Radiowave propagation considerations for 70/80 GHz backhaul links providing gigabit capacities to broadband mobile networks

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Abstract

This paper addresses atmospheric propagation aspect for millimeter wave links proving gigabit capacity for mobile network base stations. Based on measurements it shows that the 70/80 GHz radio link technology is very suitable, but there is scope for development of new prediction methods for combination of atmospheric effects, and improvement of internationally standardized rain attenuation prediction method.

1. Introduction

Mobile networks already deliver broadband services, and the traffic grows dramatically. Radio links is commonly used to provide backhaul for the base stations. But can radio links continue to deliver the future expected required gigabit capacities satisfactory? Typical backhaul link requirements are to provide connections up to a few kilometers with an availability of about 99.995%. In this paper the millimeter range 70/80 GHz line-of-sight (LOS) link is evaluated by measurements and comparison with prediction methods issued by the Radiocommunication Sector International Telecommunication Union [1] for a verification of dimensioning rules to deploy. Section 2 presents measurements at 70/80 GHz and some discussion is provided in Section 3 before concluding.

2 Propagation Considerations for Millimeter Wave Links

At the millimeter wavelengths range, i.e., frequencies from 30 GHz to 300 GHz, concerning atmospheric effects it is hydrometeor precipitation that dominates and increases with frequency up to about 100 GHz and then remaining high, attenuation due to atmospheric gases, clouds, and fog increases with frequency, and so does fast scintillation effects due to air turbulence. Also a layered atmosphere causing refractive multipath is possible, but application links are so short that it seems not necessary to consider. Other effects such as reflections and penetration through vegetation, surfaces, and walls/floors must be considered for mobile terminals or to reach non-line-of-sight (NLOS) locations. This paper deals with gigabit backhaul for LOS links and is restricted to the atmospheric effects. For NLOS applications it is significantly harder to deliver gigabit capacities, but possible. However, propagation considerations for these situations are not covered in the paper.

2.1 Measurements using a 70/80 GHz Radio Link at Fornebu

With the intention to evaluate dimensioning rules for 70/80 GHz link tests have been set up at Fornebu, close to Oslo. This frequency band is very suitable for gigabit capacity links. The receive terminal is located at the Telenor headquarter, and the other terminal at a distance of 3.4 km in 2008 and 2009, and then 3.5 km in 2011 and 2013 since the receiver was moved 100 m. Commercial links are used for the measurements, i.e., Gigabeam in 2008 and 2009, and then Eband Communications (Eband) and NEC ePasolink (ePaso) from 2011. The latter is, in fact, a Bridgewave manufactured product. The Gigabeam link was equipped with 60 cm antenna diameter. The two links, Eband and ePaso, have 60 cm and 30 cm reflector antennas, respectively, resulting in a 12 dB measurement margin difference. The experiments use measurement receiver in the higher band (81-86 GHz), see [2] for more information about the experiment set-up of radio links and meteorological measurements.

2.2 Rain and gaseous attenuation at 84 GHz

With four years of measurements it is possible to draw some conclusions. In fact, the main lesson seems to be that rain attenuation is under-predicted. But at this frequency other propagation phenomena play a significant role also, such as attenuation due to atmospheric gases, cloud, fog, and scintillation. It seems clear also that antenna wetting must be accounted for in practical deployments.

The four year cumulative distributions presented in Figure 1 show the percentage of year the attenuation (dB) is not exceeded. The percentage was calculated from the total available measurement per year indicating the lost periods will follow the same sort of distribution. Actually 2011 is the period April 2001 through March 2012, and 2013 is the period February 2013 through January 2014. A reference level is established per month as the median using the monthly histograms. A few data periods were removed from the time series data, mainly as obvious measurement errors, but also in two cases evidence of frozen snow or wet snow packed on the hard cover antenna. No antenna heating is used, and including the latter events will cause misleading results. The monthly distributions indicate, as expected, that the heaviest attenuation appears in periods with heaviest rainfall, i.e., summer and late summer or early fall.

