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Planned and early results of low elevation angle measurements at Ka-band from two projects in Norway

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English summary

Geostationary satellite fixed communication services for high latitude and mostly maritime environment are increasingly important for Norway and the regions in the high north in general. Although measurement results have been reported from several earlier experiments there is still a lack of satisfactory knowledge, particularly at Ka-band, both with respect to attenuation due to hydrometeor precipitation and to clear air scintillation and ducting effects. New measurement experiments are being and have been set up to collect more data. This report presents two initiatives: the ESA project on Ka-band radio characterization for SatCom services in arctic and high latitude regions and early results from another project run by FFI and the Norwegian Defence. The two projects will in total take measurements from 7 locations. The measurement stations' latitudes range from 57° to 78° N and cover both a maritime and in-land climates. The projects will run until the end of 2015.

Sammendrag

Kommunikasjon ved høye breddegrader ved hjelp av geostasjonære satellitter blir stadig viktigere for Norge og for nordområdene generelt. Det er begrenset kunnskap om signaldempning fra nedbør, hurtig signal funkling og ledet utbredelse av radiobølger på Ka-bånd. Få målinger har til nå vært utført i disse områdene. Det er behov for nye målekampanjer for å samle inn data. I denne rapporten beskrives to initiativer: ESA prosjektet Ka-band radio characterization for SatCom services in arctic and high latitude regions og tidlige resultater fra et prosjekt ledet av FFI og det norske Forsvaret. De to prosjektene vil til sammen samle inn data fra 7 lokasjoner. Målestasjonenes breddegrad er fra 57° til 78° N og dekker både maritimt og innlandsklima. Prosjektene vil pågå til slutten av 2015.

Contents

Preface

This report is based on a paper submitted to the workshop “First CNES-ONERA Workshop on Earth-Space Propagation”, Toulouse, France, Jan. 21-23, 2013. The article second author is Dr. Terje Tjelta, Telenor, Norway.

1 Introduction

The high latitude Northern European areas are of increasing value due to natural resources such as fishing industry and oil/gas exploration. The arctic is of crucial importance as the potential climate effects opens up frozen sea parts for longer periods of the year. Reliable communication systems to cover these regions can only realistically be delivered by satellites.

A SatCom Ka-band system is particularly attractive for broadband data serving business and applications as mentioned. Telenor Satellite Broadcasting (TSBc) is investing in a new satellite serving civilian commercial users utilising the Ka-band.

To aid the satellites payload design and overall system dimensioning, it is desirable to perform a long-term study of K/Ka-band propagation effects within the designated coverage areas. It is believed that the outcome of the two studies reported in this report can be used to further refine and enhance the relevant ITU-R radio wave propagation models for geostationary orbiting satellites, serving high latitude low elevation angle locations on land, coastal areas, and at sea. Results will also become important for other orbits.

The rain attenuation effects are of particular interest, as the recently revised version of the ITU-R rainfall intensity maps indicates significantly higher rainfall rates over water and coastal high latitude areas, compared with the prediction using the previous version [1].

Low elevation radio links are affected by atmospheric propagation mechanism that are much more severe than the ones experienced at lower frequencies at lower latitudes and higher elevation angles. In particular, due to the longer path in the atmosphere, not only rain attenuation but also other propagation effects, such as gaseous attenuation, scintillation, scattering, and ducting effects must be considered [2].

Maritime radio links at low elevation angles are challenging to dimension correctly. Lower prediction accuracy due to the lack of ground meteorological measurements, in particular for rain. Propagation at Ka-band can affect also the performance of auto-tracking systems of the large ground stations, reducing their operational capability.

2 Experimental campaigns overview

Two experimental campaigns aiming at defining the K/Ka-band radio channel characteristics relevant for the design and the performance assessment of a radio link in Norway have started up. One is performed within the ESA project *Ka-band Radio characterisation for SatCom services in arctic and high latitude regions*. The project started in September 2012 and is running for 3 years. The experimental campaign includes five stations at fixed locations. Four stations are land based and one is located at an oil installation in the North Sea. The stations will be equipped with meteorological instruments and beacon receivers. In addition two stations will be used to perform a telecom modem study, including the effect of channel dynamics on adaptive coding and modulation (ACM). The measurement campaign is planned for at least 2 years for the stations doing propagation measurements, and shorter periods for the set of stations doing telecom measurements. The participants in the ESA study include operators, industry, research institutes and academia. Telenor Satellite Broadcasting and the Norwegian Defence Research Establishment are central in planning and execution of the study.

A second measurement campaign with 4 stations started K-band beacon measurements for the Norwegian Defence in 2012. Two of the locations will be included in the ESA study, and the other 2 stations will continue measurements as well.

