19.15 The Meteorological Command and Control Structure of a Dynamic, Collaborative, Automated Radar Network

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1. INTRODUCTION

The Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) was created in October 2003 by the National Science Foundation as one of three Engineering Research Centers (ERCs) established nationwide. CASA is a joint project operated by the University of Massachusetts (lead university), the University of Oklahoma, Colorado State University, and the University of Puerto Rico at Mayaguez and in partnership with the private sector. CASA was established to develop a new generation of small, low-power, low-cost radars that could operate dynamically, adaptively, and collaboratively to detect hazardous weather, and thereby increase detection rates and warning time in order to save lives and property.

2. SYSTEM OVERVIEW

2.1 Radar specifications

A primary goal of CASA is to engineer low-power, low-cost radars that can be deployed in a high-density, distributed fashion to enhance collaborative scanning between radars. The radars are designed to be low-cost to allow for more radars to be bought and deployed for the same cost as one single, large radar, such as the WSR-88D. Such a distributed network of radars allows for 1) increasing the area of the atmosphere sampled at 1 km AGL or lower; 2) increased dynamical and adaptive sampling; and 3) better temporal resolution.

The first-generation of CASA radars will be comprised of four X-band (3-cm) radars that mechanically scan in both azimuth and elevation. Each radar will have a beamwidth of 2° with a frequency of 9.41 GHz ± 30 MHz and a peak power of 25 kW. The antenna size is 1.5 m in diameter. The radars will have some dual polarization capability. These first four radars will be mounted on the top of existing communication towers in southwest Oklahoma (Fig. 1).

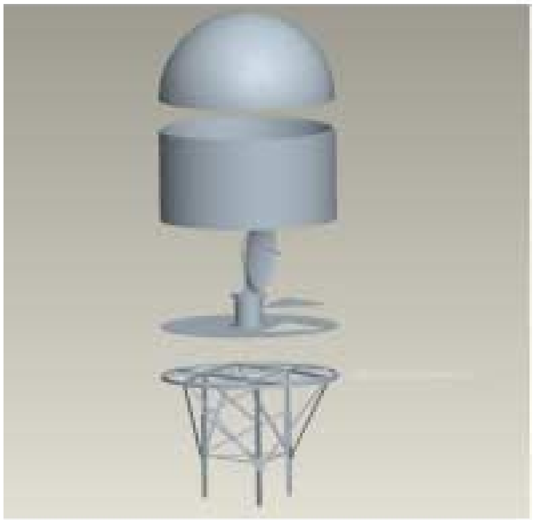

Fig. 1: Architectural design of the CASA radar, pedestal, radome, and tower structure. Figure courtesy of Michael Slattery.

2.2 System architecture

A simple architecture of the CASA system design is shown in Figures 2 and 3. The system operation begins with a set of scanning commands being transmitted to

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the radars at the beginning of a pre-determined 30-second cycle. The suite of radars collects data continuously, and the moment data are transmitted in real-time to a central location or node, called the Systems Operation Control Center (SOCC). Data are quality-controlled and merged at the SOCC, and then data flow to what is called the Meteorological Command and Control (MC&C) module. The MC&C uses existing WDSS-II (Hondl 2002) software to mine the radar data for particular hazardous weather features. The radar data and features are then summarized in what's called a 'Feature Repository', a gridded summary of the observed data. Cluster analysis are then applied to the data, and the radar network is then optimized for scanning these features until redirected after the next 30-second cycle or 'heartbeat'. A detailed description of the MC&C is provided in Section 3.

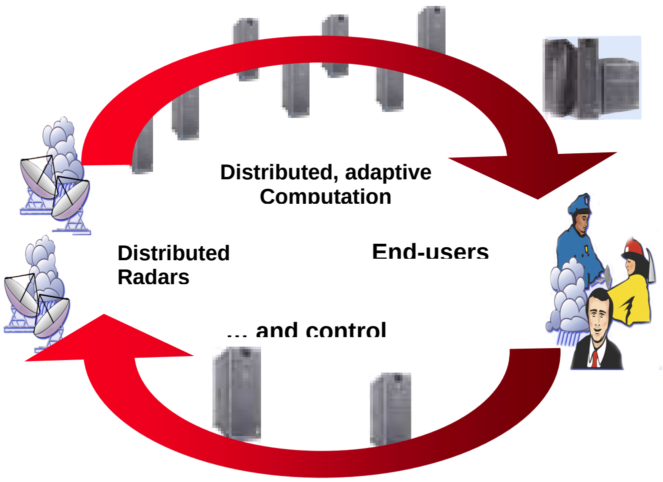

Fig. 2: System design, showing the flow of data to the end-user, followed by the feedback and response and control of the end-user to the radar network.

