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Optimum site identification for automatic weather stations using Delaunay triangulation

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Abstract: Automatic Weather Stations (AWS) have attracted attention in many areas of research related to weather forecasting. In this paper, a new coverage model using Delaunay Triangulation (DT) has been proposed for determining the possible places for installation of additional/new AWS. This method provides optimum information about the uniformity of coverage, which has remarkable influence on network efficiency. In this paper twenty five different possible cases have been considered for selecting the optimum locations for installation of AWS stations with the help of DT. Existing ISRO-AWS stations over the Indian states boundary is shown for clarity of the present weather forecasting monitoring scenario. Based on the optimum selection, 447 new locations have been proposed for installation of proposed new AWS stations.

Keywords: Wireless sensor network; Automatic Weather Stations; Sensing coverage; Communication coverage; Quality of coverage; Delaunay triangulation

1. Introduction

A close watch on weather activities especially on remote areas across the country to gather information automatically is now being done through Automated Weather Stations (AWS) which minimizes human efforts. AWS are based on an integrated concept of various measuring devices along with data-acquisition, processing and transmission units. This overall system is usually called an automated weather observing system (AWOS) or automated surface observing system (ASOS). In earlier days, weather stations used to be installed only at those places which had the facility of electricity and communication lines, but recent wireless technology has made it possible to install these stations even at remote areas to gather accurate information on various parameters. AWS for surface level meteorological observations are valuable data sources for mesoscale data assimilation and forecasting (Tang et al., 2011).

Apart from India Meteorological department (IMD), Indian Space Research Organization (ISRO) has recently deployed a high-density network of AWS across the country to collect real-time observations of surface meteorological parameters including temperature, wind speed and direction, relative humidity, pressure, and rainfall at high temporal resolution (Kumar et al., 2011).

There are about 1065 ISRO-AWS in India, while many more are planned to be installed in future to enhance the observation system comprehensively. Detailed location of ISRO-AWS can be seen on website: http://www.mosdac.gov.in. The primary purpose for the deployment of the AWS is to support high resolution operational forecasting.

This paper describes optimum location identification for installation of AWS stations using Delaunay triangulation as the coverage measurement tool. DT helps in providing detailed information about installing more AWS with optimum use of the existing 1065 ISRO-AWS stations in India.

DT methods are widely used in scientific computing in many diverse applications. In this method, triangles with large internal angles are selected over ones with small internal angles. The task of DT is to maximize the minimum angle of the triangle. In this paper square grid were formed, so the vertices of a square have a non-unique DT.

2. Study Area

Study area taken in the present work is those remote areas of India where ISRO-AWS have not been installed so far. As shown in Fig.1, all the states of India are included for selection of optimum location to install additional new ISRO-AWS stations.

3. Methodology

Wireless Sensor Network have attracted much attention in the field of communication. Coverage strategy is one of the active research areas in the field of wireless sensor network, mainly to increase the coverage of wireless sensor network. Computational geometry approach is frequently used for coverage optimization. The most commonly used computational geometry approaches are Voronoi diagram, the Gabriel graph and DT (So and Ye, 2005).

i) Voronoi diagram creates a polygon around each sensor.

ii) The Gabriel graph is a sub graph of the DT edge graph, so its edges divide the plane into larger polygons.
iii) A DT is formed by three stations provided if the stations circumcircle does not contain any other station.

