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Multiple-Antenna Techniques in Wireless Communication-Technical Aspects

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***Abstract*—Performance of wireless mobile communication can be improved by using multiple antenna techniques. For different applications different types of multiple antenna techniques are used. This paper describes the technical details of multiple antenna techniques for various types of wireless communications. A comparison of all types of multiple antenna techniques (MTA), described in this paper, is also reported.**

Index Terms—Multiple antenna; antenna array; broadband communication; mobility

I.INTRODUCTION

During last two decades, there was exceptional technological development of wireless communication. From earlier voice communication only, people demands communication services for internet, laptop, FM radio, mobile handset television, movie on demand, live sport telecast and other various multimedia data transmission with high mobility. To provide these services research work progressed towards novel networking protocols, new adaptive coding techniques, high speed data transmission, interference and fading mitigation techniques [1]. In addition to above research areas, development of antenna techniques can solve many such problems in wireless mobile communication [2-5].

This paper describes the technical aspects of antenna techniques which may be used for next generation mobile communication. Here technical details of multiple antenna techniques for high speed wireless mobile communication are explained. Multiple antenna techniques, like, sector antennas[1], beam steering/scanning antennas[1-3], diversity antennas[1], smart antenna[2,3,7], space division multiple access (SDMA) antennas [8], multiple input multiple output (MIMO) antennas [9] are described. At last, application of multiple antenna technique in distributed antenna system [10] is reported.

II. WIRELESS MOBILE ENVIRONMENT

Wireless mobile communication is affected by propagation path loss, long-term fading, short-term fading, co-channel interference, adjacent channel interference and inter-symbol interference (ISI) [1]. In order to mitigate these fading and interference in mobile environment, antenna techniques can take part a major role. Depending on applications various types of antennas are necessary. Types of antennas may be broadband antennas which operate over a wide frequency band, multi-frequency antennas which operate at two or more frequency bands of relatively narrow frequency bands, multiple beam antennas which generate simultaneous multiple beams. Also types of antennas may be omnidirectional antennas or directional antennas. Delay spread in mobile environment is more for omnidirectional antennas than directional antennas. A typical comparison of delay spreads for omnidirectional antenna and directional antenna shown in Fig. 1.

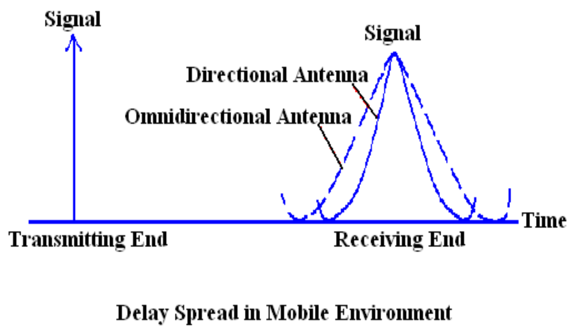

Fig. 1. Delay spread for omnidirectional and directional antennas

Multiple-antenna techniques can provide high speed broadband multimedia communication with reduced interference and fading [5-6]. Multiple antenna system, in wireless communication, may be an antenna array or may not be an antenna array.

III. MULTIPLE-ANTENNA TECHNIQUES USING ANTENNA ARRAY

Multiple-antenna system using antenna arrays is beam steering/scanning antenna, smart antenna, SDMA antenna etc.

A. Beam Steering/Scanning Antenna

This type of antenna is phased array antenna (Fig. 2) where by changing phases of individual antenna elements electronically, beam can be tilted at any desired directions [4]. The array factor of an n-element uniform linear array is

$$AF = \frac{Sin(\frac{n\psi}{2})}{Sin(\frac{\psi}{2})} \tag{1}$$

where, $\psi = \beta d Cos(\varnothing) + \alpha$, d is the inter-element spacing in the array, α is the progressive phase shift and $\beta=2\pi/\lambda$. Now, if the main beam is to be tilted at an angle $\varnothing_0$, then the

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progressive phase shift is to be adjusted in such a way so that

$$\psi = \beta dCos(\phi) + \alpha$$

That is, $\alpha = -\beta dCos(\phi)$ (2)

This MAT using scanned array is useful for vehicular applications (Fig. 3).