3 Experiment design

This section contain the main features of the beacon measurement campaigns, including measurement locations, parameters to be measured, satellite candidates, receiver design and power link budgets.

3.1 Measurement locations

The measurement locations selected for the ESA supported measurement campaign are Nittedal, Eggemoen, Ekofisk, Vadsø, and Svalbard (Isfjord radio). The measurement sites selected for the traffic study are Nittedal gateway (GW) and Vadsø, see Table 3.1.

Location	Lat (deg)	Long (deg)	Campaign
Nittedal	60	11	Beacon, telecom
Eggemoen	60	10	Beacon
Ekofisk	56	3	Beacon
Vadsø	70	30	Beacon, telecom
Isfjord radio	78	14	Beacon
Kjeller	59	11	Beacon
Bergen	50	5	Beacon

Table 3.1 Measurement locations

Svalbard is selected due to its location far North, representing the practical limit for fixed stations communicating with GEO satellites. Svalbard is a major download site for polar orbiting Earth observation satellites. To obtain results believed to be representative for typical maritime users, we have selected Isfjord radio as measurement site.

Vadsø is selected due to its location far North on the mainland. The Earth-space path crosses a fjord, enabling costal climate measurements with a variety of precipitation forms and possible atmospheric anomalies. This is important as for example wet snow attenuates significantly more than rain or dry snow for the same precipitation intensities.

Eggemoen and Nittedal are both gateway stations. Nittedal will serve Telenor's Thor 7 carrying Ku- and Ka-band payloads. Joint diversity results for these two locations might become important to ensure high availability services utilising sites with existing gateway infrastructure.

Ekofisk represents a fixed sea station enabling long term logging of meteorological conditions in cooperation with the Norwegian Meteorological Institute and the rig operator.

Two additional sites are included in the campaign run by FFI and the Norwegian Defence: Kjeller is the main location for FFI and where equipment is integrated and tested, and measurement results collected and analysed. Bergen has typical maritime climatic conditions for the West coast. This is an area where for example the rain maps from ITU-R and local rain intensity measurements deviates to quite an extent [1].

3.2 Measurement parameters

In addition to measuring signal attenuation and noise floor variations, a number of meteorological parameters are logged to enable verification of ITU-R propagation prediction recommendations. The parameters are summarised in Table 3.2.

Parameter	Range
Rain int. [mm/h]	0 ... 200 mm/h
Hail [Hits/cm^2]	
Air temperature [C]	-50 ... +60
Air rel. hum. [%]	0 ... 100 %
Atm. tot. pr. [hPa]	600 ... 1100
Wind speed [m/s]	0 ... 60
Wind direction [Deg.]	0 ... 360°
C/N_0 [dBWHz]	>10
Noise floor [W/Hz]	

Table 3.2 Parameters to be measured

The meteorological parameters are measured each minute, while the target sampling rate for signal and noise power is 10 Hz.

3.3 Measurement equipment and set-up

Each site will be equipped with a K/Ka-band antenna, temperature stable RF-frontend, beacon receiver, and PC with logging software. Compact weather stations will be utilised as well as network time protocol (NTP) for timing reference. The sites will to a largest possible extent be co-located with manned offices enabling operation and maintenance of the measurement equipment. Figure 3.1 shows a block schematic of a test setup which is both performing beacon and traffic (modem) measurements.

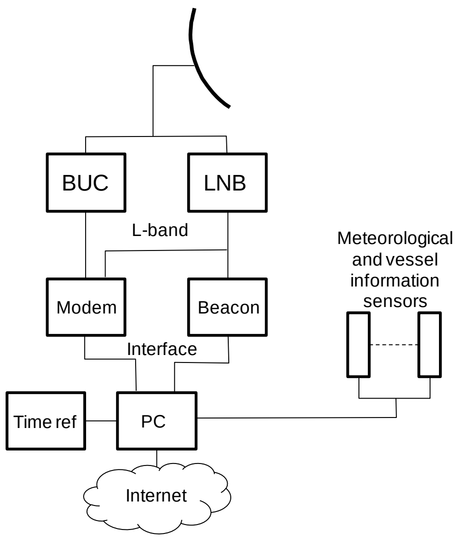

Figure 3.1 Measurement set-up

A detailed measurement set-up for Kjeller is presented in [3].

3.4 Satellites

The satellites of primary interest have Ka-band communication payloads, separate stable beacon transmitters with high effective isotropic radiated power (EIRP), and coverage towards Norway and the surrounding sea areas. For the traffic study good coverage of the selected measurement sites as well as available transponder capacity is of prime interest. A short list of considered candidates is:

- Eutelsat Ka-Sat
- Telenor Thor 7
- Astra 3B
- Astra 4A

Eutelsat Ka-Sat is positioned at 9ºE, and was launched in 2010. According to information received from Eutelsat, Ka-Sat have beacons at both 19.7 GHz and 27.5 GHz.

