ISSN:2231-0711

Sanu Thomas et al | IJCSET |September 2013 | Vol 3, Issue 9, 297-302

Event Region Refinement in A Grid-Based Wireless Sensor Network using Repeated Spatial Interpolation

Sanu Thomas and Thomaskutty Mathew

University College of Applied Sciences, Mahatma Gandhi University, Kottayam, Kerala, India.

***Abstract*—A new method to refine the event region in a grid-based WSN is presented. The proposed method determines the fine-grained event region from its coarse-grained version using repeated spatial interpolation.**

***Keywords*—Coarse-grained event region, fine-grained event region, inverse distance weighting, spatial interpolation, wireless sensor network,**

I. Introduction

An important application of a Wireless Sensor Network (WSN) is physical environment (temperature, humidity, rainfall etc.) monitoring over a large geographical area [1]. The geographical area is mapped into regions of interest according to the application based on the measurement readings of the sensors. For example, a temperature monitoring system can detect and demark the high temperature regions of the geographical area under surveillance [2]. Such regions of interest are called event regions [3], because some specific events are reported from the sensors within that region. Several earlier studies are available on the event region detection in WSN [4], [5], [6], [7], [8]. The specific events may be abnormal changes in the parameters monitored or the target parameter values crossing their threshold limits, etc. In a grid based wide area WSN [9], an event region is composed of many eventful grid cells. The granularity of the marked region and its boundary depends on the grid cell size. When the cell size is relatively large, the granularity is coarse. By increasing the number of sensors deployed in a given area, the cell size is reduced and finer granularity is achieved.

In our proposed method, the effective number of sensor measurements is increased without increasing the actual number of sensors. This is achieved using spatial interpolation for the sensor measurement values.

II. Square Grid Model

Consider a grid based Wireless Sensor Network (WSN) covering a square geographical area. The sensor field is divided into uniform grid cells and the sensors are placed at the center of the grid cells as shown in Fig.1. Each cell houses one sensor at its center and the sensing range is sufficient to fully cover the grid cell. The size of the grid cell and the number of sensors to be deployed are pre-selected by the user depending on the requirements of the applications. This is a deterministic deployment and the locations of the sensors are known. All the sensors are assumed to be identical in their performance characteristics. In our model, the total geographical area is divided into square grid cells of size bxb. The cells are arranged in M rows and N columns. The total number of grid cells is n = M*N. The width and length of the sensor field is W = b*N and L = b*M.

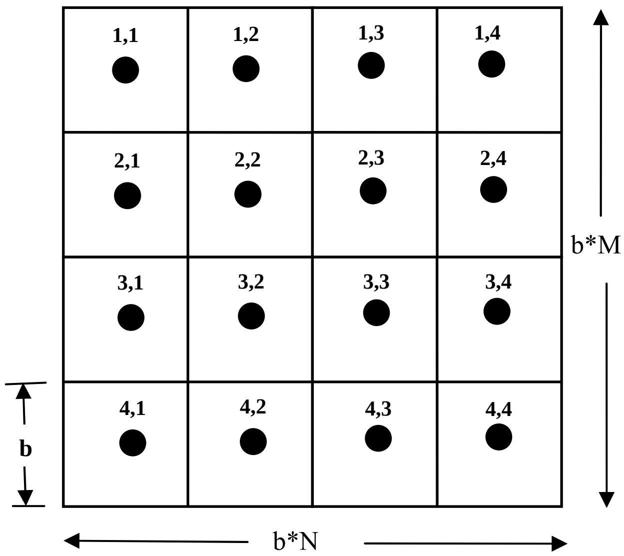


Fig.1. Square grid deployment of sensors

The grid cells are numbered according to their row-column locations as cell(1,1), cell(1,2),..., cell(i, j),..., cell(M,N). In cell(i, j), i gives the row position and j gives the column position of the grid cell. A 16 cell grid with 4 rows and 4 columns is shown Fig.1. Since there is one sensor for one cell, and the association of a sensor to its grid cell is unique, the sensor monitoring its grid cell is identified by the same subscripts. Thus sensor s(i,j) is at the center of grid cell(i,j) and monitors the environmental parameter of cell(i,j). The area covered by cell(i,j) is denoted by a(i,j) for i = 1 to M and j = 1 to N.