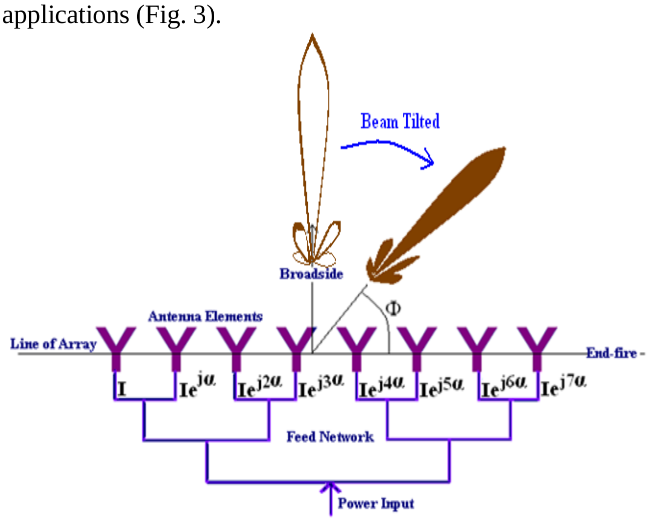

Fig. 2. Beam steering/scanning antenna array

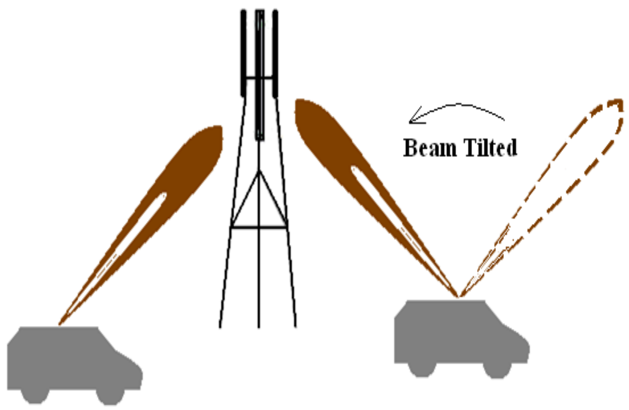

Fig. 3. Beam steering/scanning antenna for vehicular application

Beam scanning antennas are supposed to be very useful in wireless communication using millimeter wave band [11, 12], as suggested in IEEE 802.16. Architecture of intelligent transport system using millimeter wave technology [11] is shown in Fig. 4, where beam scanning antenna is used. Intelligent transport system provides wireless personal area network (WPAN) communication, inter-vehicular communication (IVC) for the prevention of accident, road-side to vehicle communication (RVC) etc. using millimeter wave technology.

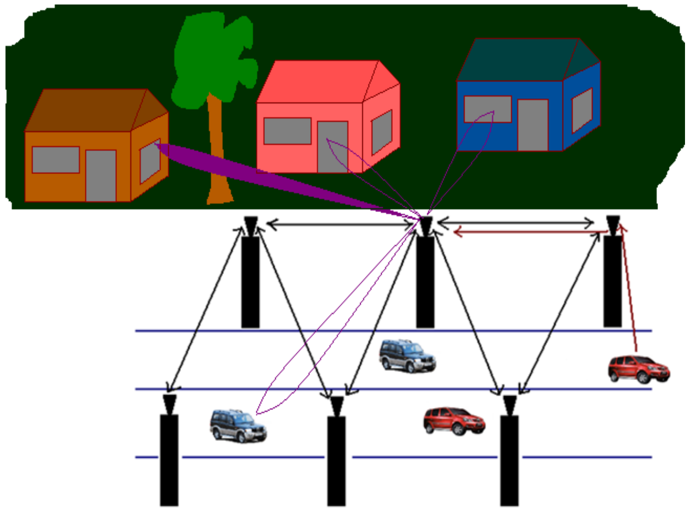

Fig. 4. Beam steering/scanning antenna for intelligent transport system

B. Smart Antenna and SDMA antenna

Smart antenna reduces wastage of power by providing point-to-point communication based on direction-of arrival (DOA) of the signal [7, 8]. Beam is adapted by adjusting the amplitudes and phases of signals for a desirable pattern using antenna array. This adaptive antenna produces nulls towards undesired (receiving) users and highly directive beam towards desired direction (Fig. 5). SNR for the other co-channel users is improved as well as the SNR at the desired receiver.

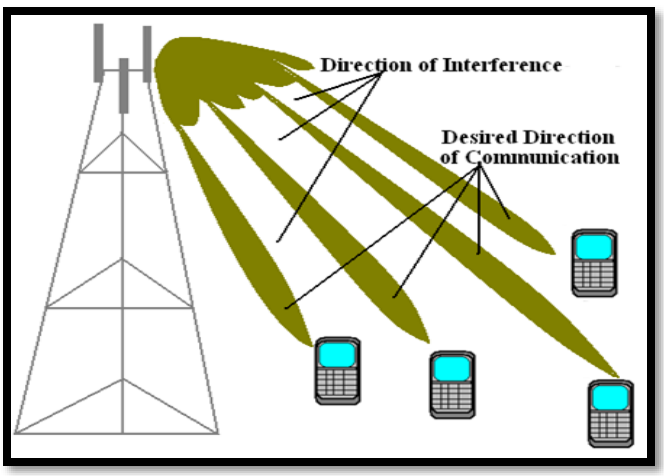

Fig. 5. Smart antenna

In SDMA technique, multiple beams at same frequency are generated with spatial angular separation (Fig. 6) to communicate with multiple co-channel users within the same frequency band [13]. SDMA is mainly MIMO-based or smart antenna-based wireless communication system and suitable for mobile ad hoc network (MANET). In this case, network capacity in terms of users per cell is high.

