



An Efficient Urban Digital Video Broadcasting (DVB) from Aerial Platforms using Smart Antenna Arrays

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Abstract: In this paper, an efficient smart adaptive antenna technique is proposed for the provision of digital video broadcasting services from aerial platforms for urban areas. The proposed smart antenna array utilizes concentric circular arrays with adaptive feeding for maximizing the signal at ground users. The array footprint from aerial platforms is analysed over the whole coverage from aerial platforms showing the link performance in terms of bit-energy to noise power spectral density ratio. The concentric circular array is optimized for providing uniform coverage over wide areas with line-of-sight propagation quality like satellite DVB systems but at very close range for both fixed and mobile stations.

Keywords: DVB Broadcasting, Aerial Platforms, Adaptive Antenna Arrays.

I. INTRODUCTION

Multimedia services have become one of the most important services provided for human beings where important information can be broadcast to users as well as entertainment content also. From these services, Digital Video Broadcasting (DVB) has direct, simple and very cheap provision for variety of information and services. The DVB standards [1-6] show the technical basis for implementing digital TV transmission in Europe, Asia, Australia, and many other regions of the world starting in 1996. DVB seems to be the best provider for global digital TV broadcasting services. The current DVB standards describe digital TV transmission over satellite and cable along with recent terrestrial transmission. Satellite DVB provides relatively low signal-to-noise ratio and large bandwidth. It utilizes QPSK modulation and scrambling and encoding techniques with variable symbol rate that allows the broadcaster to adjust the modem exactly to the bandwidth available by the transponder. Cable DVB on the other hand provides good signal-to-noise ratio but with small frequency bandwidth. The modulation scheme in Cable DVB is 64-QAM (Quadrature Amplitude Modulation) indicating high spectral efficiency. Also, a variant for the previous DVB systems is the Terrestrial DVB which provides variable signal-to-noise ratio and suffers large-scale multipath effects with very crowded frequency spectrum as it utilizes bands near to analogue TV channels.

Therefore, the DVB service is highly dependent on the propagation environment and mechanism where satellite DVB provides excellent coverage but lower signal-to-noise ratio while terrestrial DVB suffers from multipath propagation effects. Therefore, a technique should be provided to improve satellite DVB but with improved signal-to-noise ratio. In parallel with these two well-established systems, in recent years, another alternative wireless connection technique has emerged in the telecommunications community. It is based on aerial platforms [7] operating in the stratosphere and located 17–22 km above the Earth's surface. It can be considered as fixed satellite that is in the stratosphere and at these altitudes, wide coverage can be achieved up to several hundreds of kilometres with communications behaviour like satellite channel.

On the other hand, the communication performance from AP can be improved by utilizing antenna arrays with controlled feeding to provide higher gain and signal-to-noise ratio for users located in their service area. Therefore, in this paper, an antenna array with adaptive feeding is designed onboard AP for efficient DVB service provision. The paper is arranged as follows: Section II provides the proposed system model, and Section III investigates the beamforming technique and array performance. In Section IV, the results are explained and discussed, and Section V concludes the paper.

II. AERIAL PLATFORMS DVB (AP-DVB) SYSTEM MODELLING AND ANTENNA ARRAY STRUCTURE

As shown in Fig. 1, the proposed system consists of control ground segment responsible for providing DVB programs to be broadcast for users through AP-DVB station. The ground users receive services directly from AP-DVB station like

satellite DVB systems but at very close communication range which improves the signal-to-noise ratio in addition to the superior satellite propagation channel characteristics. The system performance can be further improved by using boosted signals from AP by using antenna arrays that control the footprint and gain at ground for users. Therefore, the proposed system is expected to provide users with DVB services like terrestrial systems (regarding the communication range) but with satellite channel quality. Users do not need to use large antennas for reception as the antenna arrays onboard AP provide higher gain for them. In the next section, the antenna array structure and feeding technique is explained and the footprint control is demonstrated.

