Design and Performance Antenna Diversity for MIMO WiMAX Mobile Terminals

Mohannad J Mnati

Abstract*: New evolutions in wireless communications have shown using multiple antenna elements at both transmitter and the receiver, it is possible to substantially increase the capacity in a wireless communication system without increasing the transmission power and bandwidth. This system with multiple antenna elements at both link-ends is termed the MIMO (Multiple-Input Multiple-Output) system. In spite of considerable research being done on MIMO systems; the design of realistic diversity antennas on mobile terminals for MIMO systems remains a challenging issue. The main challenge in designing two or more antennas on a small mobile terminal is to achieve a high isolation between the antennas. It is very difficult to achieve a high isolation with the existing handset antennas. This article presents the performance analysis of the multiple-input-multiple-output Diversity antenna fornext generation WiMAX mobile handset applications Planar Inverted-F Antenna (PIFA). Antenna structures considering the practical ground size of a mobile handset proposed to estimate the proposed structures, mutual coupling and envelope correlations were considered. Also the diversity gain and correlation were measured from simulation result. The relationships between all parameters were analyzed based on the measured results.

Index Terms— **PIFA, Mobile, Antenna, WiMAX, MIMO, Diversity.**

I. INTRODUCTION

Research conducted on MIMO systems has advanced significantly, with Lucent Technologies (Bell Labs Innovations) being the leading player. Lucent Technologies has conducted measurements on(2x2),(4x4)and (16x16)MIMO systems in urban surroundings – Manhattan, New York [1]. In the measurement campaigns, vertically and horizontally polarized slot antenna elements were used for both the transmitter and receiver. At the receiver (a laptop was used as the receiver terminal), the antenna elements were spaced half-wavelength apart from each other to accomplish low correlation and high capacity. System capacities of 5.5bps/Hz, 10bps/Hz and 35bps/Hz were reported, correspondingly, in (2x2), (4x4) and (16x16) MIMO systems at the 10dB system SNR. Measurement on MIMO channels in the rural surroundings has moreover been carried out by Lucent Technologies [2]. It was reported that the capacity in a 8x10 MIMO system was roughly eight times the related capacity in a (1x1) SISO (single-input single-output) system, and 3.2 times the related capacity in a (1x10) SIMO (single-input multiple-output) system.

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The measurement also found that using antenna arrays containing antennas of both horizontal and vertical polarizations could increase the capacity by about fifty percentages. Measurements on 4x4 MIMO systems over a 3G wireless network have also been conducted in an indoor surroundings and it was reported the taken as a whole capacity of 7.7 5 bps/Hz was obtained [3and 4]. In addition, Lucent Technologies has designed two prototype chips for mobile devices that employ the MIMO wireless network technology [5].In the UK, Of com (Office of communication – the independent regulator and competition authority for the UK communications industries) has supported and funded a MIMO technology investigate project –'Antenna Array Technology and MIMO Systems' [6and7] , which concerned Queen Mary University of London (QMUL), University of Bristol, University of York, BT Exact Technologies, Toshiba Research Europe Limited and Antenova Ltd. The Of com project has shown that MIMO systems can give significant capacity gains compared to single-input single-output (SISO) systems, however the channel capacity is strongly dependent on the environments as well as the antenna configurations. In the project, QMUL and Antenova Ltd developed two different four elements antenna arrays on Personal Digital Assistant (PDA); i.e. dielectric loaded folded loop antenna arrays the dielectric loaded folded loop antenna presenting though, in both designs the antennas were located on each corner of the PDA terminal which was not practical as some antennas would be covered by the user's hand for most of the time. The European Commission has supported the I-METRA (Intelligent Multi- Element Transmit and Receive Antennas) project [8]. The I-METRA project consortium comprised of University at Politecnica de Catalunya (Spain), Aalborg University (Denmark), Nokia (Finland) and Vodafone Ltd. The I-METRA project has confirmed that, by doubling the number of antenna elements at the receiver from two to four, the system's capacity and coverage will be significantly enhanced. Today, there are some MIMO products readily obtainable in the market for WLAN applications (IEEE 802.11a/b/g standards). With the introduction of MIMO technology and the OFDM (orthogonal frequency division multiplexing) modulation type, WLAN can fully take benefit of high speed broadband internet connections, accommodate bandwidth intensive applications such as video streaming and provide dependable coverage all through a business or house. Airgo MIMO Wireless Card Linux Driver [9] are used in wireless routers by Netgear (Model: Range Max 240) [10], Linksys (Model: Wireless-G with SRX 400) [11] and Belkin (Model: Wireless Pre-N Router) [12]. Also, Ruckus Wireless Inc. has developed the first wireless multimedia home distribution system using MIMO technology [13].

