COORDINATED ACTIVATION AND REPORTING FOR TARGET MONITORING IN WIRELESS SENSOR NETWORKS

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by

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Wireless sensor network (WSN) is a network consisting of several nodes equipped with sensors that cooperatively monitor physical conditions. WSNs are being used in many monitoring applications. There has been a lot of research on target-tracking in WSNs. Many papers focus on developing prediction algorithms for accurate tracking of the target's path. Other papers focus on developing selective node-activation algorithms that wake up sensors along the predicted path of the target from their sleep-mode, wherein all the nodes in the network are in sleep-mode except the active boundary sensor-nodes. One important criterion is to keep the reporting time to the base-station minimal, so as to enable the monitoring application to provide a timely response. To the best of our knowledge, there is no research work on performing target monitoring with a strict response-time deadline. Response time is the difference between the initial detection-time and the first reporting-time (to the base station). In this paper, we present a new approach to perform coordinated activation and reporting for energy-efficient target monitoring (detection, tracking, and reporting) in WSNs. Our approach aims to minimize the response time by activating sensors (from sleep-mode) that are along the target's path and then forwarding the information collected from these sensors on the same path guaranteeing to meet the response-time deadline. But if we are unable to meet the deadline, then we split tracking and reporting, ensuring that reporting to the base station happens within the specified response-time deadline. We perform extensive delay analysis and simulations on different sets of sample target-paths, and compute the response time and network lifetime for each case. We also investigate the optimal base-station placement problem, so as to improve the average response time in the network. Our work focuses on developing an analytical model for each of the scenarios and then verifying them to be accurate using simulations.

Keywords: Wireless sensor networks, target monitoring, and response time.

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CHAPTER 1

INTRODUCTION

1.1 Wireless Sensor Networks

A sensor network is a group of specialized microcomputers intended to monitor and record conditions at diverse locations. The network consists of multiple detection points called sensor nodes, each of which is small, inexpensive, lightweight, and portable. Every sensor node is equipped with a transducer, microcomputer, transceiver, and power source. The power for each sensor node is derived from the electric utility or from a battery. The transducer generates electrical signals based on sensed physical phenomena. The microcomputer processes and stores the sensor output. The transceiver receives commands from a central computer and transmits data to that computer[3]. Following are the characteristics of a sensor network:

- The number of sensor nodes in a sensor network can be higher than the nodes in an ad hoc network.
- Sensor nodes are densely deployed.
- Sensor nodes are prone to failures.
- The topology of a sensor network changes frequently.
- Sensor nodes are limited in power, computational capacities, and memory.[4]

Hence, target monitoring, which involves detecting an object by its particular sensor signature, tracking its path over a period of time and then submitting the recorded information in minimal time to a central computer, is one of the applications that can benefit from these characteristics of the sensor network.

1.2 Problem Description

One of the most important considerations in target tracking is not only to track the target accurately but also to keep the response time to the base station minimal. This helps in getting accurate and timely results. Target tracking algorithms mostly concentrate on optimizing accuracy of the target positions by reducing the difference between the actual path of the target and the estimated positions based on the computations. Thus the motivation behind our paper is to create an approach that not only tracks the target accurately but also keeps the response time to the base station minimal. There have been several different approaches to target tracking and this approach provides for a lesser detection time by the base station by meeting the response time deadline as explained in Section 2.2. To achieve this, the underlying arrangement of nodes in a network is also crucial and hence we include the detailed analysis of the framework to be used in Section 3.1 and thereby formulate the topology in Section 3.2.