Telenor Thor 7 is expected to be in service in 2014. The orbital position will be 1°W. It has both a Ka- and Ku-band payload and is well suited for traffic measurements at Ka-band in Nordic regions. Thor 7 has maritime multi spot-beam coverage, the prime GW station will be Nittedal. THOR 7 will have a beacon at 20.2 GHz. Southern Norway, the coast line and major parts of northern Norway are covered by the beacon, transmitted with an EIRP of 27 dBW.

Astra 4A is located at 5ºE and was launched in 2007. A linear horizontal polarised beacon at 19.3 GHz is transmitted through the Interconnect/Interactive Beam. The downlink beacon EIRP towards Oslo is estimated to 19 dBW. The downlink gain contours rolls off quite quickly towards the West coast of Norway, with a further reduction of about 10 dB compared to Oslo. Towards Northern Norway, the estimated beacon EIRP is about 20 dBW.

Astra 3b was launched in March 2010 into a geostationary position 23.5ºE. The beacon transmitted has a frequency of 20.2 GHz. The EIRP is approximately 18 dBW towards Oslo and Bergen, rolling off quickly further North.

3.4.1 Discussion on satellite candidates

Astra 3b and 4A, and Eutelsat Ka-Sat, currently provide stable beacons at Ka-band suitable for propagation research in the area of interest, see Table 3.3.

Satellite information					EIRP		
Satellite	**Launch**	**Position**	**Pol.**	**Freq. (GHz)**	**East**	**West**	**North**
Ka-Sat	2010	9E	H	19.7	18	17.5	17.5
Ka-Sat	2010	9E	H	27.5	17	17	17
Astra 3b	2010	23.5E	V	21.2	18	17	14
Astra 4a	2007	4.8E	H	19.3	19	9	20
Thor 7	2013	1W	RHCP	20.198	27	27	27

Table 3.3 Relevant Ka-band beacons

For the foregoing Defence campaign Astra 4A was selected, with Astra 3B serving Bergen. For the ESA project Eutelsat Ka-Sat and Telenor Thor 7 were selected for the beacon and telecom experiments respectively. It will be considered to change the equipment at Kjeller and Bergen to enable measurement on a single common beacon.

3.5 Propagation measurement

For the propagation experiment the receiver consists of a spectrum analyzer aiming at a high dynamic range as well as measurement of the noise floor beside the occupied signal frequency band. A diagram of the measurement set-up is given in Figure 3.2.

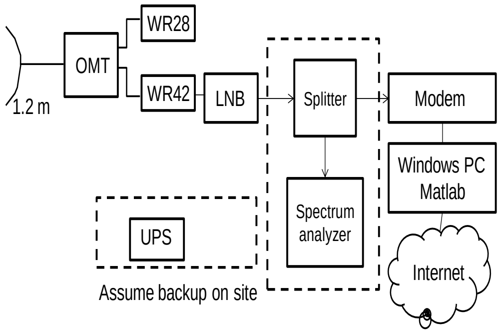

Figure 3.2 Propagation measurement receiver

The size of the Ka-band antenna and the receiver RF noise factor are to a large extent determining the requirements on the L-band beacon receiver. A reasonable compromise between cost and performance is a diameter of about 1.2 m.

3.5.1 Power link budgets for beacon measurements

Power link budgets for the Ka-Sat beacon at 19.7 GHz received in Vadsø, Svalbard, Nittedal and Ekofisk are displayed in Table 3.4. Link budgets for the Astra 4A beacon received at Kjeller and Eggemoen, and Astra 3B in Bergen, are included as well. The main assumptions for the ESA project are 1.2 m antennas and low noise block converters with a noise factor of 1.2 dB. A 1.8 m antenna is deployed at Eggemoen and a 2.4 m antenna at Kjeller.

Parameter	Sva	Vad	Eko	Egg	Nit	Kje	Ber
EIRP (dBW)	17.5	18.0	18.0	19.0	18.0	19.0	17.0
FSL (dB)	210.6	210.5	210.2	210.1	210.2	210.1	210.9
Gas att (dB)	2.2	0.8	0.5	0.4	0.4	0.4	0.9
Rain att.	-	-	-	-	-	-	-
Cloud att. (dB)	2.4	1.1	0.6	0.4	0.5	0.5	0.7
Scintill. (dB)	0.7	0.2	0.1	0.1	0.1	0.1	0.1
Tot. att. (dB)	215.3	212.4	211.3	210.9	211.1	210.9	212.4
G/T (dB/K)	21.3	21.8	22.5	25.9	22.3	28.7	22.5
C/N_0 (dBHz)	52.1	56.0	57.8	62.7	57.8	65.4	55.6

Table 3.4 Power link budget for beacon receives at the locations, 80 per cent availability

The Propa software from CNES is utilised in the calculations, following specific ITU-R recommendations.