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Airgo has reported that MIMO systems can deliver a peak capacity of 108Mbps; this is compared to a peak capacity of 54Mbps as delivered by SISO systems. Though, to date, MIMO technology is still not being implemented on small mobile terminals (e.g. PDAs and handsets).Recently the mobile WiMAX is headmost from other service, “Mobile WiMAX” denote to a rapidly growing broadband wireless access solution built upon the IEEE 802.16e-2005 air interface standard. Contrary to its name, Mobile WiMAX is similarly applicable to fixed, portable and mobile applications. The WiMAX Forum has developed Mobile WiMAX system profiles that define the mandatory and optional features of the IEEE standard necessary to construct a Mobile WiMAX complaint air interface which can be certified by the WiMAX forum. A collectionof antenna techniques are supported by Mobile WiMAX to increase throughput, especially at the cell edge. For example, the use of multiple-input multiple-output (MIMO) antenna techniques joint with flexible sub-channelization type, adaptive modulation and variable coding rates enable Mobile WiMAX technology to support peak downlink (DL) data rates up to 46 Mbps per sector and peak uplink (UL) data rates up to 14 Mbps per sector in a 10 MHz channel (DL 2x2 MIMO, 3:1 DL/UL ratio; UL 1x2 collaborative MIMO; 1:1 ratio)1[20]. In this paper focus of design MIMO PIFA antenna in mobile WiMAX and explain the important requirement need for this design.

II. ANTENNA DIVERSITY

Multipath propagation caused by scattering had in the past been regarded as impairment because it causes signal fading. In order to mitigate this problem, diversity techniques were developed. The basic principle of diversity is that the receiver should have more than one version of the transmitted signal available, where each version is received through a different signals are uncorrelated. It shows that the combined signal creates a higher mean SNR at the output compared to a single branch resulting in a diversity gain. Apart from mitigating the signal fading problem, as previously mentioned, diversity techniques are also used to exploit the MIMO channels using a space-time coding signaling scheme. There are five categories of diversities, i.e. frequency diversity, time diversity, spatial diversity, pattern diversity and polarization diversity. Amongst the five diversities, only the spatial, pattern and polarization diversity techniques are categorized as antenna diversity [21].

A. Diversity gain

The efficiency of diversity technology is generally evaluated in terms of diversity gain. Diversity gain is defined as the improvement in the SNR of the signals at the output of the diversity combiner or switch, relation to the SNR from a single branch for stated reliability. In this paper, the Rayleigh channel, which is a multipath propagation surroundings, is suggest the CDF (Cumulative Distribution Function) of a Rayleigh channel [21]:

$$P(\gamma < \gamma s / \xi) = 1 - e^{\frac{-\gamma s}{\xi}} \qquad (1)$$

Where ξ is the mean SNR, γ is the instantaneous SNR, $P(\gamma < \gamma s / \xi)$ is the probability that the SNR will fall below the given threshold, $\gamma s / \xi$. For a selection combiner with N independent branches, assuming that the N branches have independent signals (correlation equal to zero) and the same mean SNRs, the probability of all branches having a SNR below γs is equivalent to the probability for a single branch raised to the power N as [21].

$$P(\gamma < \gamma s / \xi)N = (1 - e^{\frac{-\gamma s}{\xi}})^N \qquad (2)$$

Where N is the number of branches. The normalized SNR is defined as $\gamma s / \xi$, the diversity gain is marked of where $P(\gamma < \gamma s / \xi) = 1\%$ (i.e. 99 % reliability). For low instantaneous SNR, that $\gamma \leq \xi$, equation (2) can approximated for that reason, by re-arranging equation (3) [21].

$$P(\gamma < \gamma s / \xi)N \approx (\frac{\gamma s}{\xi})^N \qquad (3)$$

The diversity gain for a 100% efficiency two branch selection combiner is 10dB with $P(\gamma < \gamma s / \xi) = 1\%$.