2.3 NetRad test bed

As a proof-of-concept study, CASA is building its first test bed in central Oklahoma (Fig. 4). Known as NetRad, the network will consist of four radars and a central processing facility (the SOCC) located at the University of Oklahoma. The radars in this test bed will be spaced an average 25 km apart, each with a maximum range of 30 km. This network configuration allows for the beams to overlap, thus maximizing collaborative sensing of the atmosphere among the networked radars (Brewster et al. 2005). One goal of this test bed is to demonstrate that the presence of a tornado can be verified within 60 seconds of touchdown and that its centroid can be located with a spatial resolution of 100 meters. To achieve this goal, collaborative, simultaneous scanning from several radars is essential. Thus, one of the challenges for CASA is to build an MC&C system that processes input from multiple radars in parallel and retasks these radars in a very short amount of time.

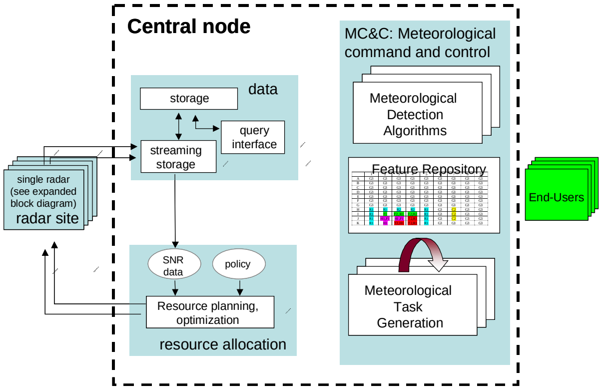

Fig. 3: Data flow within the system architecture.

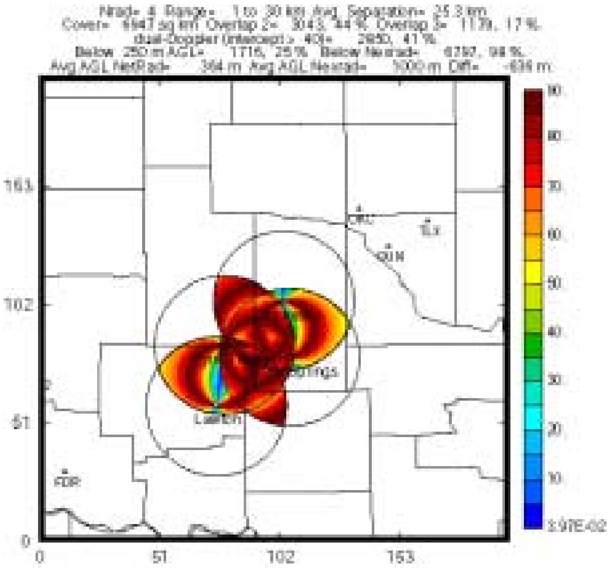

Fig. 4: The radar test bed for NetRad. Overlapping beam coverage is colored.

3. METEOROLOGICAL COMMAND AND CONTROL (MC&C)

The MC&C is the key software component that makes the NetRad system collaborative and adaptive. It ingests data as input from the sensing components, applies quality control (QC) on that data, and invokes detection and prediction algorithms on that data. All output from these detection algorithms is then organized within the Feature Repository, a 2-dimensional grid that can be used to visualize all relevant, 'real-time' features. Furthermore, the Feature Repository will store past and predictive information. This collection of feature information is then passed to a "Task Generation" module that will use cluster analysis and thresholding to identify congruent areas of interest that require scanning. The object or feature data information is then passed to the "Resource Allocation" module. This module will apply numerical techniques to optimize and generate the next radar scanning strategies, based on meteorological data, signal-to-noise ratio data (radar attenuation), and end-user priorities. It is expected that this entire feedback loop – from radar to MC&C to Resource Allocation to radar – will be completed within 30 seconds.