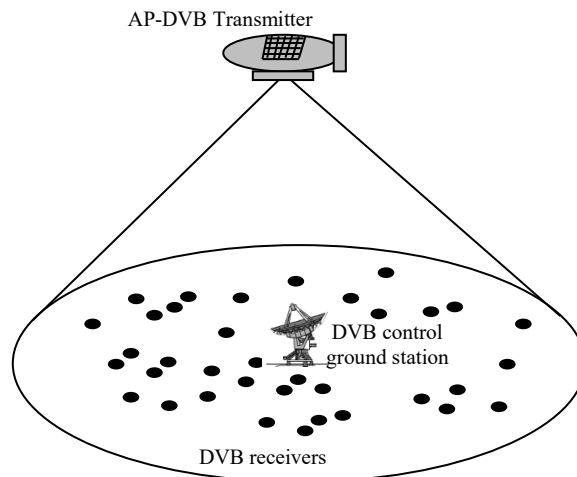


Fig. 1 AP-DVB proposed system structure

III. BEAMFORMER PERFORMANCE AND COVERAGE FOOTPRINT FROM AP-DVB STATION

There are variety of antenna array structures that can be used to provide controlled radiation pattern [8-15]. In this paper, the concentric circular array is used where it provides uniform azimuthal pattern compared to two-dimensional arrays. The array structure is shown below in Fig. 2. Concentric circular rings of antennas are arranged with uniform spacing that is almost half-wavelength with M rings and N_m elements in each ring where $m = 1, 2, \dots, M$.

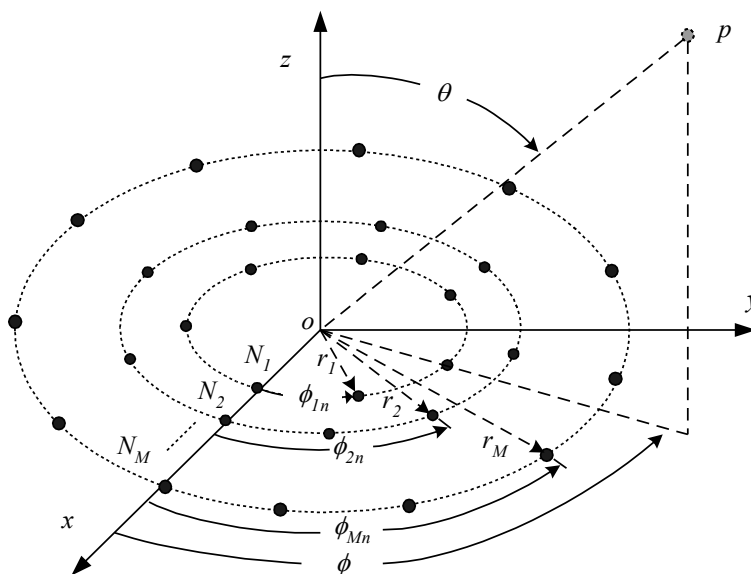


Fig. 2 Geometry of concentric circular antenna array.

The array factor for this structure is given by:

$$G(\theta, \varphi) = \text{SUM}\{W(\theta, \varphi)^H A_{CCA}(\theta, \varphi)\} \quad (1)$$

where



$$A_{CCA}(\theta, \varphi) = \begin{bmatrix} e^{jkr_1 \sin \theta \cos(\varphi - \varphi_{11})} & e^{jkr_2 \sin \theta \cos(\varphi - \varphi_{21})} & e^{jkr_M \sin \theta \cos(\varphi - \varphi_{M1})} \\ e^{jkr_1 \sin \theta \cos(\varphi - \varphi_{12})} & e^{jkr_2 \sin \theta \cos(\varphi - \varphi_{22})} & e^{jkr_M \sin \theta \cos(\varphi - \varphi_{M2})} \\ \vdots & \vdots & \vdots \\ e^{jkr_1 \sin \theta \cos(\varphi - \varphi_{1N_1})} & \vdots & \vdots \\ 0 & e^{jkr_2 \sin \theta \cos(\varphi - \varphi_{2N_2})} & \cdots \\ 0 & 0 & \vdots \\ 0 & 0 & e^{jkr_M \sin \theta \cos(\varphi - \varphi_{MN_{M-1}})} \\ 0 & 0 & e^{jkr_M \sin \theta \cos(\varphi - \varphi_{MN_M})} \end{bmatrix} \quad (2)$$

We can control the radiation pattern of the array by controlling the exciting currents. Therefore, the array factor may be determined from the following equation:

where the SUM operator is the summation of all elements in the resulted matrix $W(\theta, \varphi)^H A_{CCA}(\theta, \varphi)$, H is the complex conjugate transpose or Hermitian operator and $W(\theta, \varphi)$ is the weight matrix that controls the amplitudes and phases of the input currents.