B. Correlation

So that to obtain a high diversity gain, one of the conditions is ensure a low correlation between the signals received in the branches of the diversity system. The correlation can be characterized by complex and envelope correlations. The complex correlation ρc is characterized as the complex correlation between two signal envelopes. The instantaneous magnitudes and relation phases of the branch signals are used to calculate the complex correlation. The correlation coefficient of the received signals can be characterized by the complex correlation coefficient ρ_c and the envelope correlation ρ_e which are associated by equation (4), assuming that the received signals have a Rayleigh distributed envelope and arbitrarily distributed phase [22].

$$\rho e \approx |\rho c|^2$$

So that to assess the correlation between two antennas, the complex correlation is calculated as follows [22]

$$\rho c = \frac{\int_0^{2\pi}\int_0^{\pi} A12(\theta,\phi)\sin\theta \, d\theta d\phi}{\sqrt{\int_0^{2\pi}\int_0^{\pi} A11(\theta,\phi)\sin\theta \, d\theta d\phi \int_0^{2\pi}\int_0^{\pi} A22(\theta,\phi)\sin\theta \, d\theta d\phi}} \qquad (5)$$

$$A_{mn} = XPR.E_{\theta,m}(\theta,\phi)E^*{}_{\theta,m}(\theta,\phi)E^*{}_{\theta,n}(\theta,\phi)P_{\phi}(\theta,\phi)$$

E represented the electric far field of the antenna, and XPR is the ratio of the averaged vertical power to time average horizontal power in the fading surroundings in linear form. Thus [22].

$$XPR = \frac{PV}{PH} \qquad (6)$$

Where PV is the average vertical power and PH is the average horizontal power. The v XPR is also denoted to as the cross-polar power ratio of the incident field. $P_\theta(\theta,\phi)$ And $P_\phi(\theta,\phi)$ are the angular density functions of the vertical and horizontal plane respectively. If the correlation coefficient is greater than zero ($\rho e > 0$), then the diversity gain will be reduced. As a result, the correlation coefficient should be kept low sufficient so that the diversity is still effective. The analysis explained that where the correlation is not also close to unity or $\rho e \leq 0.7$, the degradation of the diversity gain due to envelope correlation is given by the degradation factor (*DF*) of the following equation [22]

$$DF = \sqrt{1 - \rho e} \qquad (7)$$

C. Branch power ratio and MEG (Mean Effective Gain)

The other necessary condition foraccomplish a high diversity gain requires that the power levels of the signals delivered by the antennas in the diversity system should not vary significantly from each other. One way of illustrating this is by using the ratio of two branch power levels *k* as follows in the linear form Where Pmin is the power from the antenna with the lower power, and Pmaxis the power from the antenna with the higher power in each pair of antennas. An other method [23].

$$k = \frac{P\min}{P\max} \qquad (8)$$

To get the branch power ratio of two branches is derived from the MEG (Mean Effective Gain) of the antennas as follows [23].

$$k = \min\left(\frac{MEG_1}{MEG_2}, \frac{MEG_2}{MEG1}\right) \qquad (9)$$

The MEG is the average gain of an antenna in a mobile environment and is defined as the ratio between the mean received power of the antenna (Prec) and the total mean incident power (*PV* + *PH*). The MEG is a figure of merit for the average performance of an antenna on a mobile terminal taking into account the incident radio waves in the multipath environment and also the gain patterns of the antenna. This parameter determines the efficiency of the diversity antenna in a multipath environment. The following equation can be used to calculate the MEG [23].

$$MEG = \int_0^{2\pi}\int_0^{\pi} \left[\frac{XPR}{1+XPR} P_\theta(\theta,\phi) + \frac{1}{1+XPR} P_\theta(\theta,\phi) G_\theta(\theta,\phi) \right] \sin\theta \, d\theta \, d\phi \qquad (10)$$

Where G_θ and G_ϕ are the spherical power gain (θ,ϕ) of the antenna, and $P_\theta(\theta,\phi)$ and $P_\phi(\theta,\phi)$ are the angular density functions of the incoming plane waves as used in equation (5). The ratio of the MEG between the two antennas must be close to unity to ensure a high diversity gain .Equation (3) is proper for the ideal case in which *k* equals to unity. For a selection combiner the ratio of the powers provided by the two antennas, *k* is multiplied by the diversity gain to get a further realistic diversity gain. Hence when N = 2, equation (3) becomes [23].

$$P(\gamma \langle < s/\xi)_2 \approx \frac{1}{k}\left(\frac{\gamma s}{\xi}\right)^2 \qquad (11)$$

Assuming the correlation is low enough to accomplish high diversity gain, *k* should be greater than -3dB to avoid important loss in diversity gain. An unequal branch power is a disadvantage to the antenna diversity system [23].