A. *Sensor measurements*

Let the sensors monitor an environmental phenomenon which varies widely over the geographical area of the sensor field. Without loss of generality let us take the surface temperature as the target variable measured by the sensors. The measured values from all the sensors are sent to the base station where the centralized processing takes place.

B. Event Region

Let us define the event region as those areas of the sensor field where the temperature is above certain threshold value. Therefore the event region is now the hot region. If the temperature sensed by sensor s(i, j) is above the threshold, then the grid cell(i, j) belongs to the event region. Let the temperature measured and reported by sensor s(i,j) be represented by t(i, j) and let the event region of the sensor field be represented by R. Then,

$$a(i,\ j)\ \in\ R \quad \text{if} \quad t(i,\ j)\ >\ T \qquad (1)$$

where T is the specified threshold.

The region R is composed of all the cell area a(i,j)'s for which t(i,j) > T. Thus R is a set that is the union of grid cells which satisfy Eq.(1). Thus R can be expressed as,

$$R = \bigcup_{(i,j)\in H,} a(i,j) \qquad (2)$$

where H is a set of those (i,j)'s which satisfy t(i,j) > T. That is,

$$H=\{(\ i,j)\ |\ t(i,j) > T\ \} \qquad (3)$$

For a given set of readings t(i,j)'s for i=1 to M and j = 1 to N, R can be obtained by finding H, those (i,i)'s for which t(i,j) > T, and then using this H in Eq.(2).

Example 1.

A hypothetical example of a sensor field of 36 sensors in a 6x6 grid and T = 40, has the temperature measurements shown in Table 1.

Table 1. Set of Temperature measurements

(i,j)	t(i,j)	H		(i,j)	t(i,j)	H
(1,1)	37			(4,1)	39	
(1,2)	38			(4,2)	41	(4,2)
(1,3)	36			(4,3)	44	(4,3)
(1,4)	37			(4,4)	42	(4,4)
(1,5)	36			(4,5)	43	(4,5)
(1,6)	38			(4,6)	39	
(2,1)	39			(5,1)	38	
(2,2)	41	(2,2)		(5,2)	41	(5,2)
(2,3)	37			(5,3)	42	(5,3)
(2,4)	39			(5,4)	42	(5,4)
(2,5)	37			(5,5)	39	
(2,6)	36			(5,6)	37	
(3,1)	37			(6,1)	37	
(3,2)	42	(3,2)		(6,2)	38	
(3,3)	43	(3,3)		(6,3)	38	
(3,4)	41	(3,4)		(6,4)	39	
(3,5)	39			(6,5)	37	
(3,6)	37			(6,6)	37	

In this example, H = {(2,2), (3,2), (3,3), (3,4), (4,2), (4,3), (4,4), (4,5), (5,2), (5,3), (5,4)} and R ={a(2,2), a(3,2), a(3,3),..., a(5,4)}.

The event region R is shown in orange in Fig.2. (In Fig.2, the sensors at the grid cell centers are not shown.)

C. Non-event Region

The remaining region S is called the non-event region or normal region. S is the complement set of R. In Fig.2, S is shown in white. S = U – R where U is the total area of the sensor field represented by, U ={a(1,1), a(1,2),..., a(M,N)}.

1,1	1,2	1,3	1,4	1,5	1,6
2,1	2,2	2,3	2,4	2,5	2,6
3,1	3,2	3,3	3,4	3,5	3,6
4,1	4,2	4,3	4,4	4,5	4,6
5,1	5,2	5,3	5,4	5,5	5,6
6,1	6,2	6,3	6,4	6,5	6,6

Fig.2. Event Region, marked in orange

D. Border cells and Interior cells

Those event region cells which are adjacent to any non-event region cells are event region border cells. Here adjacency includes diagonal connectivity also. Thus diagonal connectivity uses 8 surrounding cells. In Fig.2, Except cell (4,3), other orange region cells are event border cells. Cell(4,3) has no adjacent non-event region cell. Hence it is not a border cell. Cell(4,4) is diagonally adjacent to cell (3,5) and (5,5). Therefore cell (4,4) is a border cell. Similarly, those non-event region cells which are adjacent to at least one event region cell are border cells of the non-event region. An event region border cell is surrounded by at least one non-event region cell and a non-event border cell is surrounded by at least one event region cell. Border cells are the union of event region border cells and non-event region border cells. An event region non-border cell is surrounded only by event region cells. Here, the event region non-border cell is cell(4,3). So a non-event region non-border cell is surrounded by only non-event region cells. In Fig.2, cell(1,4), cell(1,5), cell(1,6), cell(2,6) and cell(6,6) are non event region non-border cells.