Typical commercial beacon receivers have a C/N_0 threshold of 43 dBHz. As seen in the last row in Table 3.4 the margins for such a receiver would be in the range 9 to the 15 dB for the ESA project sites receiving the Ka-Sat 19.7 GHz beacon. With a 1.2 m antenna receiving the Astra 3B beacon in Bergen, the margin is 13 dB. The Astra 4A sites Kjeller and Eggemoen, receives the beacon with margins of 22 and 20 dB respectively. The Eggemoen site will later be equipped with a front end for Ka-Sat in the ESA project. With a receiver C/N_0 threshold of about 10 dBHz, a calculated dynamic range exceeding 40 dB is obtainable at all sites. This is considered satisfactory for the beacon propagation campaign and motivates use of alternative receiver techniques with improved sensitivity [4]. An approach based on use of spectrum analysers is reported in [3], planned to be utilised in the ESA project as well.

4 Propagation impairments and early measurement results

4.1 GEO satellite high latitude propagation

The attenuation due to gaseous absorption and hydrometeors (e.g. rain, wet snow, clouds) is increasing with decreasing elevation angle towards the satellite due to increased path length thorough the attenuating media. The same applies to scintillation and cloud attenuation. Figure 4.1 shows the location of the five ESA project stations with elevation angles indicated for a geostationary satellite at 9 °E. As seen the elevation angles below 10° will be the case for maritime satellite communications in the High North.

The main propagation degradation factor is expected to be caused by hydrometeor precipitation, clearly subject to the amount of water and precipitation rate for the regions considered. This will be the case for the Norwegian coastal and maritime areas at higher elevation angles up to around 25°.

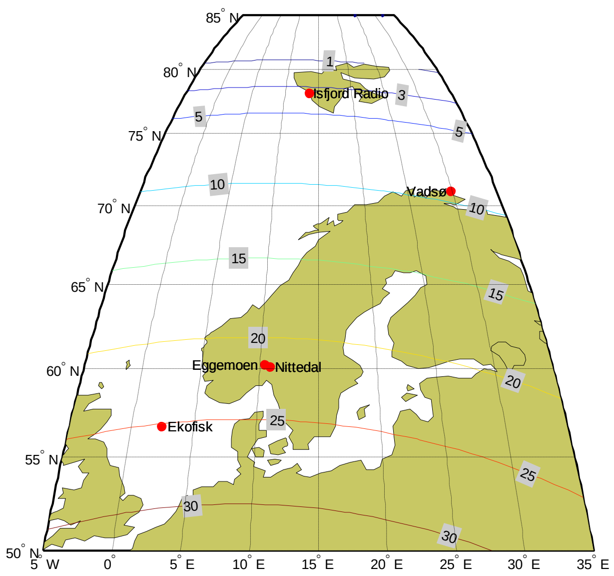

Figure 4.1 Stations locations (ESA project) showing elevation angles towards a satellite at 9°E

4.1.1 Rain attenuation

In prediction attenuation due to rainfall the most significant climatic parameter is the point rainfall rate at the site, then also rain height plays a major role. Finally, the rain attenuation prediction method introduces “effective path” through rain using horizontal and vertical path length reduction factors that in turn also have an impact on the prediction of rain. There are many potential factors that might be adjusted to improve the prediction accuracy, where the rainfall intensity is probably the most significant. A recent study [5] revealed for Norway a major deviation between local observed rain intensity data and the ITU-R map in rec. P.837-6. The actual recommendation, P.618, suggests using local rainfall rate data, if available.
The problem is that over water there are no data available as over land. When the coastal rain rate observed is 50 per cent less than the ITU-R map, what to use for the over-water areas in the region? For illustration the predicted rain attenuation is calculated using the following data:

GEO satellite location	9º E
Frequency	20 GHz
Polarisation	45º
Rainfall rate	P.87-5
Specific rain attenuation	P.838-3
Rain height	P.839-3
Terrain height	P.1511
Terminal height above terrain	0 m

The area considered is between 0 and 32º E and 55 to 82º N. This gives elevation angles from about 25 to 0 º. The gridded data are calculated using 1º resolution shown for 0.01 per cent of the time. The predicted attenuation using rec. P.837-6 (in-force) is shown in Figure 4.2.