The weighting matrix $W(\theta, \varphi)$ can be chosen carefully to control the shape of the AP radio footprint.

The received power level at ground receivers can be written as:

$$P_r(\theta, \varphi) = P_t G_t(\theta, \varphi) G_r(\theta, \varphi) \left(\frac{\lambda}{4\pi X(\theta)} \right)^2 \frac{1}{S_L} \quad (3)$$

Where P_t is the input transmitted power at HAP, $G_r(\theta, \varphi)$ is the receiving antenna power gain, $\left(\frac{\lambda}{4\pi d(\theta)} \right)^2$ is the free space path loss, λ is the wavelength in meter, $X(\theta)$ is the slant range from the AP to the receiver location and S_L is an extra loss due to other factors such as fading margin or absorption losses.

A favourable representation for $P_r(\theta, \varphi)$ is using decibel form as follows:

$$P_r(\theta, \varphi) dB = P_t dB + G_t(\theta, \varphi) dB + G_r(\theta, \varphi) dB - 20 \log \left(\frac{4\pi X(\theta)}{\lambda} \right) - S_L dB \quad (4)$$

On the other hand, the required input power at the transmitting AP antenna system can be written as:

$$P_t dB = P_r(\theta, \varphi) dB - G_t(\theta, \varphi) dB - G_r(\theta, \varphi) dB + 20 \log \left(\frac{4\pi X(\theta)}{\lambda} \right) + S_L dB \quad (5)$$

If we assume simple unity gain receiving antenna ($G_r(\theta, \varphi) dB = 0 dB$), then the received power is affected by the AP antenna power pattern $G_t(\theta, \varphi) dB$ and slant distance $d(\theta)$ assuming other factors are constant.

The slant range $X(\theta)$ is given by:

$$X(\theta) = (h + R_e) \cos(\theta) - \sqrt{R_e^2 - (h + R_e)^2 (\sin(\theta))^2} \quad (6)$$

Where R_e is the Earth's radius.

A key performance measurement for link performance is the ratio of bit-energy to noise power spectral density $\left(\frac{e_b(\theta, \varphi)}{n_o} \right)$ that is a function of the receiver location as it depends on the received signal power strength, bit rate (r_b) and noise power spectral density (n_o) as follows:

$$\frac{e_b}{n_o}(\theta, \varphi) = \frac{P_r(\theta, \varphi)}{r_b n_o} \quad (7)$$

Where $n_o = KT$, K is the Boltzmann's constant and T is the noise temperature in Kelvins.

$\frac{e_b}{n_o}(\theta, \varphi)$ is usually expressed in dB as follows:

$$\frac{e_b}{n_o}(\theta, \varphi) dB = P_r(\theta, \varphi) dB - 10 \log(r_b) - 10 \log(n_o) \quad (8)$$



or

$$\frac{e_b}{n_o}(\theta, \phi) \text{ dB} = P_t \text{ dB} + G_t(\theta, \phi) \text{ dB} + G_r(\theta, \phi) \text{ dB} - 20 \log\left(\frac{4\pi d(\theta)}{\lambda}\right) - S_L \text{ dB} - r_b \text{ dB} - n_o \text{ dB} \quad (9)$$

In the next section, the array footprint is examined and evaluated along with the communication performance.

IV. RESULTS AND DISCUSSION

First, it is very important to define the array feeding weights which control the footprint and received power levels. Assume that an urban area of a city extends to a square of 40 km length is served by an AP at 20 km high with an array of 4 concentric rings and the starting ring is composed of 4 elements separated by half-wavelength distance. Uniform feeding of this array results in the normalized footprint pattern shown in Figure 3 where its maximum is directed to the city centre.

