DESIGN CONSIDERATIONS FOR MILLIMETER WAVE RADIO LINKS IN ARID LAND

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Based on 15-year visibility data and 18-year rain data in Saudi Arabia a comparative study of millimetric wave propagation in arid land is presented. Two cities are considered, viz; Jeddah which lies on the Red Sea of the west coast of Saudi Arabia to represent the coastal regions and Riyadh; in the center, a typical of inland areas. Visibility data together with rainfall data are used to estimate the expected link outage time per year for various storm conditions. For each city, the percentage of time of the average year during which, attenuation in dB/km. exceeds a given level is found. Such time accounts for both attenuation due to rain and attenuation caused by sand storms. It is concluded that care has to be exercised when designing radio links operating at mm-wave length in arid land. In particular

1) Effect of rain cannot be neglected.

2) Outage caused by rain fall differs widely from region to region in Saudi Arabia.

3) Effect of sand storms is, on the average, comparable to the effect of rain as far as system's reliability is concerned.

4) The attenuation caused by sand storms is strongly dependent on the size of sand or dust particles and moisture content of the particles, hence, actual parameters must be determined for the pertinent region to enable the determination of optimum hop length. Based on the present analysis it is also established that attenuation in the coastal humid areas is three times greater than the dry inland regions.

I. INTRODUCTION

The utilization of frequency bands above 10 GHz for line-of-sight communications has attracted increasing attention during the last two decades due to the ever growing demand for new services and the crowding of lower frequency bands. However, practical applications in communications have, so far, been few.There are mainly two reasons for this; (i) until recently, the development of reliable components has been slow and (ii) atmospheric attenuation may prevent the operation of any free space link system. Recent progress in component development coupled with congestion present at lower frequencies have revived interest in millimetric wave bands. Many experimental and theoretical studies have been reported in the last few years, giving a better understanding of various propagation phenomena and suggesting possible systems layout.

Attenuation caused by rainfall has been identified as a major source of service interruption and system outage. The cure is in the use of short hops, which increases the cost and service interruptions due to equipment failures. On the other hand, arid land receives small amounts of rain, hence, allowing longer hop lengths with acceptable reliability. However such arid regions are usually hit by sand storms which affect the propagation in a way similar to rain.

In this paper, 18-year rain data for the cities of Jeddah and Riyadh are used to estimate the effect of rain attenuation on link reliability for the two cities.

Similarly, a record of events of visibility reduction caused by sand storms is utilized to find the expected attenuation caused by these storms.

The total effect of sand storms and rain is compared for the two cities in Section II. Section III addresses the important problem of choosing the proper hop length under meteorological conditions. Section IV presents discussion of the analysis and outlines some concluding remarks regarding the needed data and required studies in the area of millimetric wave propagation and link design. It should be noted that the analysis is based on rain attenuation and sand parameters at 40 GHz. Frequency scaling can be used to extend the validity of the results to the remainder of the mm-wave band.

II. EXCESS ATTENUATION DUE TO SAND STORMS AND RAIN

Table 1 depicts the average no. of minutes per year during which optical visibility was reduced below certain level due to sand storms. Such data can be used to predict the excess attenuation due to sand storms (1), however, the excess attenuation increases lineaily with particle size and frequency and in a more complex way with moisture content and particle size distribution (2).

Figure 1 presents the attenuation in dB/Km for medium of 0.1 and .01 sand particles for different visibility and moisture content. The Figure is based on the curves of (2) at 37 GHz, and can be found in (1), however it is included here for completion of the presentation.

The attenuation caused by rain fall events is considered in Table 2. The table presents the average time per year during which attenuation due to rain fall was exceeded in the cities of Jeddah and Riyadh. The original data was obtained in the form of rain fall, recorded every ten minutes for a period of eighteen years.

Estimating excess attenuation due to rain envolves the conversion of rain fall data to rain rate. Once the rain rate is found, excess attenuation at such rate can be found using the known $A = aR^b$ relation where A, R are excess attenuation in dB/Km and rain rate in mm/hr, respectively, and a, b are constants at a given frequency. Detailed analysis is found in (3).