CHAPTER 2

TARGET MONITORING

2.1 Related Work

2.1.1 Co-operative Target Tracking with Binary-Detection

This is a simplest distributed tracking algorithm that simply records the times when each sensor detects the object and then performs line fitting on the resulting set of points. Applying line approximation provides for optimal accuracy. Instead of looking at a single position measurement it considers the path of a moving object, which is a sequence of positions over a period of time. The only requirement for this protocol is that the density of sensor nodes must be high enough for the sensing ranges of several sensors to overlap. The outline of this cooperative tracking algorithm is as follows:[1]

1. Each node records the duration for which the object is in its range.
2. Neighboring nodes exchange these times and their locations.
3. For each point in time, the object's estimated position is computed as a weighted average of the detecting nodes locations.
4. A line fitting algorithm is run on the resulting set of points.

2.1.2 Tracking Moving Targets in a Smart Sensor Network

The goal of this protocol is to track and to predict the movement of a target and eventually alert the sensors which are close to the predicted path of the target. Hence each individual sensor node is equipped with appropriate sensory device(s) to be able to detect the target as well as to estimate its distance based on the sensed data. The sensors that are triggered by the target collaborate to predict its course. Then the sensor nodes that lie close to the predicted course of the target are alerted. This alert is meant to serve as a trigger to activate additional on-board sensors.[2]

2.2 Project Objective

As observed in Section 2.1, current research work focuses on target detection, accurate estimation of the target's path over a period of time and performing non-real time reporting to send the collected information to the base station. Non-real time reporting occurs when the base station is not in the path of the target and hence enormous time overhead is involved to send the data to the base station. Thus, the third factor, target reporting, crucial for real-time applications is ignored in most of the algorithms. Our goal is to implement real-time target reporting instead of non-real time target reporting. We achieve real-time target monitoring is by meeting a preset response time deadline. This implies that given a response time deadline, target monitoring should not exceed the deadline. To accomplish this, our algorithm performs coordinated activation and reporting as long as data can be sent to the base station within the response time deadline, after which tracking is done independently and reporting to the base station is also done independently in real-time. Coordinated activation and reporting aims to minimize the response time and energy overhead by activating only sensors that are along the target's path.

CHAPTER 3

REAL-TIME TARGET MONITORING FRAMEWORK

3.1 Framework Details

We develop a framework to model real-time target monitoring that optimizes on response time. Following are the framework parameters and assumptions.

3.1.1 Parameters

Node Parameters

- Nodes are static. The network used in our project consists of 36 nodes arranged in a 6×6 grid.

- Nodes are equidistant from each other, i.e. distance between any pair of nodes n_{ij} and n_{lk} where $0 \leq (i, j) \leq 5$ and $0 \leq (l, k) \leq 5$ is given by,
  $d(n_{ij}, n_{lk}) \quad = \quad \sqrt{(l-i)^2 + (k-j)^2}$
  This implies distance between any pair of nodes on the same row/column is d meters and those diagonally opposite is $d\sqrt{2}$ meters.

Transmission Parameters

- Transmission range of any node in the network is $R\sqrt{2}$, where R is the sensing range of any node.

- Node transmission delay denoted as $t^t = \frac{L}{t_R}$, where L is the packet length and t_R is the transmission rate.

- $t_1^p(n_{ij}, n_{lk})$: Propagation delay between any pair of nodes n_{ij} and n_{lk}, on the same row/column is given by, $\frac{d(n_{ij},n_{lk})}{c}$, where $0 \leq (i, j) \leq 5$ and $0 \leq (l, k) \leq 5$ and c is the transmission speed.

- $t_2^p(n_{ij}, n_{lk})$: Propagation delay between diagonally adjacent nodes n_{ij} and n_{lk} is given by, $\frac{d(n_{ij},n_{lk})\sqrt{2}}{c}$, where c is the transmission speed.
- t_3^p(b,n_{ij}) : Nodes one hop distance away from the base station send data to the base station. Time to send the data to base station b from node n_{ij}.

Network Parameters

- Sensing range for any node in the network is R. This implies any point p in $(x_i, y_i) \leq p \leq (x_i \pm R, y_i \pm R)$, where ($x_i$, y_i) is the coordinates of the node, gets detected.
- Sensing range of nodes on the same row/column in the grid overlaps.
- Target sensing interval is assumed to be greater than or equal to the propagation delay between any pair of adjacent nodes.
- t^d(n_{ij}) : Detection time by node n_{ij}.
- t_b^d : Time to detect by the base station b.
- $Path^b$: The set of nodes used to send data to the base station b.

