

Seasonal Variations of Cell Site Diversity Gain

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Abstract—The broadband fixed wireless access (BFWA) systems operate in microwave frequencies. In this frequency range, the wave propagation is highly influenced by precipitation caused especially by rain. With the use of cell site diversity (CSD), the rain attenuation effects can be mitigated. When the signal level falls below a certain threshold the subscriber station switches to another base station within the coverage area. This paper aims at demonstrating the performance improvements obtained with the use of cell site diversity during various seasons for measurements carried out from HYREX rain gauge network in UK. The parameters traditionally used to quantify cell site diversity are CSD gain and diversity improvement. This paper analyzes the CSD gain achieved. The gain increases with increasing frequency and distance. The link performance is compared for various seasons and the results show that the maximum attenuation occurs during summer, while the least attenuation occurs during winter. Therefore, maximum gain of up to 22 dB occurs at 54 GHz frequency during winter. The second observation is that when the angular separation between the diversity sites is 180° separation there is maximum gain for all seasons.

Keywords—Cell site diversity, diversity improvement, fade mitigation, WiMAX

I. INTRODUCTION

The WiMAX technique is aimed at provision of quality services to end users with high data rate and wide coverage. The channel capacity or data rate is limited by the bandwidth, transmission power, noise, distortion and interference [1]. The WiMAX uses frequencies between 2 and 66 GHz. It specifies a range of 30 miles for channel bandwidths from 1.75 MHz to 20 MHz [2]. The operating link has a fixed or mobile subscriber station (SS) and a base station (BS) that connects to a wired network.

Above the 10 GHz frequency range, rainfall can cause considerable attenuation in the received signal [3]. For planning and designing high capacity point-to-point and point-to-multipoint radio systems above 2 GHz frequency band, the accurate prediction of rain attenuation in the terrestrial links is essential. Mainly based on experimental data, several empirical and semi-empirical rain attenuation prediction methods have been proposed over the years. The widely used predicting models currently are the ITU-R model and the Crane model [4]. The ITU-R.838-3 predicts the effect of rain attenuation in the terrestrial link. The rain attenuation increases with the length of the radio link and depends on the rainfall climatic conditions in the region where the link has to be installed for a given frequency and polarization [3].

II. CSD SETUP FOR WIMAX LINK

When designing a WiMAX network above 10 GHz, the major concern is the provision of clear LOS path between the base stations and subscriber stations. In the absence of LOS, the effects of scattering, diffraction and shadowing from buildings and vegetation lead to considerable power loss. In order to achieve LOS and overcome power loss, highly directive antennas are employed in the SSs at this frequency band. Attenuation due to precipitation is significant due to this reason, whilst, comparatively multipath propagation is insignificant. Considering the spatial nature of the rainfall, cell site diversity technique is helpful as high intensity rain is confined to a smaller area. When the rain event occurs on the path of the base station that provides default service to the subscriber, an alternate base station can take over the connection, provided it is not affected by rain. The receiving antennas are located at various BS sites in a CSD design.

Taking into account the inhomogeneous nature of rain using two links to lessen the effect of rain attenuation, was first proposed by Hogg [5]. The aim is to calculate the service availability improvement using cell site diversity. The subscriber station needs highly directional antennas that minimize the number of multipath and interference from unexpected sources in order to achieve high quality and availability during LOS radio

propagation conditions between the subscriber station and the base stations. Inter-symbol interference is produced due to the occurrence of multipath.

In Fig. 1, the CSD configuration is shown. It consists of four base stations A, B, C, D and one subscriber station taking different paths, where the angular separation ranges from 0° to 360°. The subscriber station is assigned to a reference base station, which is located in the same cell and three diversity stations each located in different neighboring cells in order to provide cell site diversity. The angular separation between each link ranges from 0° to 90°.

