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# NETWORK ARCHITECTURE FOR SMALL X-BAND WEATHER RADARS – TEST BED FOR AUTOMATIC INTER-CALIBRATION AND NOWCASTING

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## 1. ABSTRACT

In recent years the use of small inexpensive X-band radars for meteorological and hydrological purposes has increased significantly.

Compared to the traditional C-band and S-band radars the X-band weather radar has the advantage of high temporal and spatial resolution and low financial cost; however, the trade off is attenuation due to X-band technology and short range due to the higher spatial resolution.

In relation to quantitative precipitation estimation (QPE) and forecasting (QPF) it is necessary to address the attenuation issue. Over the next two years a test bed with five X-band radars of the type Local Area Weather Radar (LAWR) will be set up south of Aarhus in Denmark. The three radars will be placed so that they overlook the same area and thereby are capable of intercepting a precipitation event from different angles, altitudes and ranges.

The overall aim is to construct a network of small X-band radars which are capable of automatic inter-calibrating and inter-correcting for attenuation on the fly by online communication. From the beginning the LAWR has been equipped with a set of attenuation corrections algorithms. However, verification of these algorithms has not been possible so far, due to lack of multi radar measurements of rainfall events. The prospects of verifying and possibly improving the method used for correction of attenuation using radar networks are promising.

The results from the test bed are expected to optimize attenuation handling and improve nowcasting capabilities.

## 2. INTRODUCTION

Rainfall measurements today are conducted with a variety of measuring equipment, the most common type still being rain gauges. They provide point measurement in contrast to weather radars which provide spatial distributed measurements. The two methods offer both advantages and disadvantages, however, the general opinion today is that they are both required in order to obtain reliable quantitative precipitation estimates (QPE). The predominant types of weather radars are based on either S or C-band technology, both of which facilitate long range measurements. However, due to the curvature of the earth the radar beam from these radars is often overshooting near surface phenomena at far ranges.

Lately, the focus has been drawn toward an approach of using a number of smaller radars instead and thereby overcoming these problems.

At present seven out of eight planned LAWRs are installed in Denmark – five LAWRs and three City LAWRs as illustrated in Figure 1. In addition four C-band radars are operated by the Danish Meteorological Institute, Gill et al. (2006).

Today, most LAWRs are operated individually, however, the process of generating a composite has begun, although it is complicated by the fact that they are owned and operated by different organizations with multiple interests.

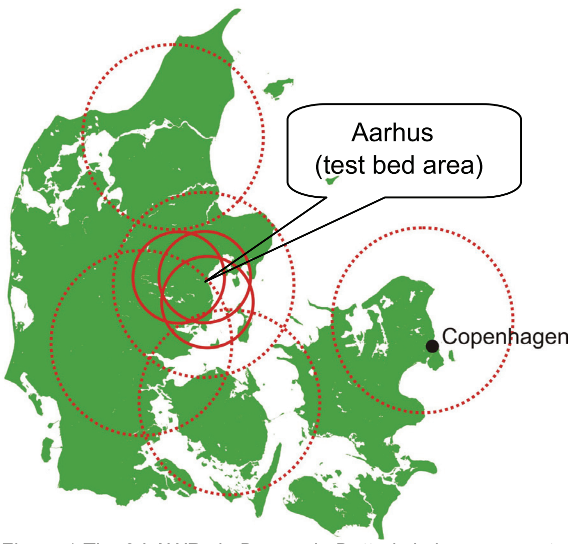


*Figure 1 The 8 LAWRs in Denmark. Dotted circles represent LAWRs, while full circles represent City-LAWRs. It is one of the City-LAWRs that still remains to go up.*

When comparing X-band weather radars to the more traditional C- and S-band weather radars usually two limiting features are pointed out. First of all the X-band radars have a shorter range and they are more sensitive to attenuation caused by rain. The positive features are the high spatial and temporal resolution of this radar type along with the much smaller physical size. The last feature makes it much easier to find a suitable installation location. Furthermore, the X-band technology used in the test bed described here is very cost-efficient compared to traditional weather radars.