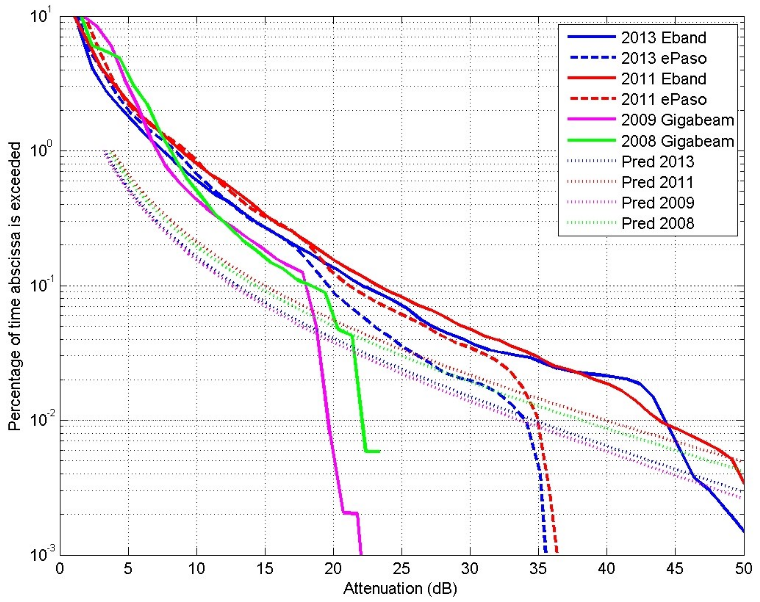


Figure 1. Measured precipitation attenuation distributions for 2008, 2009, 2011, and 2013 compared with yearly predictions using local rainfall rate data.

The monthly median variation is small and explained by varying gaseous attenuation. The meteorological measurements on site include air pressure, temperature, air humidity, wind, and rainfall. However, reliable rainfall intensity is not easily derived for all four years from the instrumentation at the receiver site. To get improved estimates data by the Norwegian meteorological office to establish a rain rate in the measurement area. The values taken are the average of three tipping bucket stations within 8 km range from the radio measurement site, with an average of 34.8, 28.4, 36.5, and 29.0 (mm/h) exceeded at 0.01% of the year for the periods 2008, 2009, 2011, and 2013, respectively. The difference between attenuation in 2008 and 2009 on one side and 2011 and 2013 on the other is not well explained by variable rain rates. It may be due to different equipment where Gigabeam is an earlier technology, or it may perhaps be calibration issues. The latter two years present results using equipment from two different vendors, showing comparable results up to about 20 dB attenuation. Beyond this level the ePaso, being an adaptive rate radio, actually change rate it uses a significantly narrower bandwidth that may cause the deviation compared with Eband beyond this fade depth.

Figure 1 indicates that predicted rain attenuation does not meet the measured attenuation distributions judged within the measurement margin range. There are obviously either other effects that count or the method under predicts. The way the ITU-R prediction method have been established indicates that gaseous attenuation is included in the prediction method, but since the majority of data used to derive the method are at much lower frequency the effect of gaseous attenuation has not been adequately accounted for. Using air pressure, temperature and relative humidity the calculated gaseous attenuation is within 1 dB/km at 83.5 GHz. This means that about 2 dB can be added in the warm period to the rain attenuation, since about 1 dB is already included in the variable reference median value. But there is still around 8 dB under prediction to explain.

The gaseous attenuation derived for the link various from low values in winter to high values in summer. Figure 2 illustrates the joint histogram of Eband radio signal strength and gaseous attenuation as observed for the 2013 period. There are two observations: one the low to high attenuation going from winter to summer, and that the gaseous attenuation increases with reduced signal strength. The first indicates that at maximum the gaseous attenuation is somewhat higher than 3 dB, suggesting a maximum of 1 dB/km rule of thumb. The second suggest that additional gaseous attenuation happen during periods with the heaviest rain attenuation. A combined prediction method for rain and atmospheric gases needs to be developed for a more precise estimate. However, it is not clear how to do it, for example whether gaseous attenuation and rain attenuation can be considered correlated. This is probably not the case on an event to event case.