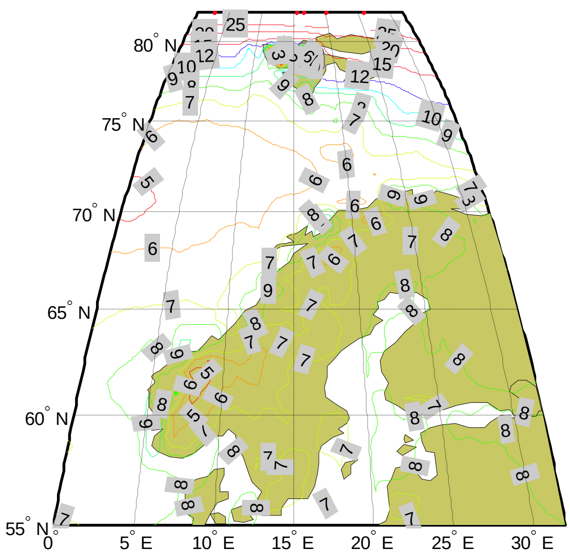

Figure 4.2 Predicted rain attenuation (dB) exceeded at 0.05 per cent of the time for a satellite at 9° E at 20 GHz circular polarisation

Long term tipping bucket data are available from Norwegian Meteorological Institute. There are about 70 stations satisfying more than 10 years of data with maximum of over 40 years [5]. Deriving rain rates from these stations and calculating the attenuation for the same satellite links, except using local terminal heights (of the rain gauges) the scatter plot in Figure 4.3 illustrates the systematic deviation.

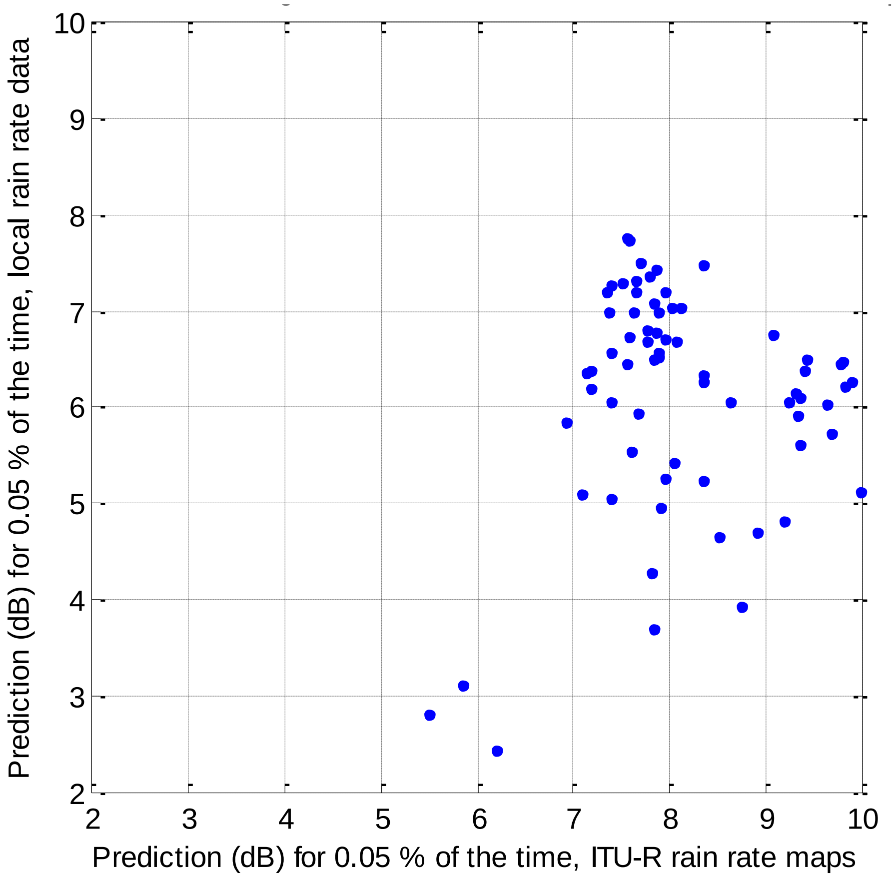

Figure 4.3 Scatter plot showing predicted attenuation for a satellite at 9E at 20 GHz circular polarisation

The largest deviations of as much as double predicted attenuation in dB using the ITU-R maps appear at the western coast. The good correspondence between the two predictions appears over in-land such as South East Norway.

4.1.2 Clear air effects

The discussion in [2] highlights two fundamentally different prediction models for low elevation fading (caused by atmospheric multipath propagation) in article [6] and ITU recommendation P.618 [7]. The ITU-R recommended model is based on results published in [8]. Further work is required to validate the models for low elevation fading.

