E-ISSN: 2706-8927
P-ISSN: 2706-8919
www.allstudyjournal.com
IJAAS 2021; 3(1): 467-469
Received: 15-11-2020
Accepted: 19-12-2020

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Analysis of space diversity beam steering microstrip BTS antenna system for 3G and 4G

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Abstract
In this paper, a microstrip BTS antenna system using a beam steering antenna scheme with a transmit diversity is presented. The proposed antenna can move its beams toward the target, i.e. the highest user density location within its serving cell. The scanning angle is calculated using the direction finding system. Performance of this antenna system is compared to sector beam antenna systems. With this antenna, high speed communication, shaped beams and high gain can be achieved.

Keywords: BTS, DOA, MEMO, beam steering and sectorization

Introductions
In the past, BTS antenna of the first generation had omnidirectional patterns whereas the second generation had sectorization patterns [1, 2]. With the development of 3G and 4G, the need for smart antenna has risen [3]. In addition, to develop BTS antenna systems dealing with very high speed communications, the MIMO strategy is suggested [4]. In this paper, an approach for BTS antenna system for 3G and 4G using a microstrip antenna system combining a beam steering antenna scheme with MIMO strategy is presented.

BTS Antenna Structure
A conventional BTS antenna system is placed on the sides of an equilateral triangle (Fig. 1). In general, the antenna on each side supports one of three sectors. If the beamwidth of each antenna is about 120 degrees, this BTS antenna system will serve nearly 360 degrees of azimuthal plane. As in [1], we can use one antenna for both transmitting (Tx_1) and receiving (Rx_1) and two receiving antennas (Rx_2, Rx_3) on each side. Rx_2 and Rx_3 are used for direction of airival (DOA) estimation.

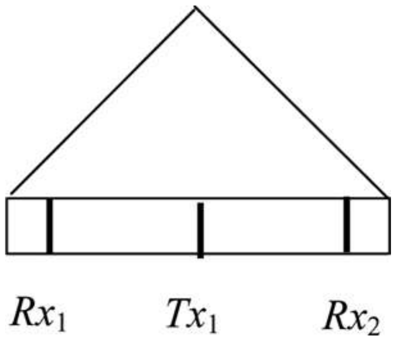

Fig 1: Conventional antenna structure

New BTS Antenna Structure
The antennas are still placed on the three sides of an equilateral triangle. However for 3G and 4G, two identical transmitting antennas (Tx_1, Tx_2) spaced by ten wavelengths are used compared to one transmitting antenna (Tx_1) for 2G (Fig. 2). These are also used for receiving, i.e. Rx_1 and Rx_2. The DOA estimation is performed using an antenna system without phase center [5]. This direction finding system is placed on the top of the triangle (Fig. 2). Tx_1 and Tx_2 consist of four patch antenna elements spaced by one wavelength. Butler matrices with four 90° hybrids and phase shifters are used for their beamforming network (Fig. 3).

The phase shifters connected to antenna elements are phased progressive whereas the phase shifters in the Butler matrices are phased by -90 degrees. At any given time there is only one input of Tx_1 or Tx_2 that is connected to the transmitter whereas the others are grounded. The direction finding system decides which input is connected to the transmitter so that there are always two beams focusing on the target within a given cell.

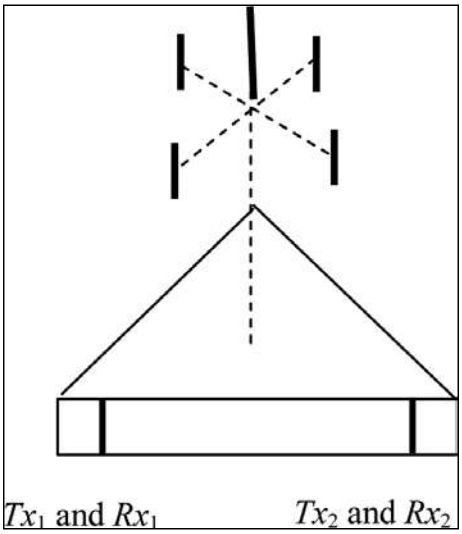

Fig 2: New BTS antenna structure.

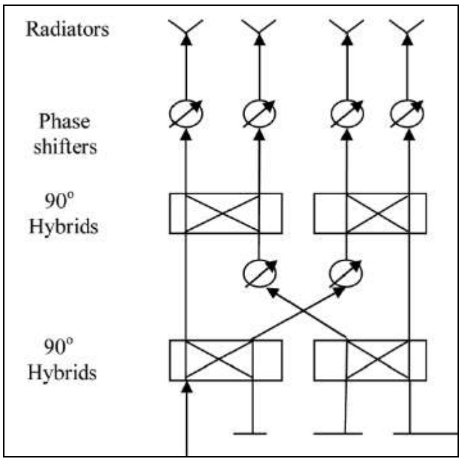

Fig 3: Structure of Tx_1 or Tx_2.