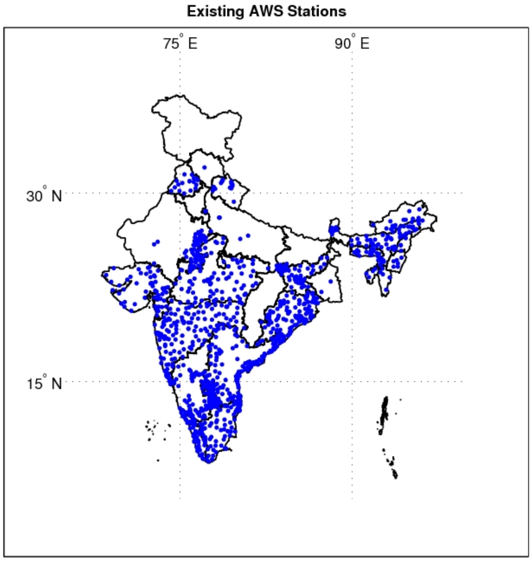

Figure 1: Existing ISRO Automatic Weather Stations in India

Voronoi decomposition partitions the points of field into convex 'area of influence' polygons around their nearest sensors. All previous work (Liu et al., 2008) has used this as a clustering system to determine sensor scheduling: coverage was still quantified using the circular model. Only the grid-based and the circular models are the only methods so far that are employed to determine how much of the desired area is sensible. A triangulation algorithm creates a graph of edges between stations, which segment the plane into triangles, where many mathematical procedures are more practical than on polygons with different numbers of vertices. Here in the present work, the DT approach has been used.

DR is widely used in scientific computing in many diverse applications (Parveen and Singh, 2012). While there are numerous algorithms for computing triangulations, it is the favourable geometric properties of the DT that make it so useful. The fundamental property is the Delaunay criterion. In the case of 2-D triangulations this is often called the empty circumcircle criterion. For a set of points in 2-D, a DT of these points ensures the circumcircle associated with each triangle contains no other point in its interior. Delaunay triangles are said to be "well shaped" because in fulfilling the empty circumcircle property, triangles with large internal angles are selected over ones with small internal angles. Also, the DT connects points in a nearest-neighbour manner. These two characteristics, well-shaped triangles and the nearest-neighbour relation, have important implications in practice and motivate the use of DT in the scattered dataset (Vu and Li, 2009).\

The coverage measurement tool proposed here uses partitioning via triangulation to identify the coverage level in different areas of thefield. There are different types of triangulation methods, but an 'optimised' one maximises the minimum angle of each triangle, making it more nearly equilateral. The simplest measure of sensing coverage divides the Indian boundary into a grid of 50 km, each pixel represents one functional area that should contain at least one sensor. The favourite definition of sensing and communication coverage is the circular model (Boukerche and Fei, 2007). In this model, the sensors have a sensing radius R, whose value could be a constant like R = 50 km.The circular model with shadowing is similar, but has an additional radius R_u for a region outside of the guaranteed sensing area, which is still sensible with some probability p>0. Accordingly, the sensing coverage integrates over all target locations the probability:

1. If the object is in R range, it will be sensed with probability 1;
2. If the object is between R and R_u, it will be sensed with probability p;
3. If the object is out of R_u range, it is not sensed.

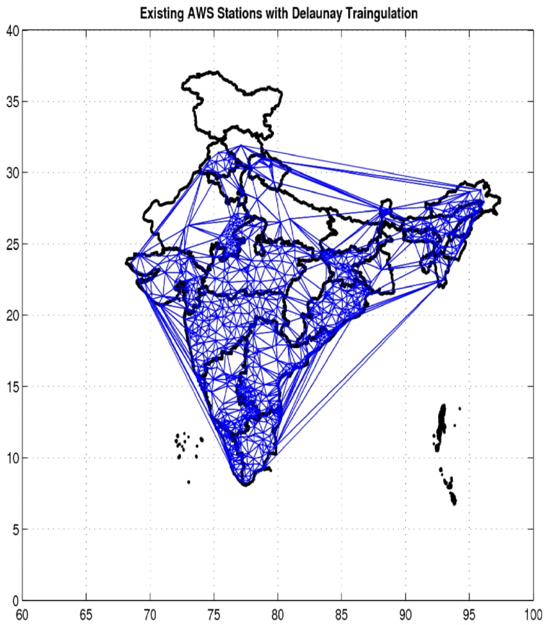

Figure 2: Existing ISRO-AWS with Delaunay Triangulation over the Indian region

Indian geographic boundary has been divided into the grid of 0.5 x 0.5 degree for proposing the site of the new AWS station, further the proposed AWS station can move between the areas of 50 km based on the optimum place based on sensing coverage optimization. Figure 2 shows the existing ISRO-AWS with DT over the Indian region.