The short range problem can be solved by constructing a network of a number of X-band radars. As a result of the lower financial cost it makes sense to have a number of X-band radars in a network to cover the area spanned by a single S- or C-band radar.

The idea is to have several radars overlooking the same area and thereby observing a given event from different angles and ranges. The test bed layout provides opportunity to test and verify attenuation algorithms. The QPE and QPF based on different radars should coincide if the attenuation correction is done correctly.

## 2.1 Future advantages of LAWR network

Most of the more than 20 LAWRs installed today operate as individual installations providing QPE and QPF for their individual coverage area.

Many of the installed LAWRs are equipped with automatic forecast facility, Jensen and Pedersen (2005b). The forecast lead time is normally in the order of one hour. One of the great benefits from developing a network structure is for the users who get a larger coverage area and longer forecast lead time. The data quality will improve since rainfall at the outer range of one radar may be closer to another one in the network and thereby better.

By combining many radars into one network and thereby obtain a composite it will be possible to cascade the information obtained by one radar in the network to the others, and in this way the calibration and attenuation correction factors or parameters can be applied on the basis of actual measurements and not just on the basis of a set of standard values.

## 2.2 Test bed radars

The radars used in this specific test bed are of the type Local Area Weather Radars (LAWR). A LAWR is an X-band weather radar based on a standard Furuno marine radar. Signal handling is performed by a specially designed AD converter while the data processing and communication are performed by two standard PCs.

There are two variants of the LAWR – the standard LAWR is based on a 25 kW radar, whereas the smaller version named the City-LAWR is based on a 4 kW radar.

Examples of the two LAWR types can be found on Figure 2. Both LAWR types are included in the test bed.

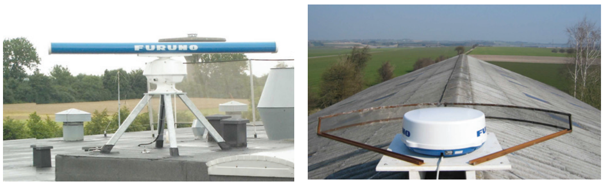


*Figure 2 Example of LAWR installations. The LAWR on the left is a standard LAWR. The one on the right is a City-LAWR. Besides the antenna unit on the image there is a small cabinet with two PC's and the radar control unit.*

The radars are calibrated on the basis on rain gauge data using the sum calibration method described in Pedersen (2004). The calibration can be performed either manually or set up to be automatical. The latter requires an internet connection to the radar as well as the gauge.

The technical details on both types of LAWRs are listed in Table 1.

| | LAWR | City-LAWR |
|---|---|---|
| Output power | 25 kW | 4 kW |
| Frequency | 9410 ± 30 MHz | 9410 ± 30 MHz |
| Image Frequency | 5 or 1 minute | 5 or 1 minute |
| Slotted Wave Guide Antenna | 2.44 m | 0.54 m |
| Horizontal beam width | 0.95° | 3.9° |
| Vertical beam width | ±10° | ±10° |
| Rotation speed | 24 rpm | 24 rpm |
| Pulse length | 0.07-1.2 μs | 0.08-0.8 μs |
| Number of vertical scans | 1 | 1 |
| Grid resolution (pixel size). All resolutions can be used simultaneously. The range in brackets is the maximum range. | 500x500 *(60 km range)* 250x250 *(30 km range)* 300x300 *(15 km range)* 100x100 *(15 km range)* | 250x250 *(30 km range)* 125x125 *(15 km range)* 150x150 *(7.5 km range)* 50x50 *(7.5 km range)* |
| Range for QPE | 20-30 km | 10-15 km |
| Range for forecast | 60 km | 30 km |

*Table 1 Technical specifications of the two LAWR types included in the test bed.*

## 3. NETWORK ARCHITECTURE

The concept of a network of X-band radars is gaining a lot of interest these years, and in 2006 CASA presented their DCAS network (Distributed Collaborative Adaptive Sensing), Brotzge et al (2006) and McLaughlin et al (2006). Donnovan et al (2006) describes a variant of the DCAS network namely the Off-The-Grid radar network (OTG) which in its basic idea is identical, but operates at smaller ranges and is independent of external power supply. The latter is based on a Raymarine radar.