III. PROPAGATION FACTORS

On an indoor environment, or in a city, we can have several reflections for a signal, and this one can follow several different ways, this is the multipath in mobile radio communications, the transmitted signals are affected by buildings and other obstacles causing multiple reflections, diffraction and scattering. The incident radio waves arriving at the mobile terminal antennas have various angles of arrival (AOAs) and cross-polar ratio (XPR) in a multipath surroundings. As evident from the correlation equation (5) and MEG equation (10) referred previously, both equations are dependent on the multipath surroundings via the angular density functions (AOA distributions) and $P_\theta(\theta,\phi)\, and\, P_\phi(\theta,\phi)$ and cross-polar ratio (XPR). Then, the AOA distributions at both $\theta\, and\, \phi$ polarizations and the cross-polar ratio have an effect on the antenna diversity performance. For simplicity, the angular density functions are modelled in elevation and azimuth separately, and they are joint according to [25].

$$P_\theta(\theta,\phi) = P_\theta(\theta)\,P_\theta(\phi)$$

$$P_\phi(\theta,\phi) = P_\phi(\theta)\,P_\phi(\phi) \qquad (12)$$

Where $P_\theta(\phi), P_\phi(\phi)$ are the angular density functions in azimuth and $P_\theta(\theta), P_\phi(\theta)$ are the angular density functions in elevation for the θ and ϕ polarizations in that order .In order to calculate the antenna diversity performance properly, it is essential to apply a proper statistical model that is similar to the real surroundings. Some measurements have been carried out for mobile radio communications on the angular density distribution at the mobile terminal in urban environments. Though, the angular density functions in the elevation direction are not uniformly distributed, and so the two most common different distributions i.e. Gaussian and Laplacian distributions are suggested

Gaussian distribution [25].

$$P_\theta(\theta) = A_\theta \exp\left[\frac{-\left|\theta - (\pi/2 - m_V)\right|^2}{2\sigma_V{}^2}\right] 0 \leq \theta \leq \pi$$

$$P_\phi(\theta) = A_\phi \exp\left[\frac{-\left|\theta - (\pi/2 - m_V)^2\right|}{2\sigma^2{}_H}\right] 0 \leq \theta \leq \pi \qquad (13)$$

Laplacian Distribution:

$$P_\theta(\theta) = A_\theta \exp\left[\frac{-\sqrt{2}\left|\theta - (\pi/2 - m_{V})\right|}{\sigma_V}\right] 0 \le \theta \le \pi$$

$$P_\phi(\theta) = A_\theta \exp\left[\frac{-\sqrt{2}\left|\theta - (\pi/2 - m_H\right|}{\sigma_H}\right] 0 \le \theta \le \pi \quad (14)$$

Where m_v and m_H are the mean elevation angles of vertical and horizontal polarized wave distribution in that order, σ_V and σ_H are the standard deviations of the vertical and horizontal polarized wave distribution in that order. A_θ and A_ϕ are constants determined by the following condition [21]

$$\int_0^{2\pi}\int_0^{\pi} P_\theta(\theta,\phi)\sin\theta\, d\theta\, d\phi = \int_0^{2\pi}\int_0^{\pi} P_\phi(\theta,\phi)\sin\theta\, d\theta\, d\phi = 1 \quad (15)$$

The cross-polar ratio, *XPR*, in the scattering surroundings has an effect on antenna diversity performance mainly on the pattern and polarization diversity. Generally, the value of *XPR* is reported between 4dB and 9dB at frequencies around 900MHz in urban macro-cell surroundings. A few different environments have been studied at 2.15GHz, and the *XPR* varied between 6.6dB and 11.4dB, being lowest for indoor environments and highest for urban microcell environments. All these reported results have shown that the *XPR* is not constant due to varying frequencies and environments [21, 25].