Assuming that AWS data is effective within a circle of 50 km resolution, the newly proposed AWS is removed if it is in the proximity of the existing AWS, i.e. encircle the existing AWS stations with a radius of 50 km. Figure 3 shows the existing ISRO-AWS stations with red colour and proposed AWS stations as green colour after the first step of removal of proposed AWS station within the encircle of coverage area of existing AWS station; circle demonstrates there area of coverage.

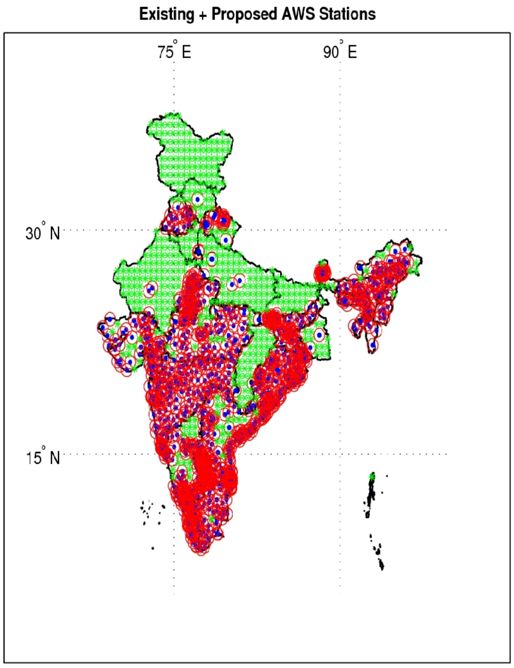

Figure 3: Proposed AWS station & Existing AWS Stations with area of coverage

4. Results

In this work, 25 different cases were considered at the various locations of 0.1 degree difference in longitude/latitude within the selected area of 50 km for the proposed new AWS station. Here, case "600_00" means first proposed AWS station is located at 60^0 longitude and 0^0 latitude, and the other proposed AWS stations moves 0.5 degree in latitude and longitude grid from this station. Similarly Case "604_04" means first proposed AWS station is located at 60^0 longitude and 0^0 latitude, and the other proposed AWS stations moves 0.5 degree in latitude and longitude grid from this station. DT tries to maximize the minimum angle of the triangle and makes it almost equilateral. The location of the AWS station was further moved, so that minimum number of AWS station should be proposed, while keeping in consideration that the sensing area should not be affected. Here four statistical comparisons are done for analysing the results of these cases. In first case the statistic for the percentage of angles occurring between the intervals of 10 degree were investigated. Similarly, in the next case between the intervals of 20 degree. Third and fourth case consider the smaller scale of 20 bins and 30 bins within angle range of 0-60 degree, i.e. corresponding to 3 degree and 2 degree interval respectively. In every case the proposed number of stations were calculated, while keeping in mind the DT principle of maximization of minimum angle. Out of these four cases, results for two cases are shown in the figure 4 and table 1. Figure 4 shows the numberof smallest angle of each Delaunay triangle forms within the study area. In most of the cases majority of different possible combination of location could increase close to 40 degree. A drastic change in the proposed number of AWS stations was obsereved in different possible location condition. In the case of "600_00" smallest number of new AWS station was proposed, i.e. "2946" in number, while case "602_04" proposed maximum "3019" number of AWS stations for the same area coverage.

Figure 5 shows the result of decisive combination of AWS stations with DT of proposed & existing AWS stations over the Indian region.