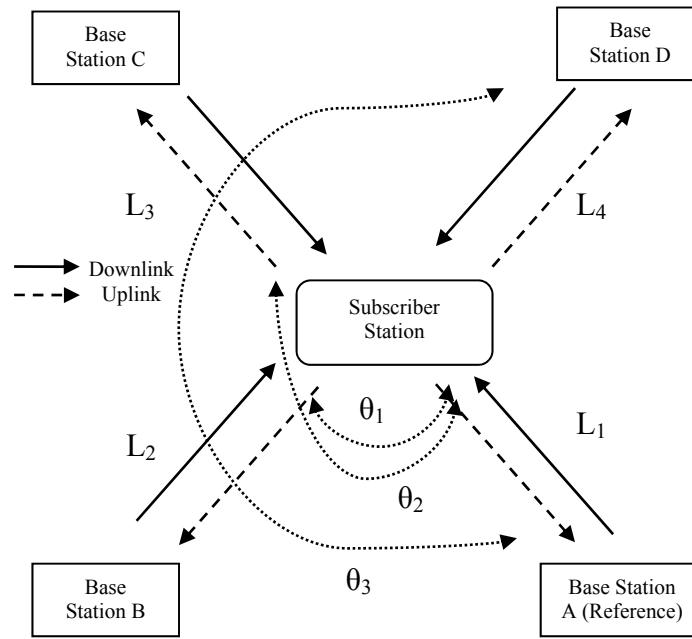


Fig. 1. Typical scenario for Cell site diversity

In Fig. 1, the distances between BS's A, B, C, D to the SS are represented as L_1 , L_2 , L_3 and L_4 respectively. Angular separation is the measure of the azimuth angle ' θ ' separating the diversity sites. The angular separations are considered with respect to the reference base station A. It is represented as θ_1 between BSs A and B, θ_2 between BSs A and C, θ_3 between BSs A and D.

A. Diversity gain and diversity improvement computation

The two measures of diversity are diversity gain and diversity improvement. The measure of the reduction in the fade margin or an increase in the average signal value is the diversity gain. It is defined as the difference between the attenuation exceeded at a certain percentage of time for a single link and the attenuation exceeded at a certain percentage of time for a joint link. The diversity gain $G(p)$ at percentage of time ' p ' can be obtained as follows:

$$G(p) = A(p) - A_d(p) \text{ (dB)} \quad (1)$$

Where $A_d(p)$ is the fade depth in the combined diversity (joint) path, and $A(p)$ is the fade depth for the unprotected (single) path occurring in time percentage ' t '. Each sample A_d of the four-link attenuation for diversity with selection combining is computed as:

$$A_d(p) = \min[A_{ref}(t), A_i(t)] \text{ (dB)} \quad (2)$$

Where, $A_{ref}(t)$ and $A_i(t)$ are the instantaneous rain attenuation values at the reference site and diversity sites respectively.

The measure of the increase in system availability is the diversity improvement, $I(A)$. It is defined as the ratio of the single link to the joint link probabilities, for a given fade depth.

$$I(A) = \frac{P(A)}{P_d(A)} \quad (3)$$

$P(A)$ is the time percentage for the unprotected path and $P_d(A)$ is the percentage of time in the combined diversity path with a fade depth larger than A (dB). Usually gain is preferred to the improvement because of its higher statistical confidence even though both gain and the improvement describe diversity completely. This is because the same amount of observation time is used for both the single distribution and for the joint distributions [6].

III. HYREX RAINGAUGE MEASUREMENT SETUP

In 1993 to examine the variation of spatial rainfall structure, the Hydrological Radar Experiment (HYREX) rain gauge network was set up. Dense rain gauges were set up in the Brue catchments in Lovington, Somerset, England as part of the campaign. The network consisted of 49 rain gauges, with separations ranging from approximately 600 m to 14.5 km. The location is a valley characterized by varying ground height above the mean sea level ranging from 40 m to 210 m [7].