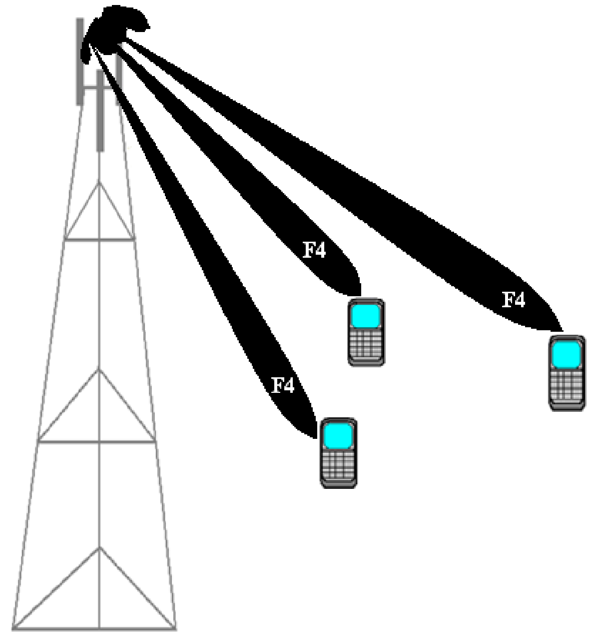

Fig. 6. SDMA antenna

Multiple antennas in SDMA protect quality of radio signal, safeguard against interference and also save power. Spatial multiplexing in SDMA is accomplished by sending several bit streams through multiple antennas increases data rate. Typical performance graphs of SDMA are compared below in Fig.7 and Fig. 8 with performances of fixed channel allocation (FCA) and hierarchical SDMA with dynamic channel allocation (HSDCA).

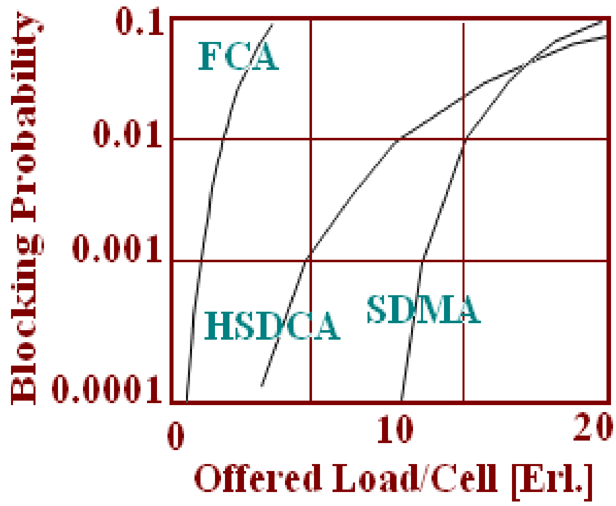

Fig. 7. Comparison of blocking probability

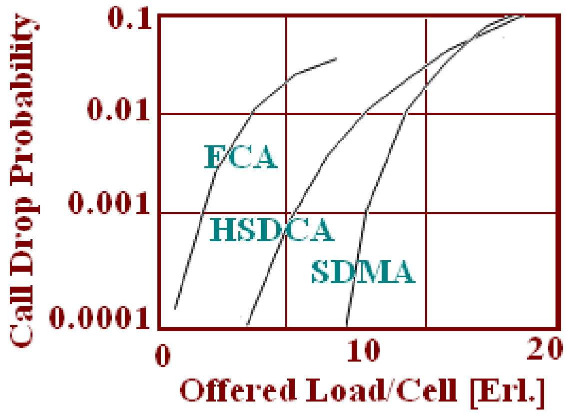

Fig. 8. Comparison of call drop probability

IV. MULTIPLE-ANTENNA TECHNIQUES USING INDEPENDENT MULTIPLE ANTENNAS

Multiple-antenna techniques without using antenna arrays include diversity antennas, MIMO antennas, sector antennas etc.