3.1.2 Assumptions

- All nodes in the network know their locations and have their clocks synchronized.
- All nodes in the network are active. Optimizing on energy reductions by having some nodes in sleep state is considered as future work.
- For all simulations, path of the target is assumed to be straight line at some angle, θ.
- The speed of the target is r m/s and the sensing interval is i seconds.
- A particular node after sensing and detecting sends its constructed data packet to at most one, amongst all of the neighboring nodes.

- Queuing delay is negligible.
- Activation delay is negligible.

Based on the framework assumptions, network analysis is done to optimize on the response time. The $*$ symbols indicate the position of the target at successive sensing intervals. We now evaluate ten scenarios for the 6×6 network. In each scenario we evaluate best-case and worst-case target paths and they are denoted in each figure.

3.2 Base Station Placement Scenarios : Number and Location

Case I(a): Single base station at northwest corner of the grid.

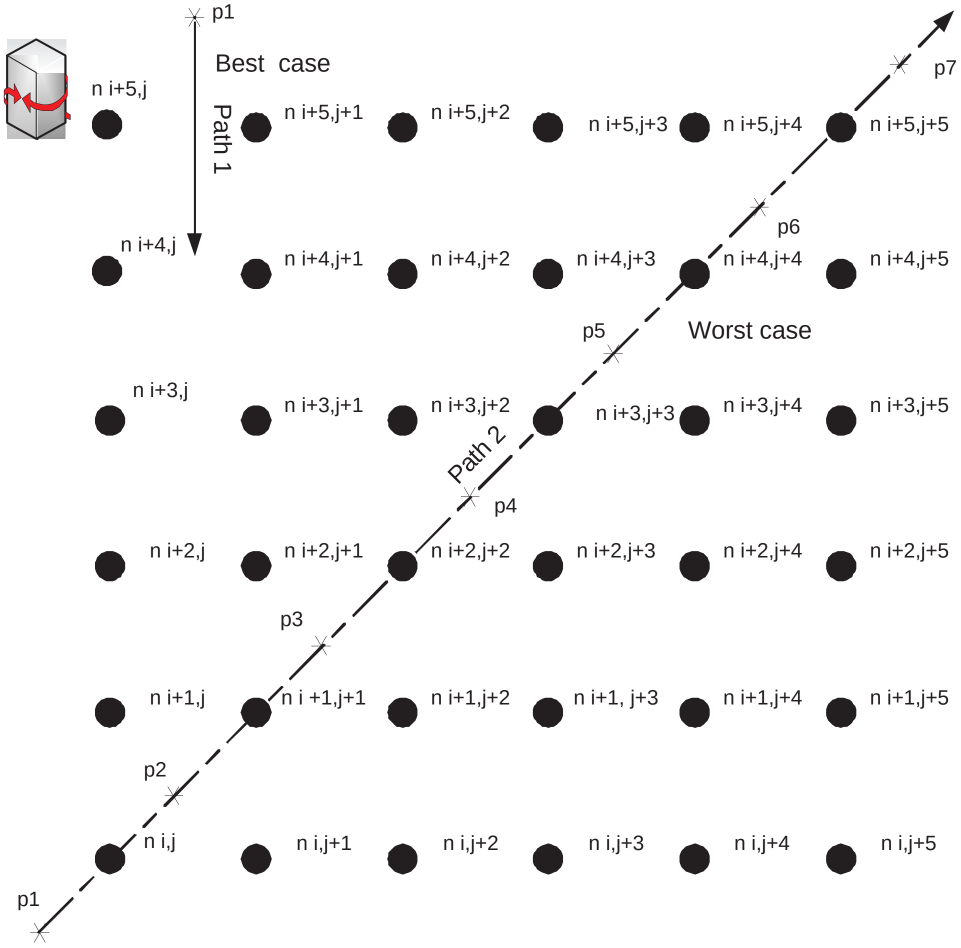

Figure 3.1. Single base station at northwest corner.