A Casella tipping bucket rain gauge of 0.2 mm was used, which consists of a divided bucket placed at a pivoted centre. Water was collected on one side of the bucket and tips occur when the collected water level reached 0.2 mm. The collected amount of water was discharged and the other half of the bucket was positioned for filling as a tip occurred. For all the 49 gauges, the data was recorded with a time resolution of 10 seconds and stored on a monthly basis. The measurements were carried out for four years.

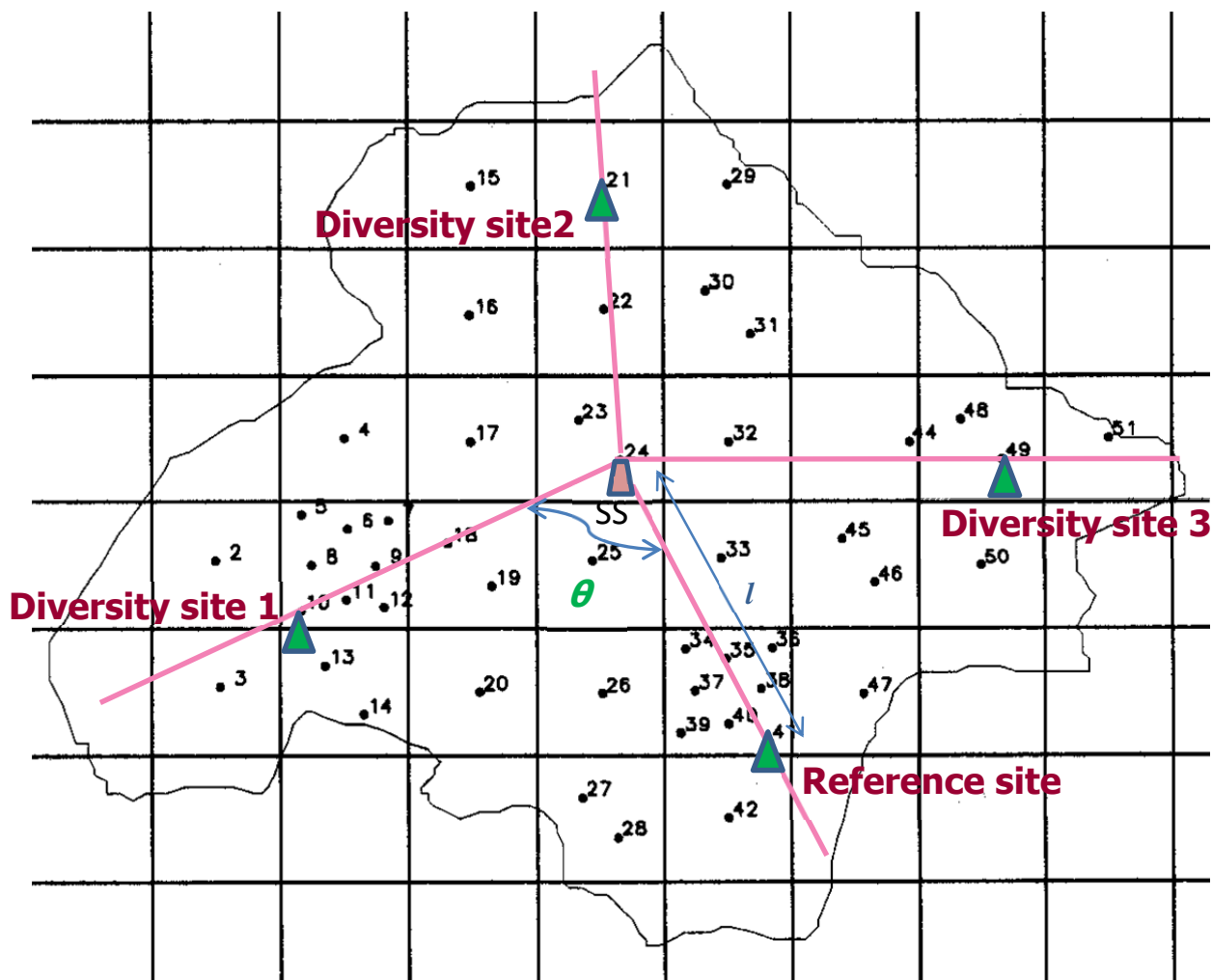


Fig. 2. The HYREX dense rain gauge network over the Brue catchment

The rain gauge data from HYREX are taken such that the base stations are located along four directions at points 21, 10, 41 and 49 for implementing the CSD technique as shown in Fig. 2. The subscriber station is located at point 24.