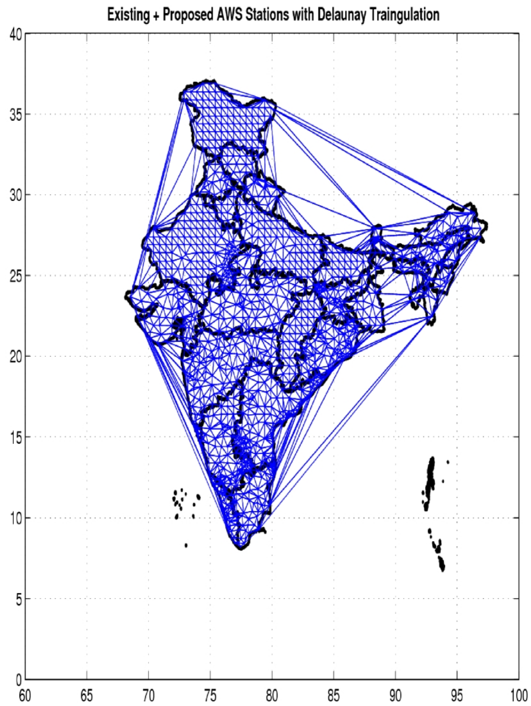

Figure 5: Delaunay Triangulation of Existing & Proposed AWS Stations

Table 1 shows the statistical comparison between the percentages of minimum angle of the all possible Delaunay triangle within the Indian region in the interval of 10 degree. In case analysis 25 different possible cases of latitude/longitude locations and the graph based on their DT optimization, were analysed. Finally the case "604_03" was selected for the installation of newly proposed AWS stations based on the outcome that AWS stations can cover complete Indian region with optimum coverage.

Table 2 shows the existing and newly proposed AWS stations in each state all over India.

5. Conclusion

In this paper DT is considered as the coverage measurement tool for the installation of AWS. Previously, there were 1065 ISRO-AWS stations in India that were not covering the whole Indian region. Some of the regions were having very dense coverage, while other remote places were very far away from the nearest AWS station. DT can provide detailed information about employing more AWS stations with optimum use of the existing AWS stations. Based on the DT technique, total 447 new AWS stations has been proposed for installation on the specific latitude/longitude location, so that the complete Indian region can be covered with necessary condition. This information could be utilized for better weather forecasting as well as by the researchers working in the field of meteorology.

Table 2: Statewise proposed and existing ISRO-AWS stations.

STATE	Proposed AWS	Existing AWS
ARUNACHAL PRADESH	9	17
DELHI	0	2
GOA	0	13
MANIPUR	0	6
MEGHALAYA	0	18
MIZORAM	1	5
NAGALAND	1	7
SIKKIM	0	16
TRIPURA	0	4
ANDHRA PRADESH	19	160
KARNATAKA	14	108
KERALA	0	55
TAMIL NADU	0	82
HARYANA	10	0
HIMACHAL PRADESH	16	1
JAMMU & KASHMIR	89	0
PUNJAB	2	18
RAJASTHAN	92	53
GUJARAT	13	54
MAHARASHTRA	2	124
MADHYA PRADESH	11	76
JHARKHAND	0	57
UTTAR PRADESH	71	8
UTTARANCHAL	8	20
ASSAM	0	50
ORISSA	1	100
WEST BENGAL	23	3
CHHATTISGARH	36	0
BIHAR	27	0
ANDAMAN & NICOBAR	2	1

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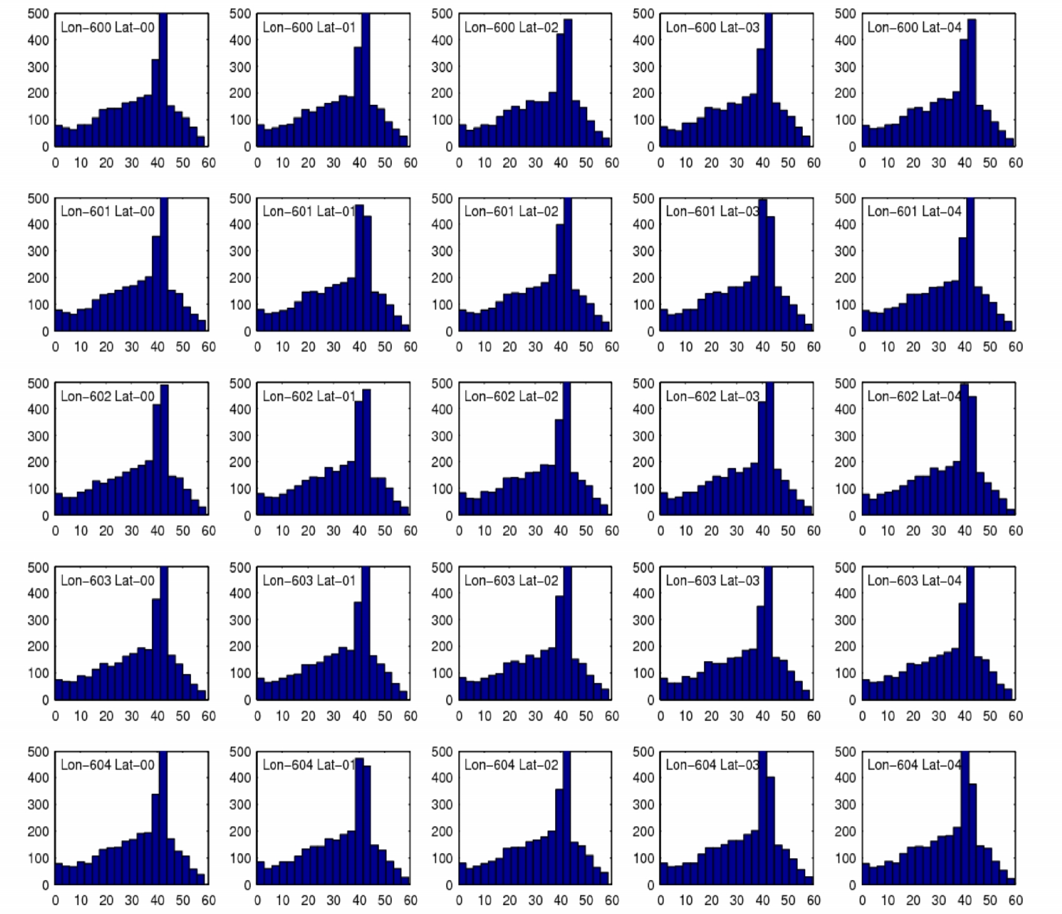