IV. ANTENNA DESIGN

The main aim was to design two elements antenna structure having a ground plane whose dimensions are compatible with Mobile WiMAX. The design simulation doing by CST microwave studio. Figure 1 shows the configuration and the dimensions of the proposed PIFA array and the typical positions of a handset. Two PIFA elements are mounted adjacent to the upper edge of a rectangular ground plane of size 40x100 mm. The two PIFA elements are symmetric with respect to the center line of the ground plane also the two antennas element and ground plane are made of copper strips with thicknesses 0.4 mm .The optimal design of the elements was chosen to minimize the coupling between elements. The two PIFA elements were a locate inside the limits of the ground plane, to increase the isolation the distance between them is 15.3 mm the top elements were placed on a ground plane at 0.25 mm and 1mm and 4 mm from x, y and z, from two end of ground . PIFA elements are of 0.4 mm thick copper and measure 15.8 x 4 mm, the dimension of short circuit plate of two antennas is 4.8x4 mm², radius of feeding port of two antennas is 0.5 mm by a 50-ohm coaxial cable and located at centre of rectangular top plate. In the 3.5GHZ, the return loss of antenna 1 is lower than -10dB (-33.5dB at 3.5GHz) also of antenna 2 is lower than -10dB (-28.5dB at 3.5GHz) and the isolation lower than -10 dB (-23 dB at 3.5GHz) for both elements is shown in Figure 2. The radiation patterns of Antenna 1 and 2 in the dual-element PIFA array are plotted along the XZ-plane, as shown in Figure 3 the co- polar radiation patterns of antenna 1 are similar to the radiation patterns of antenna 2, and the cross-polar radiation of antenna 1 and 2 are asymmetrical in the positive and negative X-directions and stronger radiation directions in positive X-direction than in negative X-direction. In Figures 2 and 3 explain this antenna presents good diagram diversity and looks suitable for MIMO systems

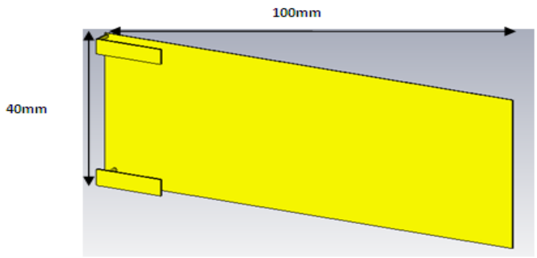


Fig (1) proposed MIMO PIFA antenna design

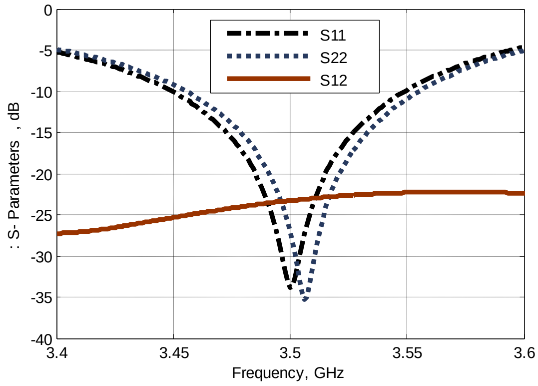
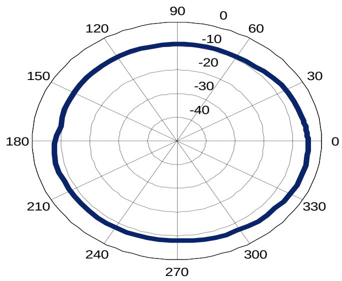
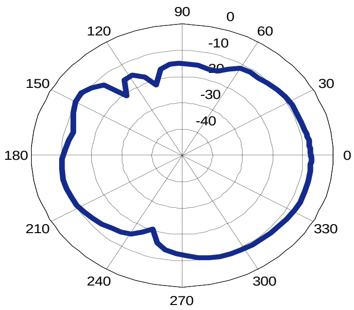


Fig.2: S- Parameters curves from the simulated result



a. Co-polar of antenna 1



b. Cross-polar of antenna 1

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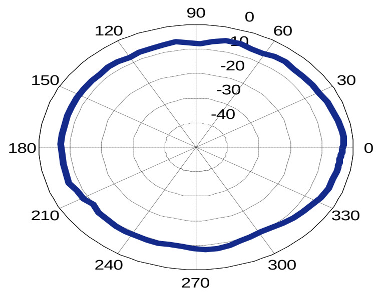
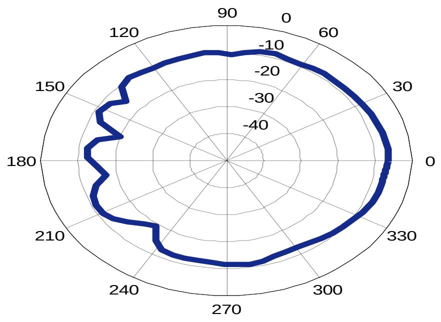


c. **Co-polar of antenna 2**



d. **Cross-polar of antenna 2**

Fig.3 Measured simulated radiation patterns on the XZ-Plane: (a) Co-polar of antenna 1, (b) Cross-polar of antenna1, (c) Co- polar of antenna 2 and (d) Cross-polar of antenna 2.