IV. RAIN ATTENUATION ANALYSIS

The data obtained during 1999 from various rain gauges is analyzed. Data from the gauges of the above network are taken every 10 seconds. The rain rate thus obtained is then averaged over 30 samples to yield 5 minutes integrated rain. Using ITU-R P.838 and P.530, the rain attenuation computation is carried out [8] [9]. The 5-minute rain rates (R_p , mm/hr) obtained from the rain gauge data are used to compute the total path rain attenuation at time, 't' (A_t , dB). It is computed as the sum of rain attenuations of individual points located along the path.

$$A_t = k \sum_{i=1}^n L_k R_k^\alpha (t) (dB) \quad (4)$$

Where, 'k' and ' α ' are the link frequency dependent coefficients obtained from ITU-R. ' L_k ' is the length of the k^{th} hop along the path, and n is the number of hops.

In the absence of a rain gauge in the vicinity of the path, the linear interpolation is used to obtain the rain rate of a point in the path. The rain rate is computed from the rain rates of more than one rain gauge by using a factor 'x'. This factor is based on the distance of the rain gauge from the path. For example, if rain gauge 'A' lies at a distance ' x_1 ', km from the path and rain gauge 'B' lies at a distance of ' x_2 ', km from the path and when $x_1 \neq x_2$, then the point rain rate (R_p) is computed as:

$$R_p = \frac{x_2 R_1}{x_1 + x_2} + \frac{x_1 R_2}{x_1 + x_2} (mm / hr) \quad (5)$$

when $x_1 = x_2$, eq. (5) is reduced to:

$$R_p = \frac{R_1 + R_2}{2} (mm / hr) \quad (6)$$

Where, ' R_1 ' and ' R_2 ' are the rain rates in rain gauges 'A' and 'B'.

The cumulative distribution for point rainfall rate and attenuation for the SS is plotted in Fig. 3. The rain rate exceeds 22 mm/hr for 0.01% of time and attenuation exceeds 2 dB for the same time. The rain attenuation computation and plotting are carried out using MATLAB.

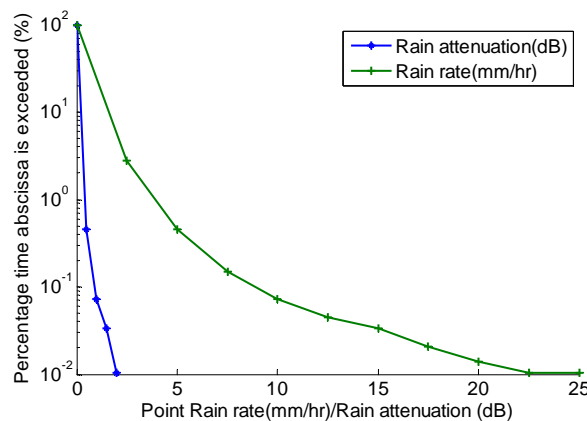


Fig. 3. Cumulative distribution of rain rate and attenuation for one year data

A. Diversity Improvement

The precipitation varies considerably in time and in space both vertically and horizontally. The improvement achieved in availability is found by using two or more base stations at any instant of time. Since the spatial distribution of rain cells depend on their temporal resolution (convective events are localized whereas stratiform events are wide-spread) the attenuation statistics for a single path and two joint diversity paths (2 km paths) with angular separation varies from 0° to 90°. The smallest attenuation occurring simultaneously on these two paths is the joint path attenuation.