The role of the Meteorological Command and Control module is to ingest radar moment data (reflectivity, velocity, and spectral width), summarize this data, and then use this data to re-direct the radars for the succeeding time step. This process has been broken down into a series of steps:

3.1 *Data mining*

A series of detection algorithms are now being developed by NSSL. These algorithms will be used to identify:

Tornadoes (T)
Mesocyclones (M)
Hail (H)
Severe winds (S)
Storm cells (C)
Flooding rainfall (F)

These algorithms will also provide some tracking and predictive capabilities.

3.2 *Summarize the detected features*

All radar data and detected features will be summarized every 30s heartbeat to the 2-D latitude-longitude "Feature Repository" (FR) grid (Fig. 5). A vector of quantities will be assigned to each grid cell; each vector will be comprised of quantities observed by the radars - reflectivity, velocity, and shear - in addition to the identified features from the detection algorithms.

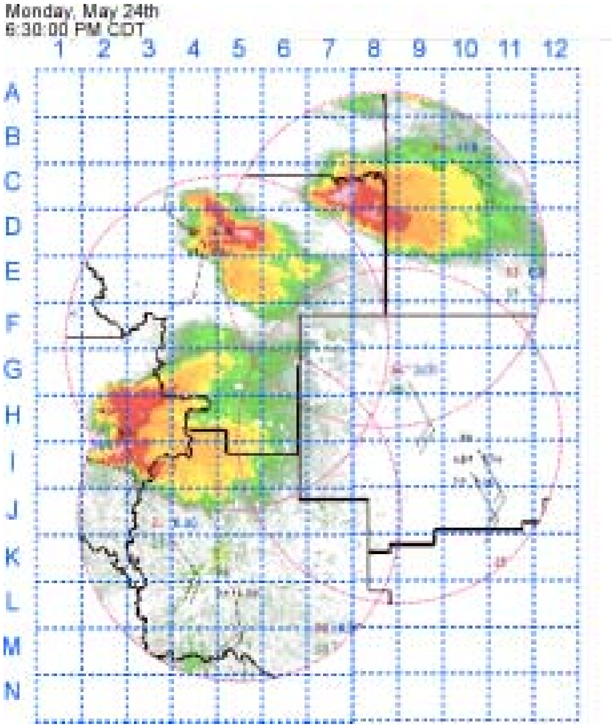

Fig. 5: Example of the grid used for the Feature Repository.

For simplicity, we will limit the number of variables per grid cell to the following parameters:

a) Radar moment data (Z and Vr)
b) Identified features and/or areas of anticipated development
c) Time since grid cell was last scanned
d) An indicator of higher interest - e.g., high-population density areas, etc.

These attributes of the FR will be combined in a weighted function to produce a utility score for each FR grid cell.

As the MC&C software matures, additional variables will be included into computing the grid cell utility. Additional variables may include variable gradient and time derivative information, historical data, feature tracks, anticipated tracks and feature development, correlated phenomenon, and estimates of uncertainty.

3.3 *Define the 'areas of interest'*

The FR will be used to define combinations of cells as specific areas of interest (Fig. 6). In addition to the utility function described above, each cell will also be assigned a feature - either a detected feature or nearby detected feature (T, M, H, S, C, or F), or "G" for general surveillance. This latter designation will be used to denote the need for general surveillance to update model analyses and to search for developing features. Thresholding and/or cluster analysis will then be used to define distinct areas of interest (AOI) that require scanning. Each AOI will share one of the common designated feature IDs - e.g., one AOI may be designated 'T' for tornado; another could be labeled 'S' for severe winds. To simplify analysis, no grid cell will contain more than one designation.

Steps #1, 2, and 3 are designed to summarize those regions of the network that require additional surveillance and are areas and weather features relevant to the end-user community.