V. SIMULATION & RESULTS

The correlations for the dual-element PIFA array on the ground are evaluated using equations (4) and (5) with the measured 3D radiation patterns which have been simulated by CST microwave studio when the dual-element PIFA array on the ground was vertically positioned, and statistical propagation models depicted in Table 1. The results are summarized in Table 2 and 3. The impact of indoor and outdoor environments on the envelope correlation has been evaluated using two different statistical models as mentioned in Table 1, Gaussian/Uniform and Laplacian/Uniform distributions).

Table 1: Propagation models used for this design [24]

Models (Elevation/ Azimuth)		*Gaussian/ Uniform*	*Laplacian/ Uniform*	*Uniform/ Uniform (isotropic)*
Statistical Distribution		$P_\theta(\theta)$ =Gaussian $P_\phi(\theta)$ =Gaussian $P_\theta(\emptyset)=1$ $P_\phi(\emptyset)=1$	$P_\theta(\theta)$=Laplacian $P_\phi(\theta)$=Laplacian $P_\theta(\emptyset)=1$ $P_\phi(\emptyset)=1$	$P_\theta(\theta)=1$ $P_\phi(\theta)=1$ $P_\theta(\emptyset)=1$ $P_\phi(\emptyset)=1$
Scenario parameters	*Indoor*	$m_v = 20^0$ $m_H = 20^0$ $\sigma_V = 20^0$ $\sigma_H = 20^0$ *XPR=1dB*	$m_v = 20^0$ $m_H = 20^0$ $\sigma_V = 20^0$ $\sigma_H = 20^0$ *XPR=1dB*	-
	Outdoor	$m_v = 10^0$ $m_H = 10^0$ $\sigma_V = 15^0$ $\sigma_H = 15^0$ *XPR=5dB*	$m_v = 10^0$ $m_H = 10^0$ $\sigma_V = 15^0$ $\sigma_H = 15^0$ *XPR=5dB*	-

Table 2 shows that an envelope correlation of less than 0.3 (as evaluated by two different statistical models) has been achieved in both indoor and outdoor environments. This low correlation values result in very small degradation of diversity gains, as evident from equation (7).The MEG of each antenna within the different environments is evaluated using equation (10) and the results are also tabulated in Table 2. It is noticed that the MEG values of each antenna within the different environments can vary up to 1.5dB. The difference of the MEG values between Antenna 1 and 2 is due to the Antenna 2 having a slightly better radiation gain than the Antenna However, the difference is less than 1dB, and therefore it leads to a small degradation on the diversity. The calculated SC diversity gain at 99% and 50% reliability in an isotropic environment are tabulated in Table3.

Table 2: Envelop correlation coefficient and MEG of the dual-element PIF Array in different propagation models

Propagation environments	*correlation, ρe*	*MEG, dB*	
	ρe12=ρe21	*Antenna 1*	*Antenna 2*
Gaussian (indoor)	*0.027*	*-4.0*	*-3.3*
Gaussian (outdoor)	*0.26*	*-4.1*	*-3.45*
Laplacian (indoor)	*0.02*	*-4.7*	*-3.1*
Laplacian (outdoor)	*0.098*	*-5.3*	*-4.5*
Isotropic	*0.03*	*-3.4*	*-3.3*

Table 3. Calculated SC diversity Gain at 99% and 50% reliability in isotropic environment

SC Diversity Gain	*99% reliability*	*50% reliability*
Calculated	*8.9dB*	*2.1dB*

VI. CONCLUSION

It has been shown that the MIMO system can increase the channel capacity significantly without increasing the bandwidth and transmission power when compared to the SISO system. The requirements (i.e. low mutual coupling and high diversity gain) for multiple antennas have been addressed. By reviewing antennas for small mobile terminals. It is not feasible and practical to place two conventional antennas in a small terminal while keeping the mutual coupling low. New antennas need to be designed in order to overcome this obstacle.

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The other requirement for multiple antennas design is having a high diversity gain which has also been explained in detail. The design of multiple antennas needs to satisfy two conditions in order to achieve a high diversity gain. It should have low correlations and similar power levels for received signals between multiple antennas. Since mobile terminals are used in different environments and they are in motion most of time, the propagation environment has to be taken into account. It has been summarized current at different environments and different operation frequencies have different incident power distributions.

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