The diversity improvement along with diversity gain with the use of joint links compared with a single link is shown in Fig. 4. At 0.05% of time, a diversity gain (gain improvements in x-axis) of 1.1 dB is achieved with the use of joint sites as compared with no diversity. As time percentages lowers, the diversity improvement factor increases along with diversity gain.

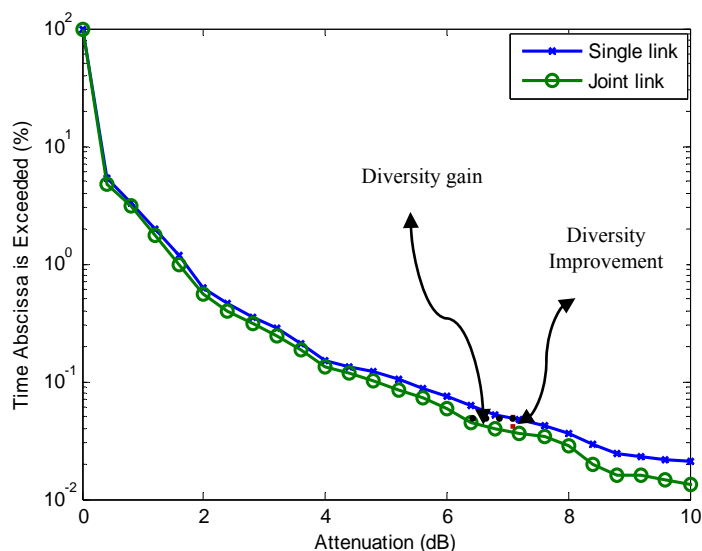


Fig. 4. Graph indicating performance improvement of joint link compared with single link at 42 GHz at 2 km

V. SEASONAL DISTRIBUTION OF CELL SITE DIVERSITY GAIN

A. Seasonal analysis of CSD gain

The seasonal information from the data is gathered and the CSD gain is determined at various seasons. According to the four seasons, the $A_{rej}(t)$ and $A_i(t)$ time series are grouped and sorted to obtain the seasonal as well as overall CDF of gain for each diversity system setup corresponding to a unique set of angular separation and separation distance values.

The seasonal CSD gain with the variation of angular separation between the sites is also determined. The diversity sites are chosen to achieve seven separate angular separations of 45° , 90° , 130° , 180° , 225° , 270° , and 315° along each of which the site separation was varied between two and five kilometres. This resulted in seven groups of diversity stations corresponding to the seven angular separations. Finally, a single CDF was obtained overall for each season by averaging over the individual CDFs of each period.

B. Seasonal observations

Fig. 5 plots the CDF of attenuation during different seasons of an year along with the annual attenuation and the corresponding diversity gains respectively. There is significant variation in overall fade levels in various seasons of a year.

For the measurements made during 1999, the Fig. 5 (a) suggests that the maximum attenuation occurs during summer, while the least attenuation occurs during winter. The overall attenuation is 39 dB during summer, 30 dB during spring, 25 dB during autumn and 24 dB during winter for 0.01 % of a year. This leads to highest CSD gain of upto 22 dB during winter, 21 dB during autumn, 20 dB during spring and 15.5 dB during summer, during the same percentage of time. Hence, the lowest attenuation is seen to occur in winter and therefore the highest gain.