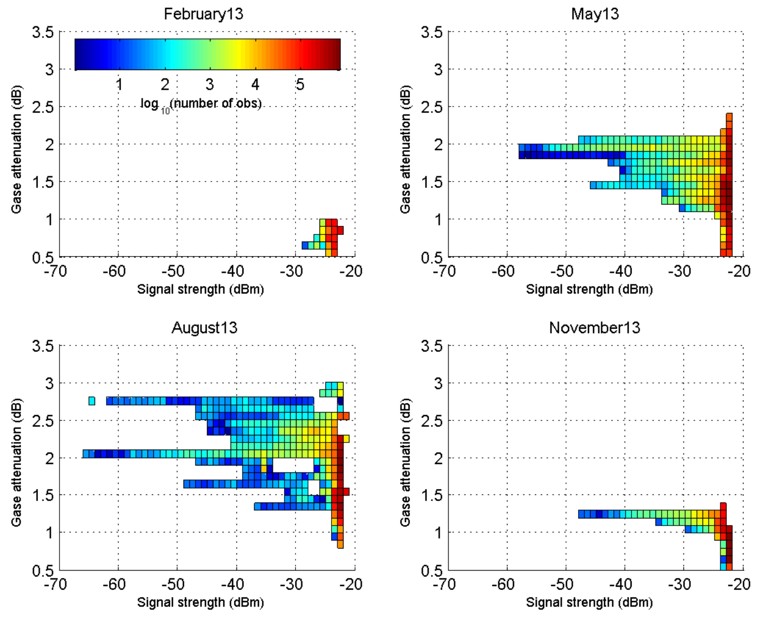
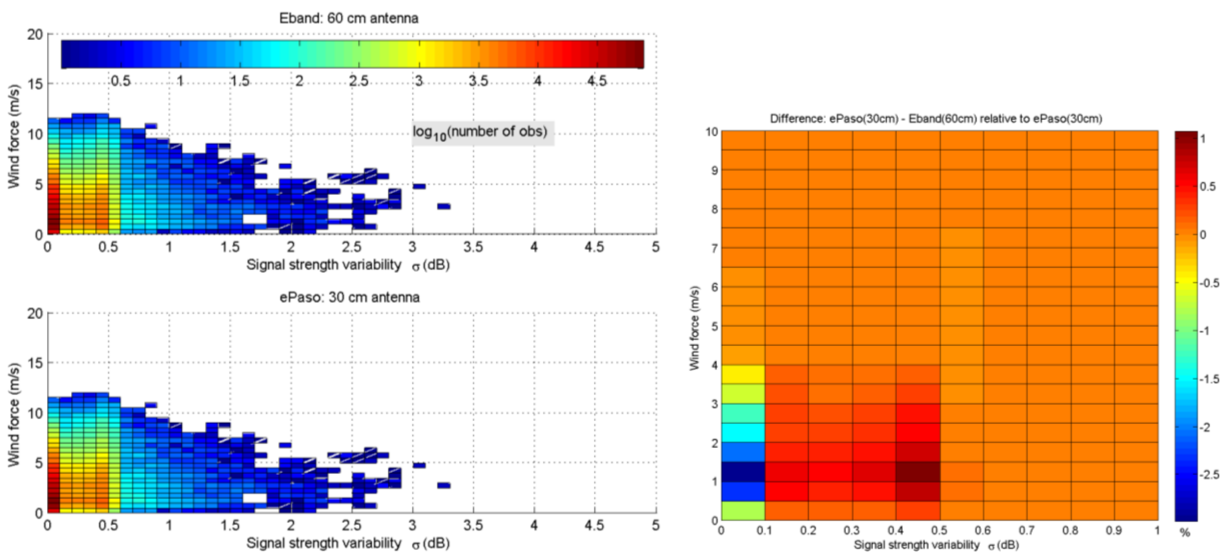


Figure 2. Joint histograms for gaseous attenuation (dB) and the Eband signal strength (dB) for 4 months in 2013.

