute Video Clip Contest. Our video is on beamforming for wireless communication systems. We have divided the video into 3 parts, each part presenting the same concept, with increasing level of complexity, to different set of people. The 1st level involves explaining the concept of beamforming using an example to young kids with very little science background. In the 2nd level we explain beamforming with a different example to college students who have some exposure to science. Finally in 3rd level we explain the concept along with its mathematical formulation to graduate students.

1. BEAMFORMING

Beamforming is a technique which focuses signals in the desired direction to enhance the transmission and/or reception. Multiple antennas are used to get constructive interference of signals and form beams in the desired direction, significantly increasing the signal to noise ratio in the desired direction [1].

Beamforming has advantages such as low complexity, higher data rate, higher gain with less errors and fewer computation, which can be used to transmit the maximum signal power in the presence of noise and other interference. Beamforming is used in many applications such as wireless communication to increase the channel capacity [2, 3], channel estimation [4], source localization [5], direction-of-arrival estimation, and smart antennas.

2. VIDEO DESCRIPTION

In the video we attempt to explain the concept of beamforming at three levels. The complexity of explanation (as well as the assumed background knowledge of the audience) increases as we go from Level 1 to Level 3. The three levels of description are targeted towards different audience: Level 1 being for children with minimal technical exposure, Level 2 for college students with some exposure to scientific principles, and Level 3 for graduate students who are assumed to have technical and mathematical knowledge. The details of different levels are explained next.

2.1. Level 1

In Level 1, we will be explaining the concept of beamforming to young kids without going into technicalities. Below is a description of the video.

Let us consider a noisy classroom, where the teacher enters and wants to call his student 'Shyam' who is among the many students inside the room. Due to the noisy environment Shyam is not able to hear and respond to the teacher (as teacher's voice is weak compared to the surrounding noise). To overcome this problem, teacher try to direct his voice such that his voice is sharply directed towards Shyam's position and Shyam is now better able to respond the teacher.

In the first case, when the teacher normally calls Shyam, his voice travels in all directions and is not properly received by Shyam. While in the second case, when teacher uses the cups, the voice is more focused towards the desired direction and travels farther to be received by Shyam with sufficient loudness to overcome the noise. This gives a simple demonstration of beamforming which is used to transmit signals in the desired direction in presence of noise.

2.2. Level 2

In Level 2, we will explain beamforming to college students using the application of Wi-Fi.

Consider a WiFi router, which converts our data (ex. video or audio) to radio frequency signals, and these signals are then received by devices with WiFi capabilities like smartphones, laptops, and tablets. Initially, when the WiFi router is not connected to any of the devices, it transmits radio signals with equal power in all directions. Once the router is connected to a user, we would like it to transmit more power in the direction of the user for better reception. This is achieved by the router using multiple antennas and the technique of beamforming. Specifically, the various antennas within the router transmit the same signal with slightly different delays such that the resultant signal has higher energy in desired spatial direction. This is the same as the interference phenomenon seen in light waves where two or more coherent sources interact to produce patterns of bright and dark bands.

The resulting signal power is transmitted in a focused manner to the users (these focused regions are called lobes). The technique of using the multiple antennas to create the lobes, which contains most of the power and are directed

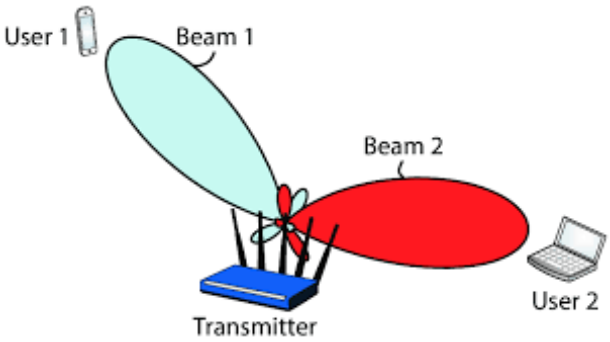

Fig. 1: Beamforming for multiple users [6]

towards desired users is known as beamforming. Fig.1 shows a graphical illustration of beamforming where bigger lobes indicate higher signal energy in those directions.

2.3. Level 3

In Level 3, we will explain beamforming to graduate students who are familiar with technical and mathematical material.

A group of antennas radiate energy in a desired direction through beamforming. In the radiations of the radio waves, main-lobe, nulls and side-lobes are produced, and the main-lobe is directed towards the user, as it contains a greater field strength. While the side-lobes are unwanted radiations in different directions. Hence, through beamforming, the radio waves which contains most of the field strength are emitted in a single direction with higher transmission efficiency. A mathematical description of this is given as follows.

Let us consider an antenna array with N elements with d distance apart. The incident wave front reaches the antenna elements with different time delays (which is equivalent to phase delay in frequency domain). The phase difference $\Delta\phi$ between consecutive sensors is given by [1]

$$\Delta\phi = \frac{2\pi}{\lambda}\, d\, sin(\theta) \tag{1}$$

where θ is the angle of incidence. Thus the received/transmitted signal phase is given by

$$y(t) = [1\ e^{j\Delta\ \phi}\ e^{j2\Delta\ \phi}\ e^{j3\Delta\ \phi}.....e^{j(N-1)\Delta\ \phi}] \tag{2}$$

'1' represents the reference signal without any phase delay. By adjusting the phase delays, the resulting signal can constructively or destructively add forming main-lobes and nulls.
Transmit beamforming: To achieve the beamforming at transmitter side, we excite antennas with phase offset to generate wave in the desired direction.
Receive beamforming: To achieve the beamforming at receiver side we multiply the received signal with conjugate of phase offsets and get the constructive reception of signal coming from different angles.

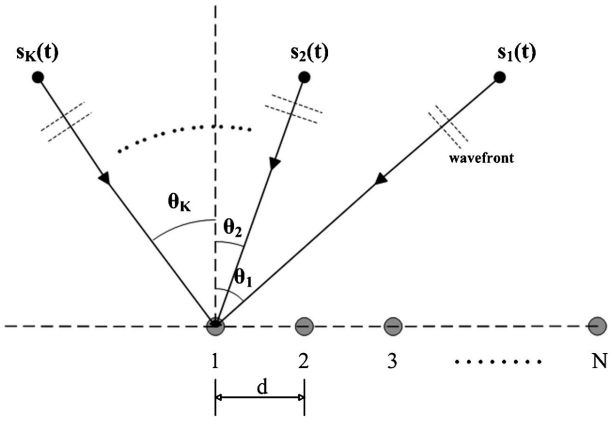

Fig. 2: Antenna array

In beamforming technique as the number of antenna elements N increases, the side-lobe gets smaller and main-lobe gets sharper. The sharper main-lobe will lead to higher signal-to-noise ratio in the desired direction.

3. CONCLUSIONS

In this 30 second video we have shown the concept of beamforming in three levels. In extension to this video we will present more detailed version of the concept in all the levels. We will extend the video in such a way that beamforming can be understood with the help of various examples and explanations along with some of its applications.

4. REFERENCES

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