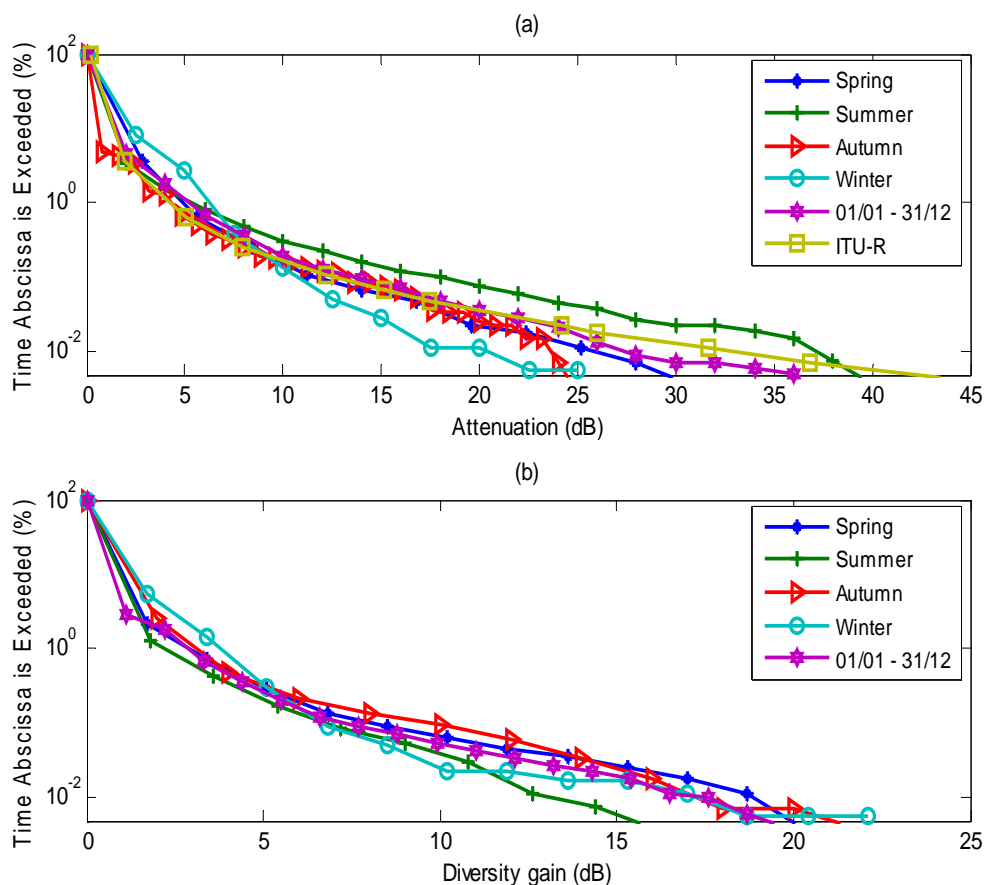


Fig. 5: Yearly and seasonal CDF of (a) Rain attenuation, and (b) Cell Site diversity gain

C. Seasonal variations with angular separation

Further analysis is carried out for each season by varying the angular separation between the sites. Fig. 6 to 9 show the CDF of each season for various angular separations. In concurrence with the overall diversity gain pattern observed during the various seasons, the figures show similar trend with maximum gain observed during winter with least gain in summer. It is observed that for shorter distances the correlation between various diversity sites is prevalent, as shown in the figures. This leads to the conclusion that differences in seasonal trends are exhibited during larger distance which is greater than 2 km. At low separation distance of 2 km the likelihood of correlation in rain attenuation is high, thus larger distances show greater seasonal variations. The work reported by Otung et al. [10] suggests that the seasonal trend is due to a predominance of convective rainfall during summer, which has been reported to have a limited spatial extent of about 10 km and the occurrence of stratiform rain with larger spatial extent during the other seasons.