2.1 Comparing Coastal and In-land Regions

Based on the rain and visibility data for the in-land city of Riyadh and the coastal city of Jeddah, depicted in Table 1 and Table 2, Figure 2 can be established. The Figure depicts the percentage of time, of the average year, during which the attenuation from either sand storms or rain showers exceeds a specified value. Events of combined rain and sand storm are not considered. Although such events are common, the duration of the event is small enough to be disregarded in the present analysis.

In converting rain rate into signal attenuation in dB/Km,the CC1R adopted conversion is used (4). Converting visibility data into attenuation is not as simple, however. Knowledge of particle size distrisbution, average particle size and moisture content is essential. For simplicity, the particles may be assumed equisized and two extreme sizes are considered. Fine grain sand of .01 mm and course sand of 0.1 mm are the chosen level to represent typical storms. Figure 2-a is based on sand particles of 0.1 mm diameter, hence it represents the upper limit on attenuation while Figure 2-b may, similarly, be considered to give the lower limit. An important parameter is the percentage of moisture content of sand particles, since attenuation increases markedly with moisture content. However, no data is available on the moisture content during sand storms in either city. In fact such data have not been presented before in the literature.

For the humid coastal city of Jeddah, along the western coast on the Red Sea, a moisture content of 20% is assumed. On the other hand, a moisture content of 5% is assumed for sand particles during storms in the inland dry city of Riyadh. Such figures as intutively reasonable, since moisture content is bound to increase with the relative humidity in the surrounding atmosphere.

At the first glance, Figure 2 shows that more attenuation is expected for Jeddah for a longer time. Such a result is, however, expected since individual effects of both rain and sand storms for Jeddah, exceeds that of Riyadh. From both Figure 2-a and Figure 2-b it is evident that the percentage of time, of the average year, during which a given attenuation level is exceeded in the coastal areas is about three times more than that in the inland region. Or, alternatively, for a given fade margin and hop length, the probability of outage in the coastal areas due to sand storms or rain showers is three times greater for humid, coastal regions than that of the inland areas.

III. OPTIMUM HOP LENGTH

For microwave radio links operating at the centimetric wave length viz; the band 1 - 10 GHz; a typical hop length of 50 Km can give a 99.99% propagation reliability if properly designed. At millimetric wave length, however, excess attenuation due to rain and sand storms may restrict the hop length to few kilometers. Even with a modest propagation reliability of 99%, hop length of 1 to

5 Km is expected for regions of average and high rain fall (4). For arid land, marked with scarce rain, much higher reliabilities can be obtained as can be seen from Figure 2. Study of Figure 2-a and Figure 2-b reveals the following:

i) For a propagation reliability of 99%, an extended hop of 40 Km can be operated at a frequency of 40 GHz in coastal areas, with the assumption of highest humidity (resulting in a moisture content of 20%) and worst storm conditions (sand particles with 0.1 mm diameter). This can be seen from Figure 2-a, since attenuation of 1 dB/Km is exceeded 1% on the average year.

ii) similarly; attenuation of 5 dB/Km is exceeded 0.1% on the average year in coastal areas. Hence a propagation reliability of 99.9% can be obtained if the hop length is limited to 8 Km.

iii) if the high reliability of 99.99%, typical of backbone microwave radio links, is required, a hop length must be reduced to 2 Km.

iv) for the inland areas links of 2 to 4 times as long can be operated with the same reliability.

v) for the more realistic assumption of sand particles of .01 diameter, a more relaxed design allowing double the above hop length can be used.

Throughout the above analysis the assumptions of 40 GHz operating frequency and equal particle size during sand storms were used.

It is also assumed that attenuation due to rain and sand storm increases linearly with distance.

IV. CONCLUSION

Long term metrological data for an inland and a coastal city in Saudi Arabia; viz, Riyadh and Jeddah, has been utilized to determine optimum hop length of millimetric wave radio links operating in arid land. Rain fall and visibility records of the two cities have been converted into number of minutes per year during which a given attenuation level was exceeded.

Figure 2 compares the excess attenuation in the two cities and reveals that the probability of outage due to sand storms and rain is three times; on the average; greater in the coastal areas than in the interior regions.