The most fundamental difference of LAWR network compared to the DCAS network is that the LAWR network is not aiming at distributing the calculation load in the network and it will depend on an external power supply which in this case is the ordinary power grid.

The key feature to be facilitated by the LAWR network is online inter-calibration and automatic attenuation correction of multiple radars in a network with overlapping coverage. At present the communication is handled by wired internet, however, part of the research will be directed towards wireless inter communication between the nodes. One option being considered is the use of radio modems, due to the low data rate required.

The layout for the network between the radars is illustrated in Figure 3. The present version of the test bed only consists of the network in Figure 3 which only is only a subpart of the full future network as shown on Figure 4.

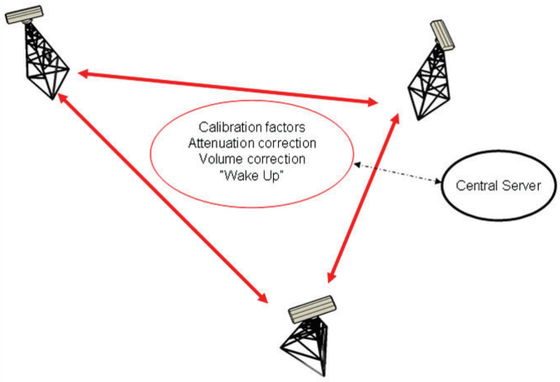


*Figure 3 Network architecture.*

Today each radar handles sensing, data storage and server facility. In the future the plan is to include a central server handling the composite image generation along with a range of other tasks including central data storage (backup) and interface between the users and the data. Furthermore, the idea is to facilitate other data sources, e.g. rain gauge data for calibration.

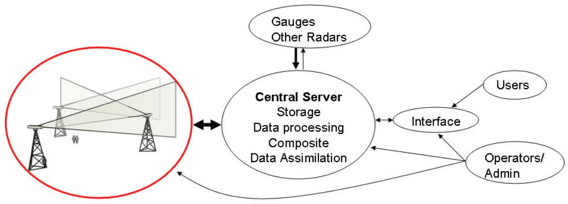


*Figure 4 General LAWR network layout.*

This work focuses on the layout of the LAWR network, marked with a red circle in Figure 4, in relation to installation of radars in the test bed.

### 3.1 Identification of key parameters in test bed layout

First step is to determine the key parameters to take into consideration. In this test bed the initial bounds are defined. First of all the radar technology is X-band and the radars used is of the type LAWR. Secondly, the aim is to use customary communication solutions in order to keep the network cost-efficient.

The test bed network architecture has been designed by taking the following factors into account in order of priority:

- Physical geographical features
- Power availability
- Distance requirements
- Existing radar and gauge installations
- Communication technology
- Bandwidth of communication channels
- Data formats.

The first four points all regard the location of the installation, while the latter three regard the communication. The focus of this paper is on the first four points, due to the current stage of the project. The wireless communication part of the network is still in the design phase and the first test bed will therefore be using wired communication.

### Physical geographical features

One geographical feature to be concerned about in relation to the radar test bed was to find an area without interference from beam blockage. Fortunately, Denmark is a very flat country, so the issue of beam blockage is minor. The main issues in relation to geography have been to avoid areas massively affected by ground or sea clutter. This has been facilitated by choosing an area which has been covered by LAWR radars for almost 10 years and thus is well described in manner of clutter.

The location has also been selected so that the radars are relatively close to the office to facilitate regular inspections.

### Power availability

Continuously scanning radars as the LAWR are quite power consuming and it has been opt out to make an off-the-grid solution for now. The locations chosen all have grid power.

### Distance requirements

The characteristics of the three City-LAWRs can be found in Table 1, where it can be seen that especially the horizontal opening is large (3.9 degrees). This results in an increasing beam width distance as shown in Figure 5.