3.4 *Prioritize each AOI*

While each individual grid cell is assigned a grid utility value, each AOI contains within it many individual grid cells. Each area of interest will also be rated by a value, which is denoted the 'AOI utility'. The AOI utility reflects the need for that particular AOI to be scanned within the next heartbeat. This AOI utility is based upon:

a) An average of the grid utilities within each AOI.
b) End-user need for that AOI.

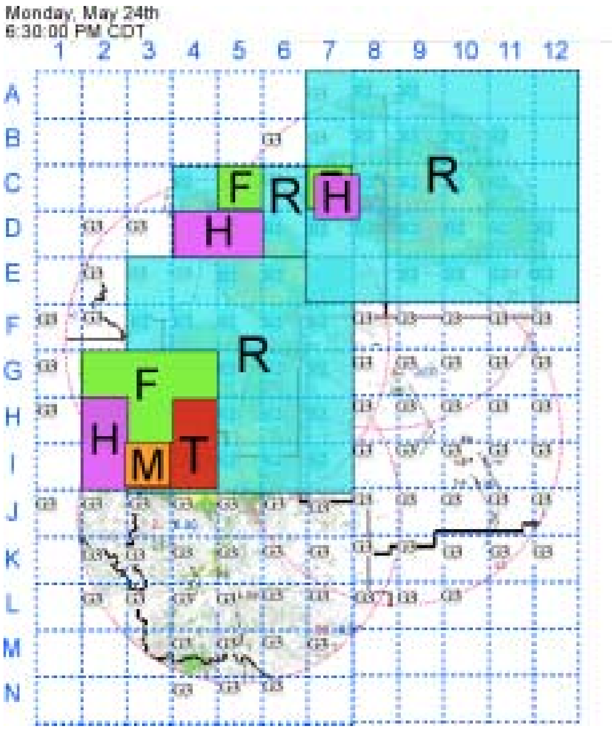

Fig. 6: Example of the 'Areas of Interest' as defined within the Feature Repository.

c) Time since at least a majority of the feature was last scanned.
d) Sampling frequency required for the features in that AOI.

3.5 *Assign sampling strategies to each AOI*

The next step in the MC&C process assigns a sampling strategy to each AOI. The azimuthal scanning required for the AOI (i.e., sweeping angles of the radar) is determined by its horizontal dimensions. The vertical sampling and radar scan characteristics are defined a priori in a static table called the Sampling Strategy Table (SST). This table defines a scanning rate, vertical sampling depth, and PRF assigned to each type of feature. In other words, if an AOI is assigned the feature "Tornado", then the look-up table has a set of radar scanning characteristics assigned a priori for tornado scanning.

Once the sampling strategy and horizontal dimensions are known, a 'time to scan' can be computed for each AOI. This 'scan time' can then be used during the optimization step.

Steps #4 and 5 are designed to cluster specific regions for scanning and to prioritize and define when and how the network should scan these regions. The final step defines specifically which radars will scan which feature as well as the time and duration of sampling per radar.

3.6 *Optimize the use of the radars for scanning the AOI*

The final step is to optimize the use of the CASA radars for scanning the AOI. Several variables and rules are used to properly optimize the use of the network radars:

1. AOI utility defines the prioritization of scanning.
2. AOI scan time defines the time required for scanning each AOI.
3. Radar scanning must be optimized to use the maximum number of radars as possible.
4. Radar scanning must be optimized to maximize sampling of dual-Doppler regions.
5. Attenuation (SNR) data determine those radars unavailable for scanning a given AOI.

4. TIMETABLE AND CONCLUSIONS

The first two CASA radars will be installed during the summer and fall of 2005, with two additional radars installed during the spring of 2006. It is expected that much of the system infrastructure and software will be operating by September 2005.

The CASA Meteorological Command and Control will be a first ever attempt at automating a radar network test bed. The module will be implemented in stages, and the architecture and structure of the system will likely increase in complexity as we gain experience with the system. Much more complex methods (such as use of a combinatorial auction solver) are planned for optimization of the radar scanning. Once operational, however, the MC&C module will enable the network to operate dynamically, adaptively, and collaboratively in real-time.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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