ITU-R Rec. P.618-10 predictions of scintillation and multipath fading for a 20 GHz satellite link with 1 m antenna and 0.65 efficiency are shown in Figure 4.4.

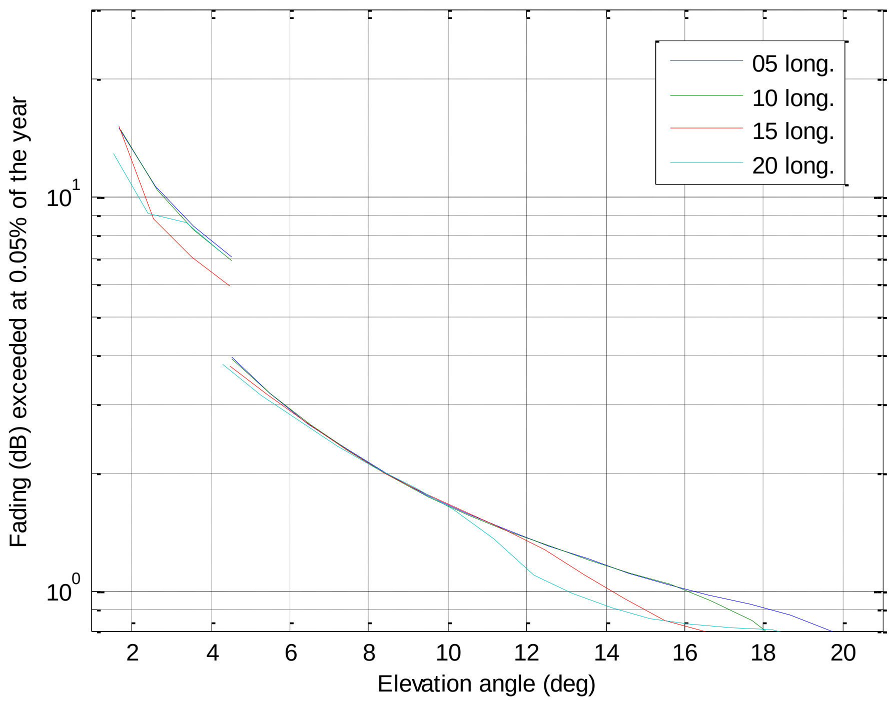

Figure 4.4 Scintillation and multipath Rec. P.618 exceeded at 0.05 per cent of the time for a 20 GHz signal shown versus elevation angle along constant longitudes

The satellite earth station is assumed located on the surface of the earth located between 600 and 800 N and 50 to 200 E. The scintillation and multipath fading are calculated along four constant longitudes ranging from 5º to 20º E from 60 °N to 80° N giving elevation angels ranging from 1° to 21° to a GEO satellite located at 9 °E. Values for ducting layer statistics pL are derived from maps in ITU-R P.453.

Firstly, it will be interesting to check whether these distributions can be verified from measured data. Secondly, there is a discrepancy between the methods for scintillation and multipath; actually they give different predictions for the overlapping elevation angles (4º -5º). The scintillation method is not said valid beyond 20 GHz, at lower percentages of the time than 0.01 per cent, and a lower elevation angles than 4º. The multipath method is indicated valid in the range 0.5º to 5º elevation.

4.2 Beacon measurements at Eggemoen

The Astra 4A beacon is received at Eggemoen with a 1.8 m antenna, followed by a pressure waveguide section and amplified with a LNB. The antenna horn is shielded from rain and snow by a plastic protector; no de-icing equipment is currently in use. An air dehydrator dries the receive waveguide chain. The signal is transferred to a receiver located indoor by RF over fibre equipment.

During March, a Peak PTR 50 beacon receiver was utilised, replaced by an Agilent CXA spectrum analysator. The analysator utilise a slight different software routine compared to the one described in [3]. The carrier observed on the analyser drifts slowly in frequency over time. The centre frequency is adjusted periodically according to the maximum power within the frequency span. If the carrier drifts towards one of the neighbouring bins in the FFT in between frequency adjustments, a dip in received power is registered. In the current implementation the power a few Hertz on each side of the assumed carrier frequency is measured to avoid this. The marker with the registered largest power is then selected as the carrier power estimate. The resulting sampling rate is about 11 Hz. Measurements were performed with both PTR 50 and CXA receivers overlapping in time. The results show a similar behaviour at low and medium attenuation levels, with less quantification error from the spectrum analyser. At high attenuation levels the PTR 50 beacon receiver lost track, while the spectrum analyser still were able to receive the signal.

The weather sensor utilised is a Vaisala WXT 520 compact weather station located relatively high above ground in a mast about 50 meter from the antenna.