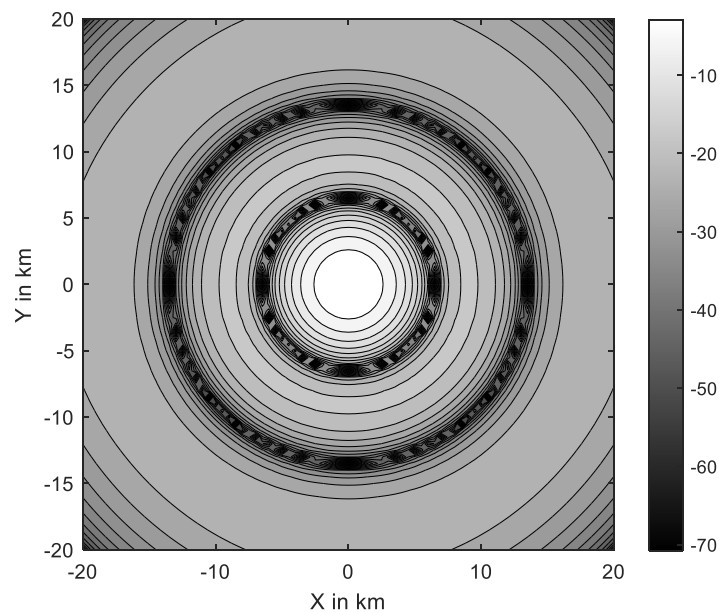


Fig. 3 AP footprint pattern using uniformly fed concentric circular arrays at 20 km high.

The vertical bar in this figure represents the normalized footprint power level. At the coverage boundaries, the normalized power level drops to about -22 dB with some deep rings in the coverage between sidelobes in the array factor. For a city extending to a radius of 4 km, this kind of coverage is sufficient however the regions around city will suffer from deep gap rings in the coverage. To overcome this coverage gap, the feeding of the array should be windowed using binomial weights which provides the widest beam coverage with reasonable power gain.

The binomial feeding is applied to the different rings m where $m = 1, 2, \dots, M$ and M is the number of rings in the array as follows:

$$W(m) = \frac{1}{2^{M-1}} \frac{(M-1)!}{m!(M-1-m)!} \quad (10)$$

The resulting footprint is shown in Fig. 4 where the coverage area is widened to include more areas around city centre. For example, at 10 km from the city centre, the normalized power pattern drops to -16 dB without any coverage gaps, so users can receive much better signals far enough from the city centre.

The improved footprint profile can be inserted into eq. (9) utilizing the Terrestrial DVB general specifications where 700 MHz is the carrier frequency, the channel bandwidth is chosen 8 MHz, and with an average data rate of 50 Mbps. The transmitter power is set at 1 Watt or 0 dBW. In this case, we will not normalize the antenna gain to get more realistic case study.



Fig. 5 displays the array power gain profile in dB with distance which affects the value of $\frac{e_b}{n_o}(\theta, \phi)$ that is isotropic with the angle ϕ . The system performance can be investigated by the probability of $\frac{e_b}{n_o}$ that is less than a specific value as shown in Fig. 6 which shows very good reception performance over wide urban areas with good probability.

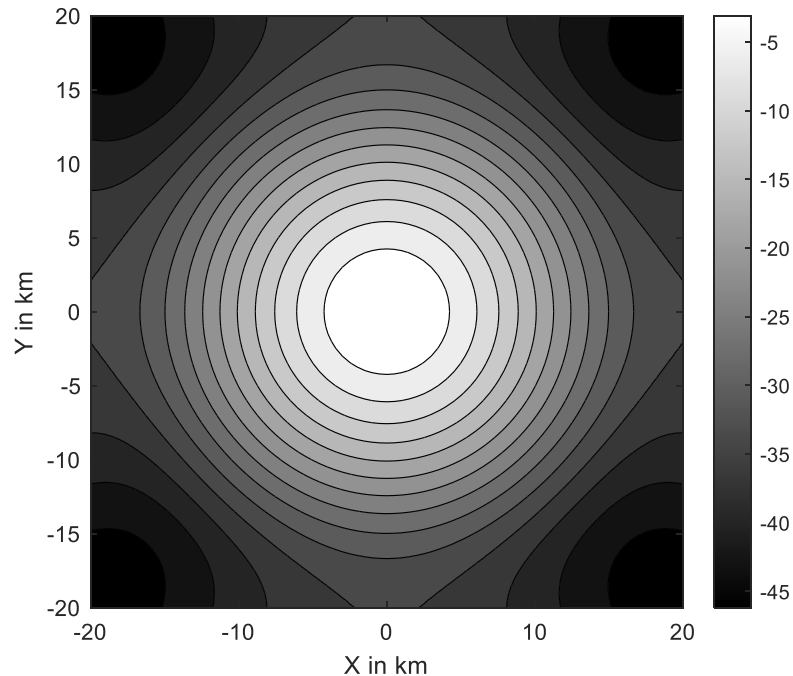


Fig. 4 AP footprint pattern using binomially fed concentric circular arrays at 20 km high.