E. Determination of border cells

Symbol B is used to represent the border cell set. B is a collection of all border cells for a given set of sensor readings. Each cell is examined to check whether it is a border cell or not. If it is one, it is included in B.

1) 8-surround cells of a given cell (i,j): The 8 surround cells of (i,j) for i =1 to M and j =1 to N are as follows.

Northwest: at (i-1, j-1). See Fig.3. This exists if (i-1) > 0 and (j-1)>0. Note that cell (1,1) has no northwest neighbour.

North: at (i-1,j). This exists for i-1> 0. Note that the cells of the first row of sensor field grid have no northern neighbours. **Northeast:** at (i-1,j+1). This exists fir (i-1)>0 and (j+1)≤N.

West: at (i, j-1), exists for j-1>0.

East: at (i,j+1), exists for (j+1)≤N.

Southwest: at (i+1,j-1), exists for (i+1)) ≤ M and (j-1)>0.

South: at (i+1,j), exists for (i+1)) ≤ M.

Southeast: at (i+1,j+1), exists for (i+1)) ≤ M nd (j+1) ≤ N.

We examine all the existing surround cells of (i,j) and check their region type (whether event region or non event region).

Algorithm 1.

1. Get H, the event region cell set using Eq. (3).
2. Initially set B =[]= a null set.
   //examine each cell
3. for i = 1 to M
4. for j =1 to N
   // Examine the existing surround cells of (i,j) and
   //count the number of event region and non event
   //region cells among them. Use *ne* for event region
   //count and *nn* for non event region count as follows.

```
ne = 0    //Initialize the event region counter
nn = 0   // Initialize the non event region counter
  // Get the northwest cell of (i,j) if it exists
    If (i-1)>0 and (j-1)>0     //northwest cell exists
  northwest cell = (i-1, j-1).
  if (i-1, j-1) ∈H     //it belongs to event region
      ne=ne+1         // increment that counter
  else
     nn=nn+1     //increment the other counter
  endif

  // Get the north cell of (i,j) if it exists
    If (i-1)>0      //north cell exists
  north cell = (i-1, j)
  if (i-1, j) ∈H     //it belongs to event region
      ne=ne+1         // increment that counter
  else
     nn=nn+1     //increment the other counter
  endif
//This process of incrementing the counter is repeated
//for all the existing surround cells, northeast, east, etc.
```

5. Get total ne and nn.
   // check whether the present cell is a border cell or not.
   If (i,j) ∈H and nn>0 // it is an event region border cell.
   B=B U (i,j)
   Endif.
   If (i,j) ∉H and ne>0 // non event region border cell.
   B=B U (i,j)
   Endif
6. Endfor j loop.
7. End for i loop.
8. Exit.

Now B gives the set of border cells.

III. EVENT REGION REFINEMENT

Once the event region R is determined for a given grid cell of size bxb, its granularity is bxb. That is, R is made up of tailed grid cells of size bxb. Now, the event region is refined by increasing its granularity by recalculating the event region in terms of smaller sized grid cells (tails). The smaller size selected is (b/2)x(b/2) . The length and width of the original cell is exactly reduced by 2 so that the calculation becomes simpler. This is the first level refinement.

A. First Level Refinement

The initial event region R is comprised of cells of size bxb. Consider an event border cell cell(i,j) which is a member of R. It is a member because the reading of the sensor placed at the center of the cell specified by t(i,j) > T. Since, at this stage, there is only one reading per cell, we assume that the reading covers the entire cell. But in practice, the measured value t(i,j) at the center of the cell may not be same at other sub regions of the cell. In our method, the values of the target environmental parameter (say temperature) at sub regions (sub cells) are estimated by spatial interpolation [10], [11], [12]. In the first level refinement, the sub regions of cell(i,j) are marked as shown in Fig.3.