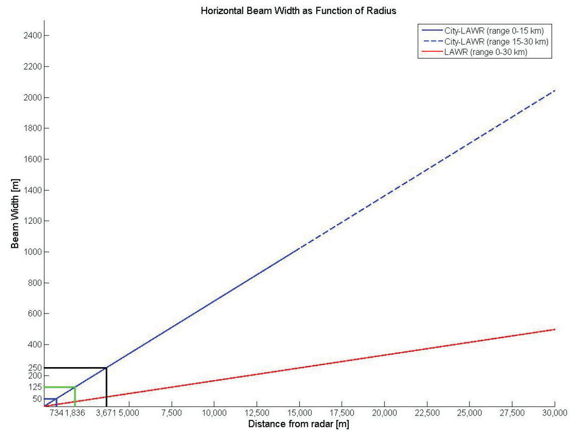


*Figure 5 Beam width of City-LAWR and LAWR as function of radius. The radius at the pixel sizes given in Table 1 is marked.(blue=50 m, green=125 m and black=250 m).*

The ranges where the beam width exceeds the given pixel width are illustrated. The consequences are only at very short distances the QPE/QPF in a pixel the average of a single pixel. At distances further away the QPE/QPF are based on weighed averages of pixels.

Part of this test bed setup is to evaluate the performance of both LAWR types. This is done by comparing the QPE to that found on the basis of a very dense network of rain gauges and the official rain gauge sites operated by the Danish Meteorological Institute in the area. The rain gauge setup is described later on in this section.

Vertically, the openings of the City-LAWR and the LAWR are identical. Only the upper part of the beam is used since the lower part is either cut off by the surroundings or a clutter fence. The vertical beam height reaches quite far, cf. Figure 6.

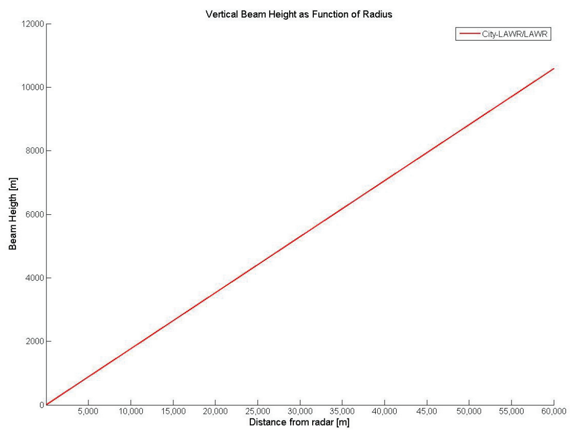


*Figure 6 Vertical Beam Height based on the positive part of the vertical opening angle.*

At 60 km (maximum range) from the LAWR the top of the beam is reaching just above 10 km up in the atmosphere and the City-LAWR is reaching just above 5 km (shorter range). In relation to QPE and QPF this can be a problem due to the altitudes of different types of rain. The majority of cloud types causing rainfall such as the stratiform type are occurring in the lower part of the atmosphere usually below 2-3 km. A cumulonimbus cloud can fill the full vertical volume even at 60 km range.

This issue of different degrees of partially beam filling creates some challenges in order to obtain solid QPE/QPF. The setup of the test bed has been designed to facilitate further investigations of these issues.

By placing the radars relatively close together, but with varying distances between them, it becomes possible to have simultaneous radar measurements of the same rain event at different altitudes and on the basis of different degrees of beam filling. The overall idea of this problem is illustrated on Figure 7.

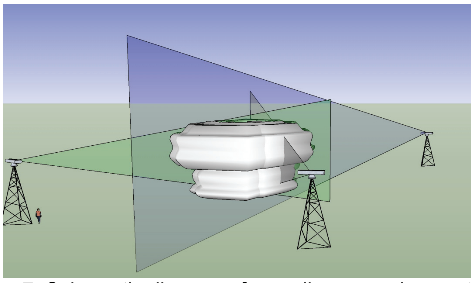

*Figure 7  Schematic diagram of sampling one rain event from different radars.*

### Existing radar and gauge installations

As illustrated in Figure 1 there already exist 5 LAWR installations in Denmark, and it would be preferable to utilize as many of these as possible in the test bed layout.

In addition to the test bed of radar network a field campaign with nine rain gauges takes place within the same frame work. The field campaign is a reproduction of the one described by Jensen and Pedersen (2005a) and takes place 25 km south of Aarhus near the village of Rude. The field experiment aims at determining the spatial variability within one LAWR pixel of 500x500 meter based on nine tipping bucket gauges set up under identical conditions (no shelter effects and same elevation).