Although only the total effect of rain and sand stroms on link's reliability has been presented, it can be shown that both rain and sand storm contribute to outage time. Depending on the parameters of sand particles during the storm (particle size and moisture content), the effect of sand storm may be comparable to that of rain, negligible or dominant. Hence the accurate measurement of such data is essential for accurate engineering of millimetric wave radio links in arid land. The following conclusions can be made:

i) for a fade margin of 40 dB, hop lengths may be varied from 10 Km to 4 Km with propagation reliability increasing from 99.9% to 99.99%, for coastal areas. Such a conclusion has been based on the more realistic .01 mm particle size during the sand storm.

ii) for inland regions; 40 dB fade margin will enable hop lengths of 40 Km to 10 Km with reliabilities of 99.9% and 99.99% respectively.

iii) for countries with appreciable variations in climate from region -to-region, a regional propagation map is needed to reflect variation of humidity and rain fall. Optimum hop length can be obtained accordingly.

Finally, meteorological data and actual field studies are needed before millimetric wave links can be satisfactorily engineered.

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Visibility Meters	500	400	300	200	100	10
Ave. No. of minutes/year Jeddah	480	385	340	275	175	78
Ave. No. of minutes per year Riyadh	2332	1502	1272	870	690	24

TABLE 1:

Average time per year for which visibility was reduced based on 15-year record of Jeddah and Riyadh.

Attenuation dB/Km	20	15	10	8	6	4	2	1	0.3
Ave.time per year(minutes) Jeddah	15	51	110	194	850	1020	3110	5070	10250
Ave. time/ yr. minutes Riyadh	0.6	1	6	15	27	50	150	400	1400

TABLE 2:

Average time per year for which attenuation dB/Km caused by rain fall is exceeded for Jeddah and Riyadh. (for 40 GHz)