Figure 4: Shows the statistical comparison between the numbers of smallest angle of each Delaunay triangle forms within the Indian region

Table 1: Percentage of minimum angles in the interval of 10 degree.

Case	0-10	10 -20	20-30	30-40	40-50	50-60	No. of Station
case_600_00	8.14664	11.43924	17.51527	25.05092	30.99117	6.85675	425
case_600_01	8.09812	11.32392	16.76747	24.76478	32.49328	6.55242	440
case_600_02	8.01603	10.92184	17.26787	24.6159	32.59853	6.57983	450
case_600_03	7.71277	11.40293	16.78856	25.36569	31.61569	7.11436	454
case_600_04	8.22057	11.40054	16.77943	25.60893	31.49526	6.49526	426
case_601_00	7.99194	11.5178	17.39422	25.15111	31.46407	6.48086	437
case_601_01	8.03631	11.26429	16.91325	24.74781	32.21251	6.82582	437
case_601_02	7.84117	11.44478	16.51652	25.12513	32.39907	6.67334	449
case_601_03	7.71533	11.40672	16.66112	24.87529	32.62388	6.71766	455
case_601_04	8.11536	11.50235	16.93494	25.0503	31.92488	6.47217	439
case_602_00	8.15508	11.69786	16.5107	25.70187	31.5508	6.38369	446
case_602_01	8.15436	11.37584	17.18121	25.06711	31.6443	6.57718	444
case_602_02	8.03601	11.27042	16.87229	25.14171	32.07736	6.6022	449
case_602_03	7.89386	11.07794	16.91542	24.61028	32.90216	6.60033	457
case_602_04	7.98278	11.3945	16.92613	24.67705	32.59357	6.42597	462
case_603_00	8.28859	11.71141	16.37584	25.53691	31.77852	6.30872	440
case_603_01	8.11623	11.15564	16.70007	25.1503	32.53173	6.34603	449
case_603_02	8.27194	11.21902	16.91226	25.38513	31.78165	6.43001	446
case_603_03	8.01871	11.19278	16.80588	25.25894	32.14166	6.58202	447
case_603_04	7.96253	11.4085	16.66109	24.92472	32.71997	6.32319	445
case_604_00	8.20392	11.2424	17.04929	25.42201	31.80284	6.27954	435
case_604_01	8.17694	11.19303	16.99062	25	32.17158	6.46783	442
case_604_02	7.98263	11.08884	16.83367	25.5845	31.66333	6.84703	450
case_604_03	8.09365	11.17057	16.85619	25.45151	31.2709	7.15719	447
case_604_04	8.01336	11.41903	16.62771	25.47579	32.02003	6.44407	447