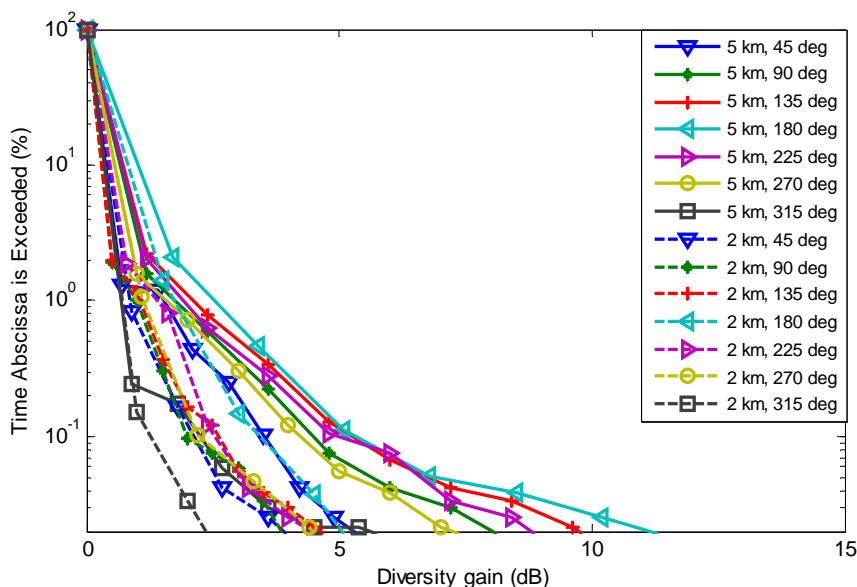


Fig. 6: CSD gain distribution for Spring

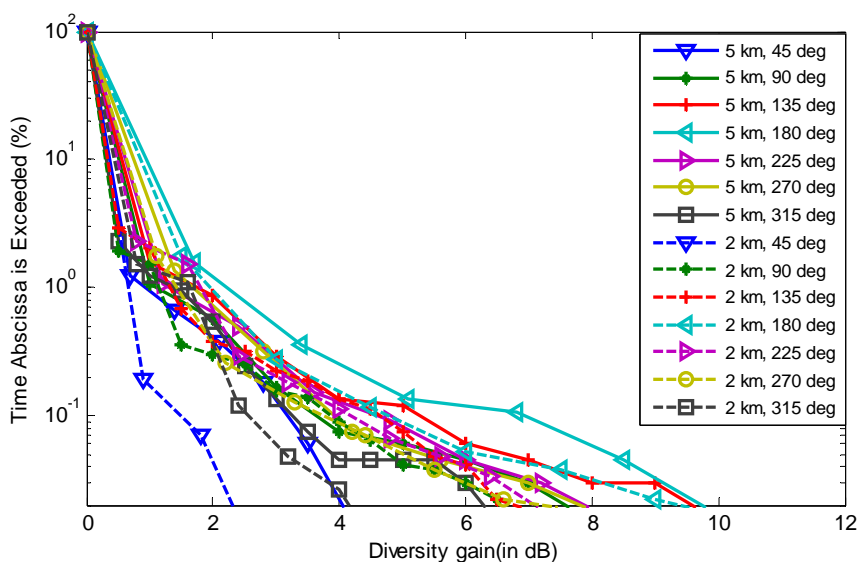


Fig. 7: CSD gain distribution for Summer

The patterns of the diversity gain distributions clearly indicate an increasing in CSD gain with increased separation distances. It is observed that the diversity gain has strong bearing on the azimuth angle at which the diversity site is located from the reference site. The results indicate that as the angular separation increases, the diversity gain increases. So with increasing azimuth from 0° to 180° there is increased CSD. The maximum CSD gain is observed at 180° azimuth angle, which is considered the optimum angular separation between two sites in obtaining the maximum CSD gain. This is due to the fact that there is less likelihood of rain occurring in an opposite direction to the reference site. After 180°, the gain continues to reduce till it reaches 360° point. So the angles that are in symmetric angular separation tend to show approximately equal CSD gain. The three pairs of angles that show similar gains are, 45° and 315°, 90° and 270°, 135° and 225° - with each pair differing from the reference site at 0° azimuth by 45°, 90°, and 135°. The work by Hendratoro et al. [17] suggests that the angular separation of 108° is acceptable as this can contribute to a slight reduction in gain. However, the current work suggests that there is a significant change in gain increasing up to 4 dB at 180° compared to 108° at 54 GHz for 5 km separation.