## 4. TEST BED PRESENTATION

Figure 9 contains a map of Denmark with the area of interest marked with red. If compared to the map in Figure 1 it can be seen that this area is the most LAWR covered area.

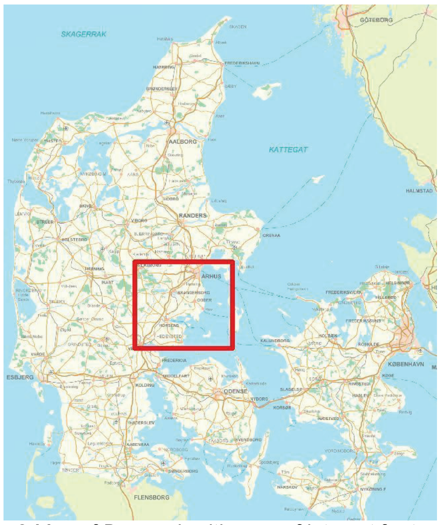

*Figure 8 Map of Denmark with area of interest for test bed marked with red.*

The field experiment with rain gauges also takes place within this area. A close up is shown on Figure 9 with the four radars already installed. The Vejle LAWR (red) and the Aarhus LAWR (green) are both permanent installations. The opportunity to use these as additional radars in the test bed has been one of the main reasons for choosing this specific area.


*Figure 9 Overview of test bed area*

So far 2 of the 3 planned City-LAWRs have been set up – the location of the last one (Mårslet) has been determined, however, the final approval from the owners of the location has not yet been given. The Aarhus LAWR and the Aarhus City-LAWR are placed on the same location and thereby provide excellent opportunities for comparing the result of the different radar types.

The distances between the radars will then be 4 km, 8.5 km and 11.5 km as illustrated in Figure 10. Furthermore, the location of the rain gauge field experiment is shown. The distance from the Rude City-LAWR to the rain gauges is ranging from 600 to 1100 meters.


*Figure 10 The distances between the three City-LAWRs in the testbed.*

The Rude City-LAWR is installed on a barn rooftop on a simple wooden structure. The PCs are placed inside. The setup can be seen in Figure 11, where the field in the background is the location for the before-mentioned field experiment with nine rain gauges.

*Figure 11 Rude City-LAWR. The rain gauge experiment take place in the field in the background.*

## 5. CONCLUSIONS AND FUTURE WORK

The Rude and the Aarhus City-LAWR started operation early April 2007. The Aarhus City-LAWR is now being considered moved due to problems with blocking trees. At the time of installation the trees had no leaves, but after they have set leaves there seems to be some blocking issues. So either the radar is to be moved or the threes in front to be pollarded. Which step to be taken is still to be decided.

After these first months of operation it has become clear that it is very important to have a stable communication to the radars in order to monitor experiments closely. Another issue that was known, but which is still causing some challenges is the extreme amount of data to be handled. To illustrate this, the number of pixels within a 2x2 km area of the test bed is listed in Table 2.

| | City-LAWR resolutions | | | LAWR resolutions | | | |
|---|---|---|---|---|---|---|---|
| | 50 m | 125 | 250 | 100 | 250 | 500 | Sum |
| Aarhus LAWR | - | - | - | 400 | 64 | 16 | 480 |
| Vejle LAWR | - | - | - | - | - | 16 | 16 |
| Aarhus City-LAWR | 1600 | 256 | 64 | - | | - | 1920 |
| Rude City-LAWR | 1600 | 256 | 64 | - | | - | 1920 |
| Mårslet City-LAWR | 1600 | 256 | 64 | - | | - | 1920 |
| Total no. of pixels | | | | | | | **6256** |

*Table 2 Number of pixels within a 2x2 km area within the test bed area per 5 minutes.*

For a small sub area of 2x2 km there are 6256 individual pixel values to compare and inter relate per time sample.

The next step in the process is calibration of the radars and establishing the optimum way of handling the attenuation. Concurrent to this the plan is to develop the communication algorithms enabling the radars to exchange information.

## 6. REFERENCES

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