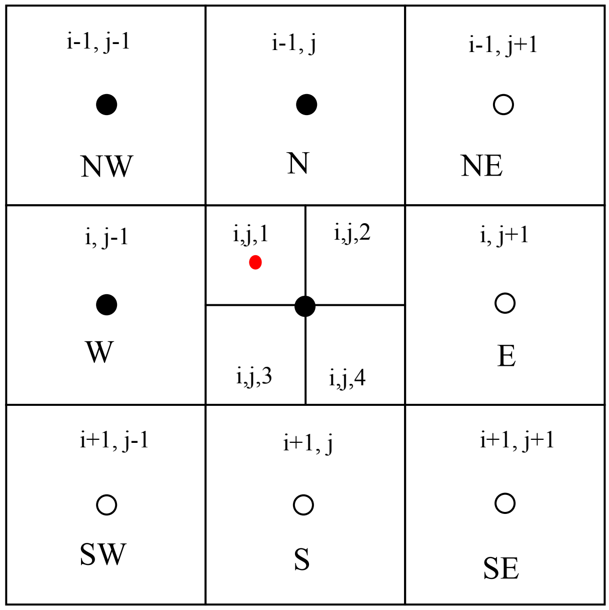


Fig.3. sub cells of cell(i,j)

The subregions of cell(i,j) are marked as (i,j,1), (i,j,2), (i,j,3) and (i,j,4) which are the symmetric quadrants of cell(i,j). They occupy the regions northwest, northeast, southwest and south east quadrants of cell(i,j) respectively.

1) Influencing sensors for subregions: The temperature of the subregion (i,j,1) is taken as the interpolated temperature value at the center of the sub region (i,j,1). The center of the sub region is marked by a red dot in Fig.3. It is immediately surrounded by 4 sensors, marked in black filled circles in Fig.3. These are at the centers of cell(i,j), cell(i,j-1), cell(i-1,j) and cell(i-1,j-1). We consider the readings of these 4 nearer sensors in calculating the interpolated value for sub region (i,j,1). We assume that other far away sensor readings have negligible influence on the sub region (i,j,1). We neglect their contribution while calculating the interpolated value at the center of the sub region (i,j,1).

Sub region (i,j,1) is the north west sub region of cell(i,j), therefore the influencing sensors are those at north which is cell(i-1,j), at west which is cell(i, j-1), at northwest which is cell(i-1, j-1) and the parent sensor at (i,j) itself.

Similar to sub region (i,j,1), the influencing sensors for other sub regions are determined based on the nearness. Table.2 gives the influencing sensors for the subregions of cell(i, j)

Table 2. Influencing Sensors

Sub region	Influencing sensor involved in interpolation			
(i,j,1)	s(i,j)	s(i-1,j) for i≠1	s(i,j-1) for j≠1	s(i-1,j-1) for i≠1 and j≠1
(i,j,2)	s(i,j)	s(i-1,j) for i≠1	s(i,j+1) for j≠N	s(i-1,j+1) for i≠1 and j≠N
(i,j,3)	s(i,j)	s(i+1,j) for i≠M	s(i,j-1) for j≠1	s(i+1,j-1) for i≠M and j≠1
(i,j,4)	s(i,j)	s(i+1,j) for i≠M	s(i,j+1) for j≠N	s(i+1,j+1) for i≠M and j≠N

2) Distance Calculation: The distances between the center of a sub region and its influencing sensors are calculated as follows.

Let the center of sub region (i,j,1) be represented by E and the influencing sensors by, A,B,C and D as shown in Fig.4.