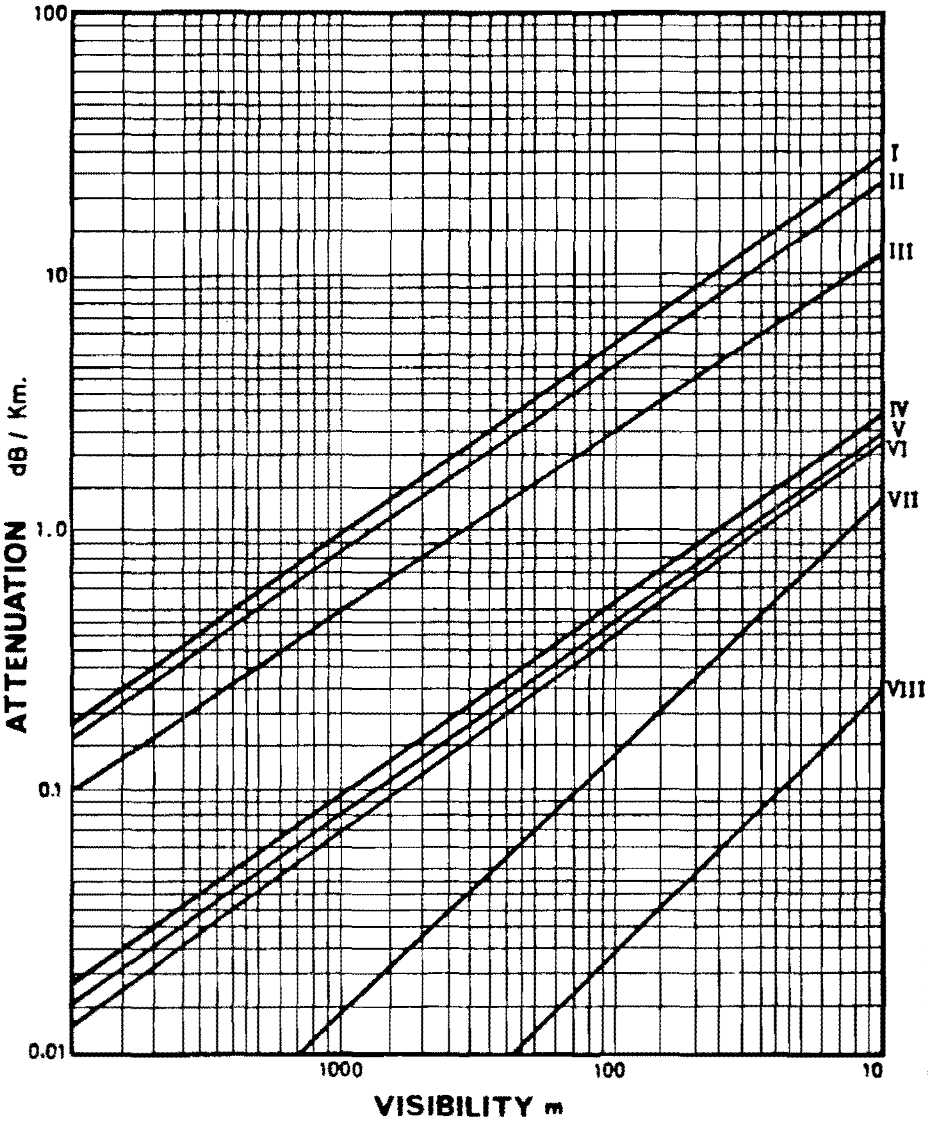

Fig. (1) Attenuation against visibility for loamy fine sand at 37 GHz [2]

I. 20% mois.	a = 0.1 mm	V. 10% mois.	a = 0.01mm
II. 10% mois.	a = 0.1 mm	VI. dry	a = 0.1 mm
III. 5% mois.	a = 0.1 mm	VII. 5% mois.	a = 0.01mm
IV. 20% mois.	a = 0.01mm	VIII. dry	a = 0.01mm

Excess Attenuation Due to Rain and Sand Storms.

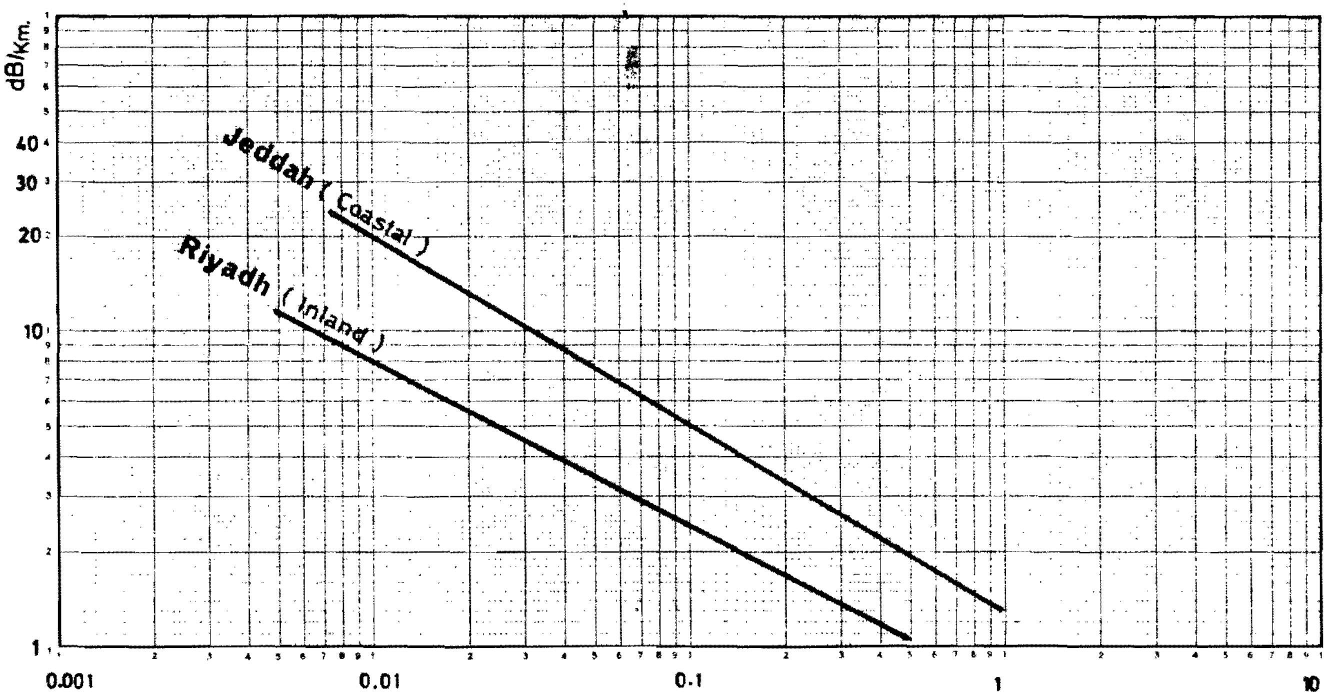

Fig. 2: Percentage of time, based on the average year, during which attenuation was exceeded.
(a) Sand particles 0.1 mm diameter.