A. Diversity Antenna System

Diversity antenna uses multiple antennas to improve system performance in fading environment. Antennas are located to receive high cross correlation signals. Properties of antenna array elements are combined at the RF level (broadside, end-fire, any desired direction) but in diversity scheme signals from diversity antennas are combined at either in IF level (Maximal-ratio combining) or in Baseband level (Equal-gain combining) [1]. The basic diversity system is shown in Fig. 9.

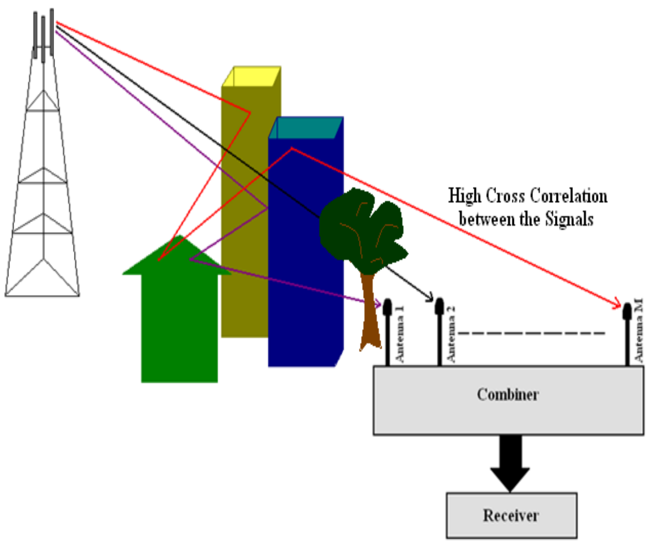

Fig. 9. Diversity system

There are various types of diversity schemes, used to achieve best quality signal at different applications. In space diversity, antennas are separated more than coherence distance. In frequency diversity, antennas are used to receive different frequencies. In pattern diversity, different antennas have different radiation patterns and system receives incoming signals, almost with 180^0 coverage. In polarization diversity scheme, a number of antennas are used to receive vertical polarized signal and for horizontal polarized signal or to receive right handed circularly polarized (RHCP) signal or left handed circularly polarized (LHCP) signal. In Fig. 10, diversity system in a mobile handset uses two planar inverted-F antennas (PIFAs).

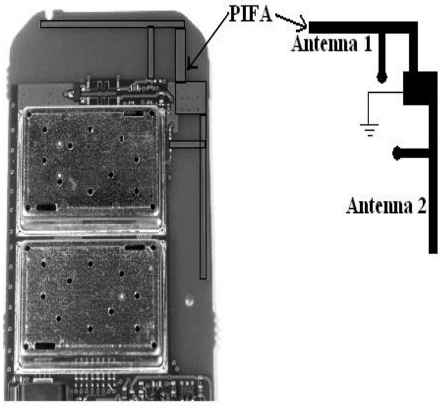

Fig. 10. Diversity system used in mobile handset

B. Sector Antennas

Sector antennas (Fig. 11) are directional antennas having radiation pattern like a sector, covering a portion of a cellular area [1, 4]. Sectors of 120^0, 90^0, 60^0, 30^0 are known as 3-sector, 4-sector, 6-sector and 12-sector antennas respectively. 3-sector antennas are widely used. Antenna beam is tilted downward.

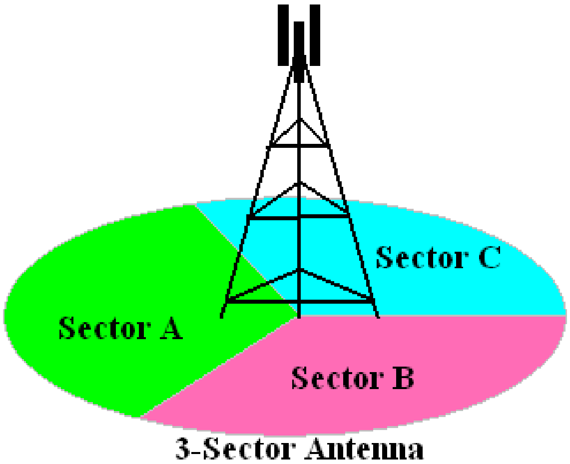

Fig. 11. Sector antenna

Antenna gain of sector antennas decreases as the number of sector increases. Multiple antenna technique used in sector antenna reduces co-channel interference, increases spectral efficiency in cellular communication, minimizes delay spread and therefore, reduces bit error rate (BER). Application of sector antennas in a cell provides efficient frequency re-use.