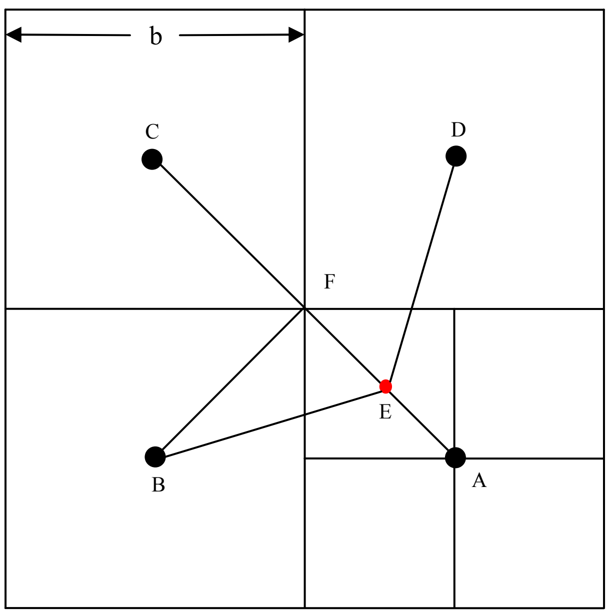


Fig.4. Calculation of distances

The basic grid cell size is bxb. Therefore its half diagonals are,

$$AF = BF = CF = DF = \frac{b}{\sqrt{2}} \quad (4)$$

Therefore,

$$AE = EF = \frac{AF}{2} = \frac{b}{2\sqrt{2}} \quad (5)$$

$$BE^2 = BF^2 + FE^2 = \frac{b^2}{2} + \frac{b^2}{8} = \frac{5b^2}{8} \quad (6)$$

Therefore,

$$BE = DE = \left(\frac{\sqrt{5}}{\sqrt{8}}\right)b \quad (7)$$

$$CE = CF + FE = \frac{b}{\sqrt{2}} + \frac{b}{2\sqrt{2}} = \frac{3b}{2\sqrt{2}} \quad (8)$$

These distance values are used for interpolation calculations. The distances are similar in other sub regions.

3) *Inverse Distance Weighted Interpolation:* In our method, we use Inverse Distance Weighted (IDW) interpolation [13], [14], [15]. In IDW method, the value u at the interpolation point q in terms of the sample values u_k's at sample points k = 1,2, … ,K is given by,

$$u(q) = \frac{\sum_{k=1}^{K} w(k) * u(k)}{\sum_{k=1}^{K} w(k)} \quad (9)$$

where the weighting function used is,

$$w(k) = \frac{1}{(d(k,q))^p} \quad (10)$$

Here d(k,q) is the distance between the sample point k and the interpolation point q. In our case, the power parameter p is set to 2. Then the interpolated value at E (see Fig.4) is given by,

$$t(E) = \frac{t(A) * w(A) + t(B) * w(B) + t(C) * w(C) + t(D) * w(D)}{w(A) + w(B) + w(C) + w(D)} \quad (11)$$

Here,

$$w(A) = 1/AE^2, \quad w(B) = 1/BE^2, \quad w(C) = 1/CE^2, \quad w(D) = 1/DE^2 \quad (12)$$

Now, t(E) is same as t(i,j,1). After calculating it, the remaining t(i,j,2), t(i,j,3) and t(i,j,4) are also calculated.

4) classification of sub regions: Once t(i,j,k)'s are calculated for k = 1,2,3 and 4, the sub region (i,j,k) is classified as event region or non event region based on the interpolated value of t(i,j,k) as,

$$\left.\begin{array}{l}\text{Sub region } (i,j,k) \in \text{event region if } t(i,j,k) > T \\ \text{Sub region } (i,j,k) \in \text{non event region if } t(i,j,k) \le T\end{array}\right\}$$

That is, if t(i,j,k) > T and sub region (i,j,k) not in R, it is added to R. If t(i,j,k) ≤ T and sub region (i,j,k) is in R, it is deleted from R. In this way R is refined. This can be expressed as,

If cell(i,j) ∉ R and if t(i, j, k) > T, refined R is obtained as,

$$R = R \cup \text{subcell}(i,j,k) \quad (\text{merge}) \quad (13)$$

If cell(i,j)∈R and if $t(i,j,k) \le T$, refined R is obtained as,

$$R = R \setminus subcell(i,j,k) \quad \text{(delete)} \quad (14)$$

This process of classification of sub regions of a border cell is repeated for all the border cells. Now the event region R is modified with merges and deletions of sub regions of size (b/2)x(b/2). Thus the granularity R is refined.

Fig.5 shows a very simple example. Here the event region is, R = cell(1,1) + cell(2,1) + cell(3,1) + cell(3,2). R is shown in orange. The interpolated value t(2,2,1) is found to be greater than T. Hence subcell(2,2,1) marked in green is added to R. But t(3,2,4) is found to be ≤ T. Therefore subcell(3,2,4) marked in red, is deleted from R. After refinement,

R (refined) = R + subcell(2,2,1) – subcell(3,2,4).