Operation

For the transmitting strategy, we assume that a transmitted symbol is constant during the sampling period T_1. At time t, symbol S_0 is transmitted by Tx_1 and symbol S_1 is transmitted by Tx_2. At time t + T_1 symbol $-S_1$ and S_0 are transmitted by Tx_1 and Tx_2, respectively. We assume that at time t + $2T_1$ the target moves by an angle of α degree compared to its previous position. At time $t+2T_1+T_2$($T2 << T_1$), the antenna system moves its beams toward the target using a beam steering technique. In order to move its beams by an angle α, the phase difference between consecutive elements has to be equal to $-\beta d \cos(\theta_M+\alpha)$ where β is the propagation constant, d is the distance between two consecutive antenna elements, and M θ is the maximum radiation angle at time t. The angle, α, is calculated using the direction finding system given in [5].

Evaluation

We assume that f=3 GHz is the operation frequency and that Teflon fiberglass with thickness h = 1.59 mm and dielectric constant ε_r=4.8 is used for patch material. According to antenna design principles [4, 7], the design parameters of Tx_1 or Tx_2 are obtained as follows.

The width of the patch, W, and the length of the patch, L, are given by

$$W = \frac{c}{f}\sqrt{\frac{2}{\varepsilon_r + 1}}, \quad L = L_{eff} - 2\Delta l \tag{1}$$

Where

$$L_{eff} = \frac{\lambda}{2\sqrt{\varepsilon_{eff}}} \text{ and } \Delta l = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{2}$$

The effective dielectric constant is given by

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-0.5} \tag{3}$$

The input resistance of the patch can be written

$$R_{in} = \frac{60\lambda}{W} \tag{4}$$

The half power beamwidth and the side lobe level of Tx_1 or Tx_2 are given by

$$\theta_{HPBW} = 2\left[\frac{\pi}{2} - ar\cos\left(\frac{0.4428}{Nd}\lambda\right)\right], \quad SLL = 10\log\frac{1}{N\sin(3\pi/2N)} \tag{5}$$

Where N is the number of antenna elements and d is the distance between two consecutive elements.

The limited scanning angle of Tx_1 or Tx_2 is given by

$$\theta_{\max} = 2\left(\frac{\pi}{2} - ar\cos\left(1-\frac{0.8128}{N}\right)\right) \tag{6}$$

The gain of Tx_1 or Tx_2 is given by

$$G = 10\log\left(\frac{4\pi A}{\lambda^2}\right) - \frac{\alpha}{2}(d_1+d_2) - L_1 - L_2 \tag{7}$$

Table 1: Design parameters.

Patch width (W-mm)	Patch length (L-mm)	Effective dielectric constant (ε_{eff})	Patch input resistance (R_{in}-Ω)	Half power beamwidth ($\theta_{HPBW}{}^{o}$)	Gain with no loss (dBi)	VSWR	Side lobe level (SLL -dB)	Limited scanning angle ($\theta_{\max}{}^{0}$)
58.7	22	4.5521	102.2	12.7	15.76	1.5	-5.67	105.66

From Table 1, the limited scanning angle is 105.66 degrees, thus the beam scanning of Tx_1 or Tx_2 covers the angle of 118.33 degrees (θ_{max}° + θ_{HPBW}°) which is nearly one sector of 120 degrees.

In 3G and 4G we use a directional antenna for a mobile unit (MU). Let D, D_0, D_1, and D_2 be the directivity of the receiving antenna of the MU, the directivity of the sector beam transmitting BTS antenna, and the directivity of Tx_1 and Tx_2, respectively. For comparison, the transmitted powers of Tx_1 and Tx_2 are equal to half of the transmitted power of the sector beam transmitting antenna (P_t).

For the suggested antenna system, the MU received power is given by

$$P_{r2} = \frac{P_t}{2}\frac{D_1 D}{(4\pi d/\lambda)^2} + \frac{P_t}{2}\frac{D_2 D}{(4\pi d/\lambda)^2} \tag{8}$$

For the case of sector beam, the MU received power is calculated as

$$P_{r1} = P_t \frac{D_0}{(4\pi d/\lambda)^2} \tag{9}$$

The diversity gain is obtained as follows:

$$DG = 10\log\left(\frac{D(D_1 + D_2)}{2}\right) - 10\log D_0 = 10\log\left(\frac{D}{2}\right) + 10\log(D_1 + D_2) - G_0 \tag{10}$$

As in [2], G_0 is 17 dBi for sector beam antenna. From (7) we get 37.68=D_1 = D_2, hence

$$DG = 10\log\left(\frac{D}{2}\right) + 1.77 \text{ (dBi)} \tag{11}$$

From Table 1 and (11) we can see clearly that the proposed antenna system is better than the sector beam antenna system. With this antenna, high speed communications, shaped beams, beam steering and high gain can be obtained.

Conclusion

An approach for BTS antenna system was presented. Its benefits were pointed out. It is an important step in telecommunications research toward applications for next generation wireless networks.

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