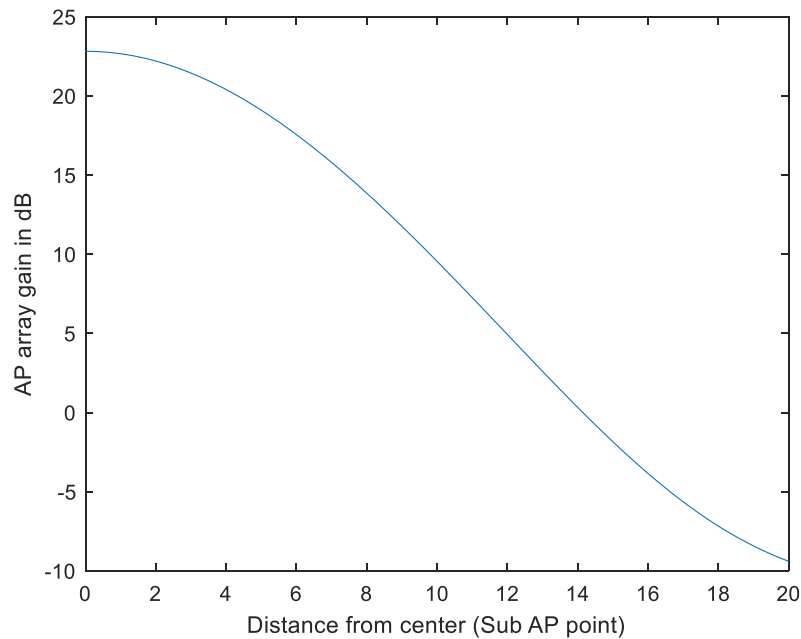


Fig. 5 AP array gain in dB profile with distance from sub-AP point

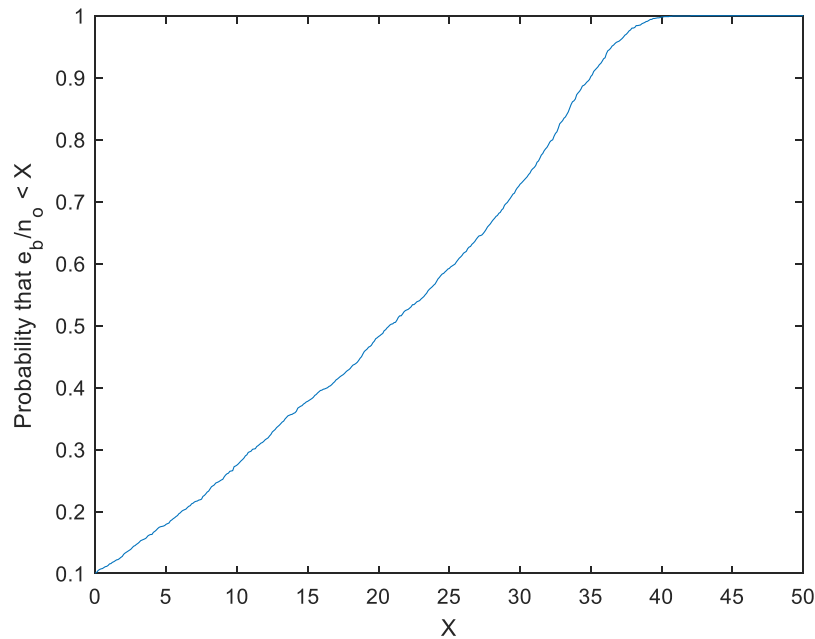


Fig. 6 Coverage performance in terms of $\frac{e_b}{n_o}$ distribution

V. CONCLUSION

In this paper, a system for providing DVB services using AP and smart adaptive antenna arrays is proposed for urban areas that include large cities with combined areas at its boundary which can extend to 20 km wide. The DVB is provided using single AP transmitting station along with onboard adaptive smart antenna arrays to enhance signal performance and control the coverage footprint. To reduce the deep gaps in coverage and widen its access to city boundaries, the adaptive array is designed using concentric circular arrays with binomial function feeding.

The resulting $\frac{e_b}{n_o}$ in the coverage zone shown very optimizing results that ensure high quality in performance for a typical DVB service.

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