In Fig. 3.1, only one base station is present in the network. The location of the base station is given as, $\mathrm{n}_{i+5,j}$.

Hence for the Path 1 taken by the target, the time to detect by the base station, b, obtained from uniform sampling points of the sensing interval is given as,

$t_b^d = t^d(n_{i+5,j}) + t_3^p(n_{(i+5,j)}, b)$.

$Path^b = \{n_{i+5,j}\}$.

Evaluating the equation for the Path 2 of the target,

$t_b^d = t^d(n_{i,j}) + \sum_{k=1}^{5} t_2^p(n_{i+k,j+k}) + t_3^p(n_{(i+5,j+5)}, b)$.

$Path^b = \{n_{i,j}, \sum_{k=1}^{5} n_{i+k,j+k}\}$.

Generalizing the above equation we have,

$t_b^d = t^d(n_{i,j}) + \sum_{k=1}^{\sqrt{N}-1} t_2^p(n_{i+k,j+k}) + t_3^p(n_{(i+5,j+5)}, b)$.

$Path^b = \{n_{i,j}, \sum_{k=1}^{\sqrt{N}-1} n_{i+k,j+k}\}$.

Having a base station only at one corner does not always provide a lesser lower bound for different paths of the target. Moreover it also provides a high upper bound on target paths that are not in the direction of the base station. Thus a better choice would be having a base station at the left middle of the grid.

Case I(b): Single base station at midwest of the grid.

In Fig. 3.2, only one base station is considered to be present at the middle west of the network. The location of the base station is given as,

$\frac{n_{i,j}+n_{(i+5,j)}}{2}$. Hence for the Path 1 of the target, the time to detect by the base station, b, obtained from uniform sampling points of the sensing interval is given as,

$t_b^d = t^d(n_{i+2,j}) + t_3^p(n_{(i+2,j)}, b)$.

$Path^b = \{n_{i+2,j}\}$.