2.3 Signal variability and other effects at 84 GHz

Scintillation increases with frequency, but the common volume confined by the 3dB antennas opening angles is very small. Figure 3a shows the concurrent Eband signal strength and gaseous attenuation for 2013. Per minute of meteorological data the standard deviation of the signal strength in dB has been calculated. This is a first attempt to study to what extent scintillation causes concerns. It uses all data such that it includes variability regardless for the attenuation level. It is noted that the two antenna sizes largely show the same variability where Figure 3b focuses on the differences suggesting 1% to 2% difference in the lower range of variability. The narrower beam shows some more variability within 0.1 dB, perhaps due to the narrower beam. It is not clear how to interpret the measurement, but no difference may suggest that the active propagation medium is confined within the first Fresnel ellipsoid. If the antenna beams dominates there should be more variability for the ePaso link, given that the link mounting does not vibrate, which is seen around 0.4 dB. Visual inspection of some events may suggest around 10 dB peak to peak which is four times the standard deviation illustrated in Figure 3a.



a) b)

Figure 3. Signal variability (dB) per minute wind force a) comparing the links 60 cm and 30 cm reflector antenna diameters, and b) the difference (%) between to wider beam and the narrower beam relative to the wider beam.

Fog or cloud attenuation can be significant, perhaps more than 3 dB/km. This depends on the liquid water vapor content estimated by visibility. Since there is no measurement of visibility there are no quantified figures for the experiment. Only some observations showing the cold dense fog may cause the attenuation quoted.

Antenna wetting causing attenuation was verified spraying water on the Eband and ePaso radomes. If it is forming droplets on the hydrophobic hard cover antennas the additional attenuation may largely be constant [3] when it is raining. Looking at the distributions for the Eband links, in 2011 and 2013 an additional constant would seem reasonable. Using Schleiss et al [3] from measurement at 28 GHz the value of 5 dB is suggested

3 Discussion of measurements and predictions

The rain attenuation tests shown in Figure 4 depict the measurement from the ITU-R database [4] and prediction. Each individual year is displayed and the prediction is shown in black symbol color in the upper part of the figure. Tests show under-prediction for most of the various time percentages. In fact, there are only two different sites: one multiple-frequency set from the UK and another single-frequency site (81 GHz) from Japan.

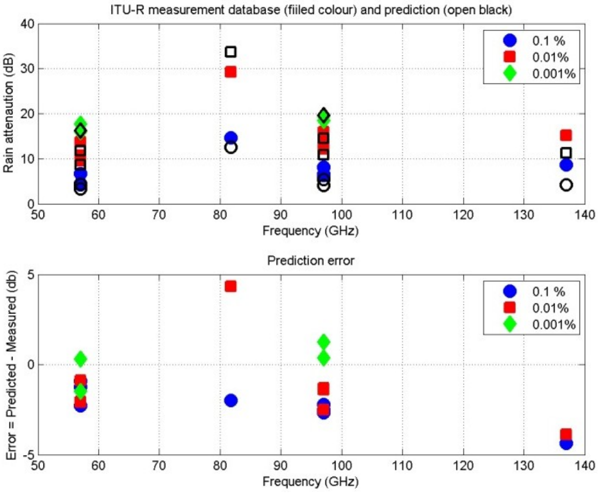


Figure 4. Predicted and measured rain attenuation for links at and above 57 GHz in the ITU-R data base.

4. Conclusion

The results in this paper show that millimeter wave links is a suitable network element to provide gigabit capacities to base stations. Apparently fundamental mechanisms must be investigated further to increase the accuracy of rain attenuation prediction methods for practical links at 70/80 GHz. More measurement data for this type of radio links should be submitted to the ITU-R, both for the purpose of testing prediction methods and to help revise them. A revised recommendation is needed to deal with combination of effects such as hydrometeor precipitation, atmospheric gases, and clouds and fog. This seems particularly important for low margin systems.

5. Acknowledgments

The Norwegian Meteorological Institute provided rain intensity measurement data.

6. References

1. Propagation data and prediction methods required for the design of terrestrial line-of-sight systems, *ITU-R Recommendation P.530-14, Int. Telecommun. Union, Geneva*, 2012.

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4. Study Group 3 databanks - DBSG3 - Table III-1a & VHF/UHF, Radiocommunication Sector, *Int. Telecommun. Union, Geneva*.