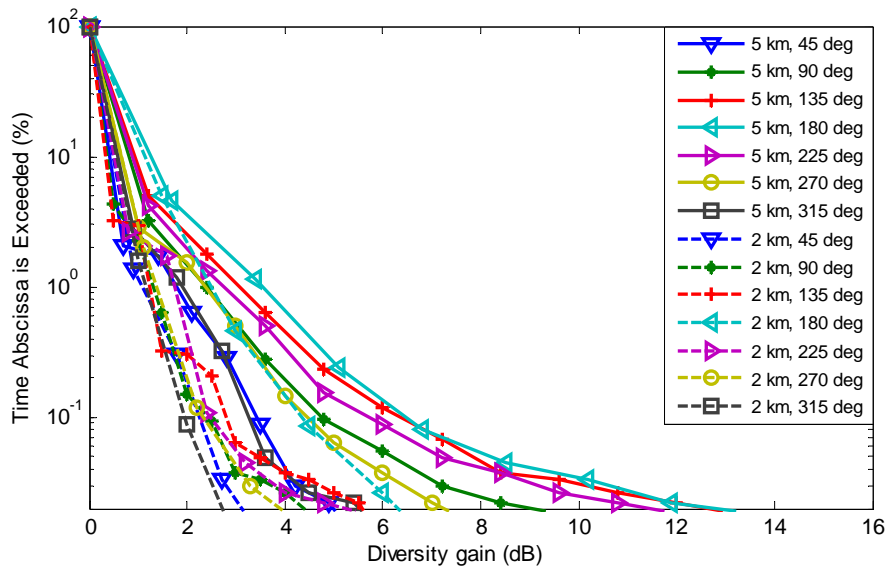


Fig. 8: CSD gain distribution for Autumn

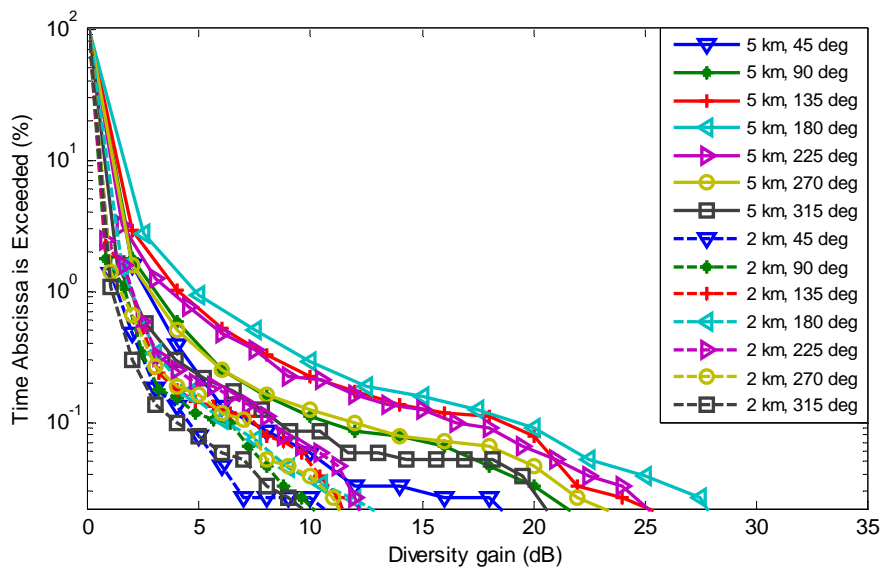


Fig. 9: CSD gain distribution for Winter

VI. CONCLUSION

Rain attenuation is a significant propagation impairment for a fixed LOS WiMAX link. In this paper a detailed analysis of CSD gain for frequencies extending from 20 GHz to 54 GHz which is optimum for the LOS operation at various seasons of a year is carried out. The work is extended at various combinations such as separation distances, and various azimuth angles. The results suggest that an increase in link distance provides increased CSD gain. The diversity sites also provide strong correlation in the presence of small azimuth angles. The optimum angular separation is obtained at 180°, the point providing maximum CSD gain. The diversity gain shows significant variations during various seasons and the order in which the gain increases is summer, spring, autumn and winter, during which the CDF of attenuation decreases in the same order. The seasonal distribution suggests that there is significant variation in the CSD performance with link distances greater than two kms.

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