An example of a significant attenuation event is given in Figure 4.5, where the attenuation reached about 50 dB. At the same period of time, high intensity rain was registered.

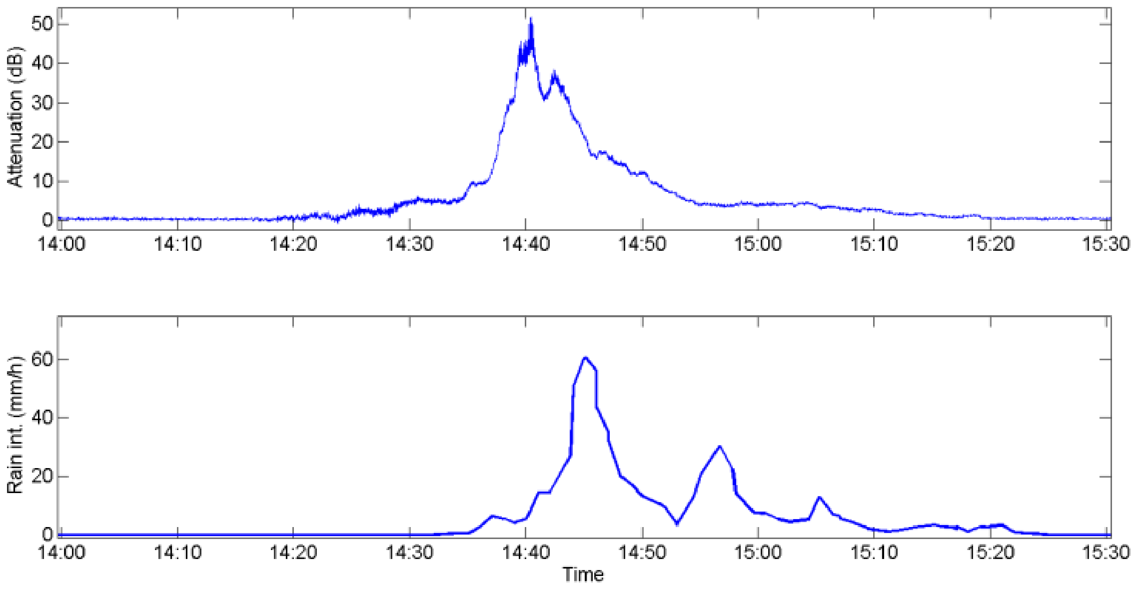

Figure 4.5   Attenuation event and rain rate 5. August 2012

The measured rain intensity and attenuation complementary distribution functions (CCDF) are shown in Figures 4.6 and 4.7 respectively. The monthly and yearly averaged measured rain intensity CCDF is displayed together with predicted rain attenuation and rain intensity from ITU-R.