First level refinement is given in algorithm 2.

Algorithm 2. INPUT: Sensor readings t(i,j) for i=1 to M and j=1 to N. OUTPUT: refined event region represented by R1.

1. Get initial R using Eq. (3) and (2).
2. Initially set R1 = R
3. Get border set B using Algorithm 1.
4. For each cell in B, cellB(i,j) process its 4 sub cells.
5. For k=1 to 4
   Get t(i,j,k) using spatial interpolation.
   if cellB(i,j) ∉ R and if $t(i,j,k) > T$
   R1 = R1 U subcell(i,j,k)
   endif
   if cellB(i,j) ∈ R and if $t(i,j,k) \le T$
   R1 = R1\ subcell(i,j,k)
   endif
6. Endfor k loop.
7. Endfor loop started at step 4.
8. Exit.

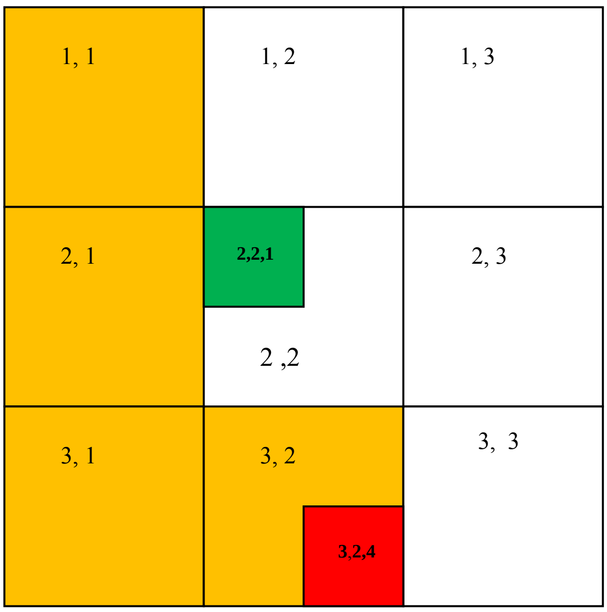


Fig.5. First level Refinement

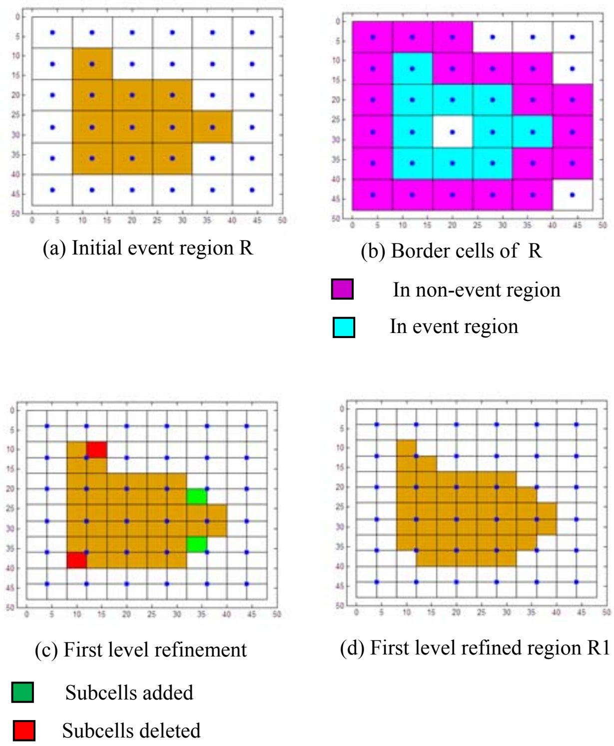


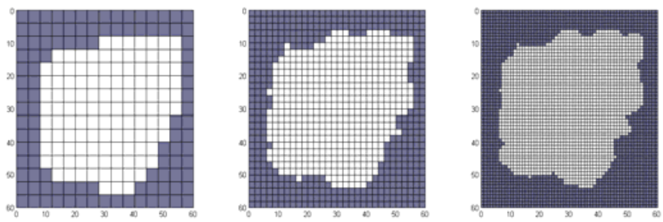
Fig. 6 First level refinement

Example 2.