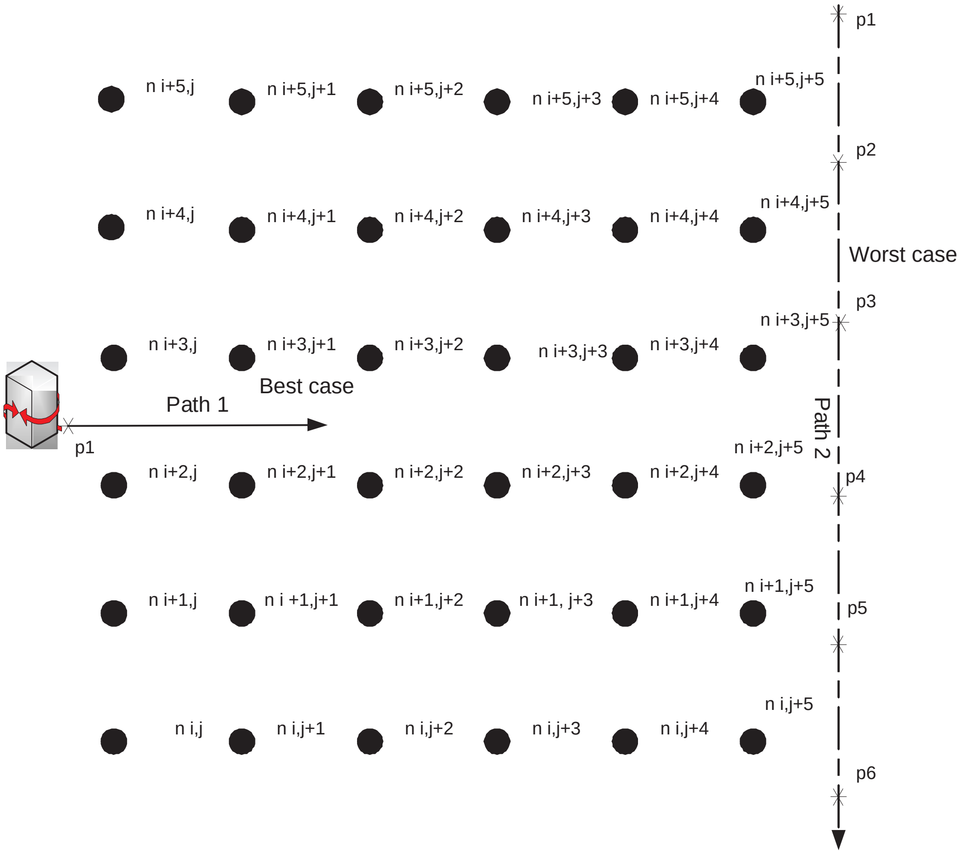

Figure 3.2. Single base station at midwest.

Evaluating for the Path 2 of the target we have,

$t_b^d = t^d(n_{i+5,j+5}) + \sum_{k=0}^{4} t_1^p(n_{i+k,j+5}) + t_3^p(n_{(i,j+5)}, b)$.

$Path^b = \{n_{i+5,j+5}, \sum_{k=0}^{4} n_{i+k,j+5}\}$.

Generalizing the above equation we have,

$t_b^d = t^d(n_{i+5,j+5}) + \sum_{k=0}^{\sqrt{N}-2} t_1^p(n_{i+k,j+5}) + t_3^p(n_{(i,j+5)}, b)$.

$Path^b = \{n_{i+5,j+5}, \sum_{k=0}^{\sqrt{N}-2} n_{i+k,j+5}\}$.

Having a single base station at the middle left corner does not always provide a lesser lower bound for different paths taken by the target. Also it provides a high upper bound on target paths that are not in the direction of the base station. Hence we not have substantial improvement in response time in comparison to when the base station is at the north west corner. Thus a more optimal choice would be having a base station at the center of the grid.

Case I(c): Single base station at center of the grid.

In Fig. 3.3, only one base station is considered to be present at the center of the network. The location of the base station is given as,

$\frac{n_{i,j}+n_{(i+5,j+5)}}{\sqrt{2}}$ Hence for the Path 1 of the target, the time to detect by the base station, b, obtained from uniform sampling points of the sensing interval is given as,

$t_b^d = t^d(n_{i+2,j}) + \sum_{k=1}^{2} t_1^p(n_{i+2,j+k}) + t_3^p(n_{(i+2,j+2)}, b)$.

$Path^b = \{n_{i+2,j}, \sum_{k=1}^{2} n_{i+2,j+k}\}$.

Generalizing the above equation we have,

$t_b^d = t^d(n_{i+2,j}) + \sum_{k=1}^{\lceil\sqrt{\frac{N}{3}}\rceil} t_1^p(n_{i+2,j+k}) + t_3^p(n_{(i+2,j+2)}, b)$.

$Path^b = \{n_{i+2,j}, \sum_{k=1}^{\lceil\sqrt{\frac{N}{3}}\rceil} n_{i+2,j+k}\}$.

Now, for the worst-case, represented by the Path 2 of the target we have the following equation,