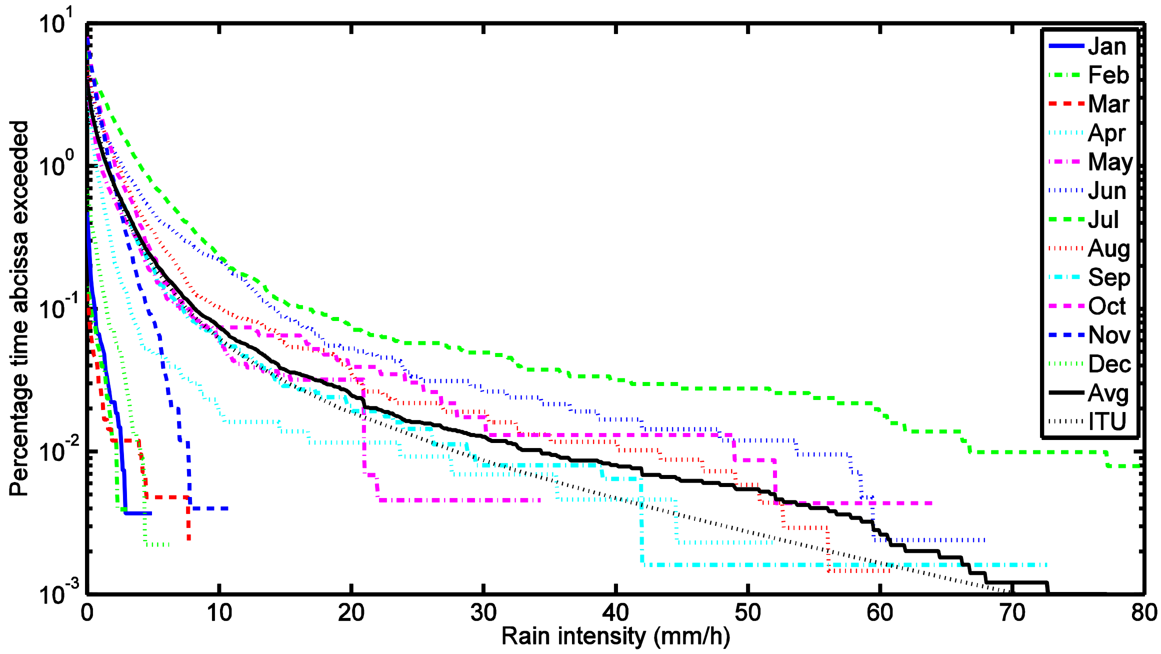

Figure 4.6 Monthly rain rate statistics at Eggemoen, 2012

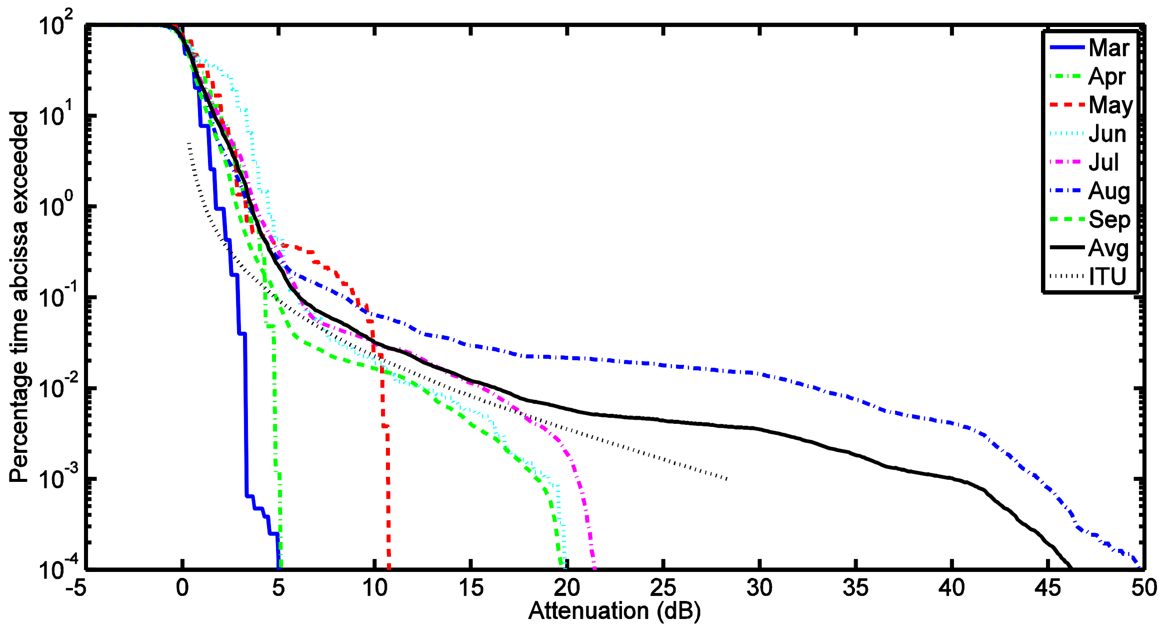

Figure 4.7 Monthly attenuation statistics at Eggemoen, 2012

The measured yearly average rain intensity at Eggemoen for 0.01 per cent of the time is 34 mm/h, the corresponding values from ITU-R Rec. P.837-5 is 28 mm/h. The 12 months of measured rain intensity thus correspond reasonably well with the yearly average estimate provided by the ITU-R. As described in [2], the rain sensor has a tendency to overestimate the occurrence of high intensities, especially relevant for the summer months.

The corresponding monthly attenuation CCDFs for the months March to September 2012 are shown in Figure 4.7. The observed averaged attenuation during 7 months slightly exceeds the predicted one for an average year. It should be noted that only the rain attenuation from ITU-R Rec. P.618-10 is included in the estimate, explaining some of the deviation as for example cloud attenuation is not included.

5 Conclusions

Geostationary satellite communication services for high latitude and mostly maritime environment, are increasingly important for Norway and the regions in the high north in general. Two new measurement experiments are described, aiming to collect K/Ka-band data in Norway: One recently started ESA project and an FFI project conducting measurements for the Norwegian Defence. The two projects will in total take measurements from 7 stations. The measurement stations' latitudes range from 57° to 78° N and cover both a maritime and in-land climates. The projects will run until the end of 2015. Predicted rain attenuation is compared to measured, and a systematic deviation is observed. The discrepancy between the two methods for scintillation and multipath is discussed for low elevation angles. Preliminary results from beacon and rain rate measurements at Eggemoen are presented.

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