C. MIMO Antennas

MIMO Wireless Systems is a spatial multiplexing to increase spectral efficiency or transmit diversity (space-time coding) techniques [1, 9] to improve link reliability using multiple antennas (Fig. 12). MIMO performance depends on antenna height, spacing and nature of scatterer. Antenna separation is kept more than coherent distance. MIMO is most suitable technique for WiFi, WiMAX, IEEE 802.11, 802.16, 4G and long term evolution (LTE) system.

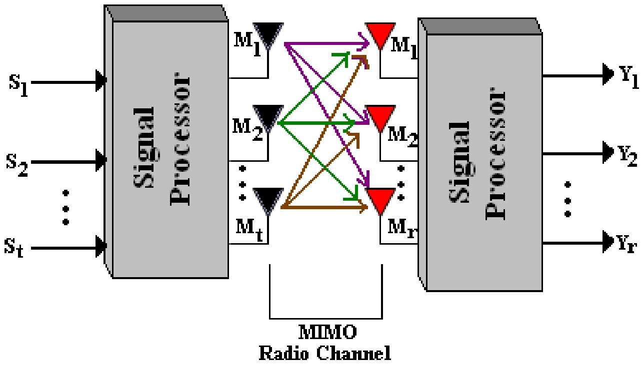

Fig. 12. MIMO system

Within a next few years millions of people will try to transmit and receive holographic video in all directions continuously and then the present MIMO system will fail to provide good quality service. A new system, called massive MIMO is coming up using multiple antenna system which will be a large-scale antenna system [14, 15].

D. Distributed Antenna System

In distributed antenna system, multiple antennas are used to provide good quality secured wireless communication in the urban and suburban areas where signal quality is relatively poor. In DAS (Fig. 13) the main processing antenna module is centralized at a location which is central unit (CU) and is connected with distributed antenna modules (DAM) [10]. Optimization of antenna location in DAS based on signal-to-noise ratio and power consumption is important.

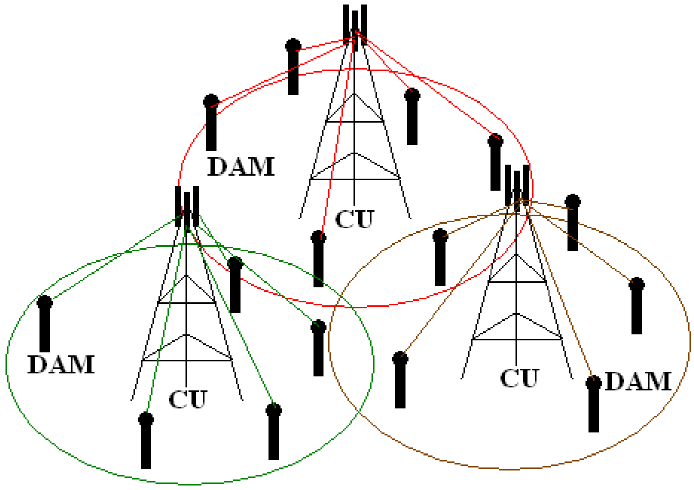

Fig. 13. Distributed antenna system

In future high data rate multimedia communication, like, 4G, 5G and LTE, this technique might be very effective.

V. COMPARISON OF MULTIPLE-ANTENNA TECHNIQUES

The performances of multiple antenna techniques, explained above, are tabulated in Table I.

TABLE I. COMPARISON OF DIFFERENT MULTIPLE ANTENNA TECHNIQUES

Multiple Antenna Techniques	Performances in Mobile Communication
Beam Steering Antennas	Reduces multipath effect, low delay spread, less inter-symbol interference
Diversity Techniques	Reduces effect of multipath fading and reduces polarization mismatch at the receiving end
Sector Antennas	Enhances spectral efficiency and frequency re-use, reduces interferences , minimizes delay spread and reduces bit error rate (BER)
MIMO Antennas	Increases channel capacity, Improves signal quality
Smart Antenna	Power saving, increases signal detection capability by estimating DOA, nulling out co-channel interference and noise, jamming suppression is possible
SDMA Antennas	Efficient frequency re-use & high bit rate data, enhanced network capacity in terms of users per cell
Distributed Antenna System (DAS)	Effective in poor signal condition, more power consumption, hardware implementation is expensive

VI. CONCLUSION

The reason behind the use of different multiple antenna techniques for different applications are presented here. In spite of several advantages in wireless mobile communication of multiple antenna techniques in wireless applications, it has some drawbacks also. In multiple antenna technique, multiple parallel transmitter/receiver chains are required, leading to increased hardware costs. This technique may increase power consumptions and real-time implementations of near-optimum multiple-antenna techniques can be challenging, specially, for massive MIMO.

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