Here, we continue from Example 1 where the initial event region R is marked in orange as shown in Fig. 6(a). The border cells are shown in Fig. 6(b). Non-event region border cells are shown in magenta while the event region border cells are shown in cyan. In the first level refinement, 2 subcells are added which are shown in green and 2 subcells which are deleted are shown in red Fig.6(c). Fig. 6(d) gives the result R1 after addition and deletion of respective subcells.

Example 3.

A 15x15 sensor grid with cell size 4x4 (in proper units) is used for event region sensing. The initial event region R, the first level refined region R1 and the second level refined region R2 are shown in Fig.7(a), 7(b) and 7(c) respectively.



(a) Initial region R (b) First level refined region R1 (c) Second level refined region R2

Fig. 7. Two level refinement of an event Region

IV. CONCLUSIONS

A new technique is described to determine the fine grained versions of an event region using spatial interpolation. Multilevel refinement can be carried out to achieve the required granularity. For spatial interpolation we have used inverse distance weighting method. Methods like kriging or cubic spline interpolation also can be used.

REFERENCES

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, Wireless sensor networks: A survey. Computer Networks, 38(4):393–422, December 2002.

[2] F.J. Pierce and T.V. Elliott, “Regional and on-farm wireless sensor networks for agricultural systems in Eastern Washington”, ELSEVIER, Computers and Electronics in Agriculture, Volume 61, Issue 1, April 2008, Pages 32–43.

[3] JaWon Ko and Yoon-Hwa Choi, “A Grid-Based Distributed Event Detection Scheme for Wireless Sensor Networks”, *Sensors* 2011, *11*, 10048-10062;doi:10.3390/s111110048. w.mdpi.com/journal/sensors

[4] Krishnamachari, B and Iyengar, S. “Distributed Bayesian algorithms for fault-tolerant event region detection in wireless sensor networks”, *IEEE Trans. Comput.* 2004, *53*, 241–250.

[5] K Ren, K Zeng and W. Lou, “Secure and Fault-Tolerant Event Boundary Detection in Wireless Sensor Networks*”, IEEE transactions on wireless communications,* vol. 7, no. 1, january 2008. pp. 354-363.

[6] T-Yi Wang , “ Collaborative Event-Region and Boundary-Region Detections in Wireless Sensor Networks”, *IEEE transactions on signal processing,* vol. 56, no. 6, june 2008, pp. 2547-2561.

[7] T-Yi Wang , Qi Cheng, “Distributed Sequential Event-Region Detection In Sensor Networks”, *IEEE 66th Vehicular Technology Conference, October 2007,* Baltimore, MD, USA.

[8] X. Luo, M. Dong and Y. Huang, “On distributed fault-tolerant detection in wireless sensor networks.”,*IEEE Trans. Comput.* vol, 55, 2006, pp. 58–70.

[9] K. Xu, G. Takahara and H. Hassanein, “On the robustness of grid-based deployment in wireless sensor networks”, *Proceedings of the 2006 international conference on Wireless communications and mobile computing,* New York, USA. pp. 1183-1188.

[10] M. Angjelicinoski, V. Atanasovski, L. , “Comparative analysis of spatial interpolation methods for creating radio environment maps”, *Telecommunications Forum (TELFOR), 19th International Conference,* 2011, Belgrade, Serbia.

[11] X. Luo, Y. Xu and S. Yi, “Comparison of interpolation methods for spatial precipitation under diverse orographic effects”, *19 th International Conference on Bioinformatics,* Jume 2011, Shanghai.

[12] Z. Li, X. Li, C. Li and Z. Cao, “Improvement on inverse distance weighted interpolation for ore reserve estimation”, *Seventh International Conference on Fuzzy Systems and Knowledge Discovery (FSKD),* August 2010, Yantai, Shandong.

[13] D. Shepard, “A two-dimensional interpolation function for irregularly spaced data”, Proceedings of the 23rd ACM national conference, 1968, New York, USA, pp. 517-524.

[14] S. Lukaszyk, "A new concept of probability metric and its applications in approximation of scattered data sets”, *Computational Mechanics,* March 2004, Volume 33, Issue 4, pp 299-304.

[15] D.F. Watson and G.M. Philip, “A refinement of inverse distance weighted interpolation”, *Geo-Processing 2,* 1985, pp. 315- 327.