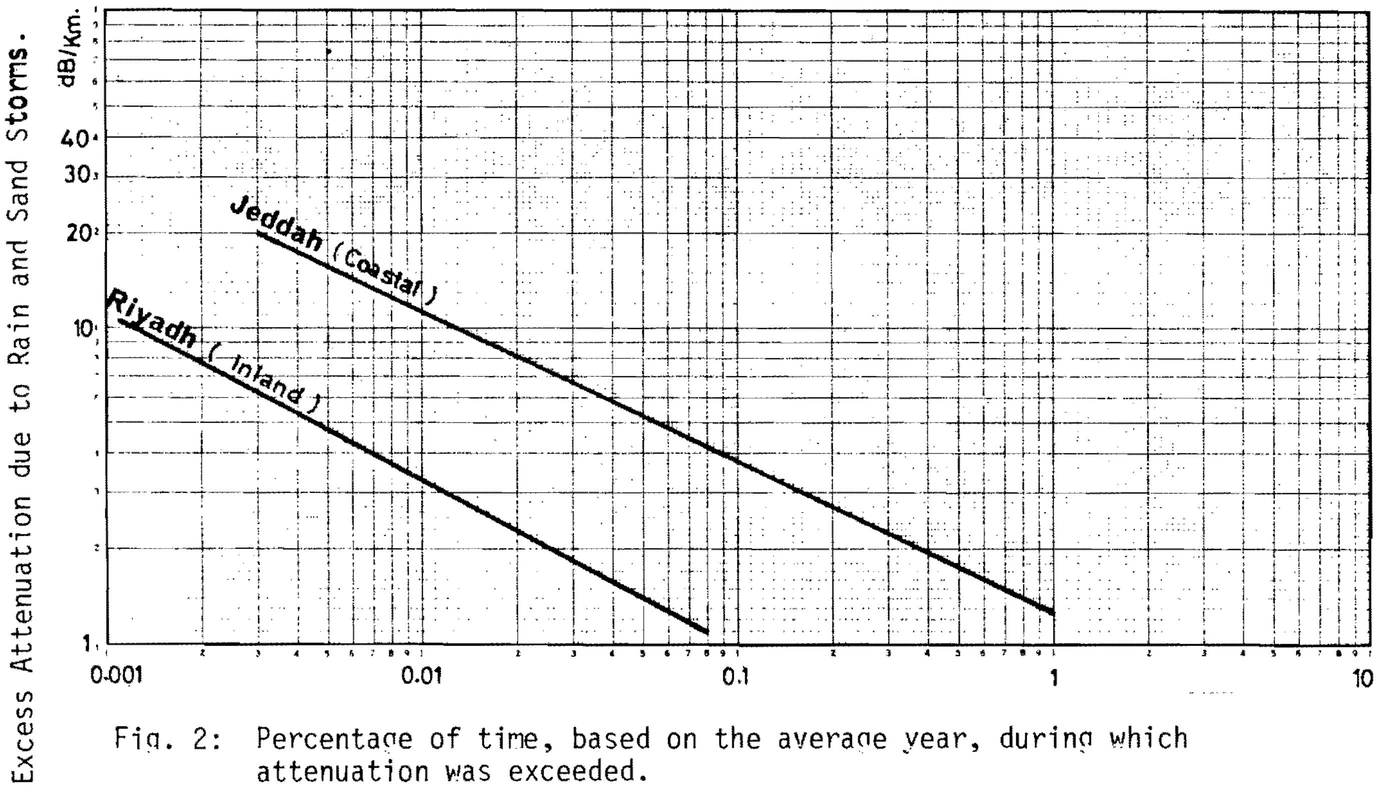

Fig. 2: Percentage of time, based on the average year, during which attenuation was exceeded.
(b) Sand particles 0.01 mm diameter.