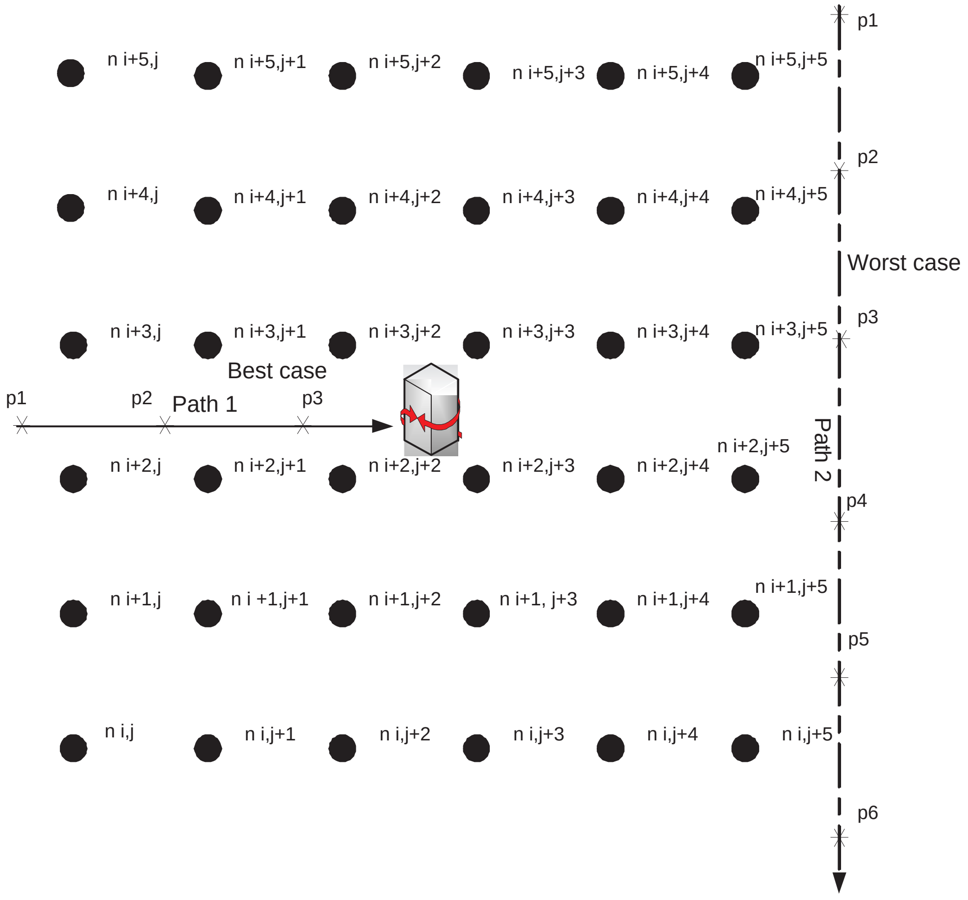

Figure 3.3. Single base station at the center.

$t_b^d = t^d(n_{i+5,j+5}) + \sum_{k=0}^{4} t_1^p(n_{i+k,j+5}) + t_3^p(n_{(i,j+5)}, b).$
$Path^b = \{n_{i+5,j+5}, \sum_{k=0}^{4} n_{i+k,j+5}\}.$

Generalizing the above equation we have,
$t_b^d = t^d(n_{i+5,j+5}) + \sum_{k=0}^{\sqrt{N}-2} t_1^p(n_{i+k,j+5}) + t_3^p(n_{(i,j+5)}, b).$
$Path^b = \{n_{i+5,j+5}, \sum_{k=0}^{\sqrt{N}-2} n_{i+k,j+5}\}.$

Having a single base station at the center always provides for lesser upper bound on the response time for any direction of the target. But it also provides a high lower bound on the response time as target can be tracked but cannot be reported,when it just enters the network. Thus a more better choice would be increasing the number of base stations in the network.

Case II(a): Base stations at northwest corner and midwest of the grid.

In Fig. 3.4, two base stations are considered to be present in the network. The location of the base stations $b1$ and $b2$ is respectively given as,
$\frac{n_{i,j}+n_{(i+5,j)}}{2}$ and n$_{i+5,j}$.
Hence for the above Path 1 of the target, the time to detect by the base station, $b1$, obtained from uniform sampling points of the sensing interval is given as,
$t_{b1}^d = t^d(n_{i+2,j}) + t_3^p(n_{(i+2,j)}, b1).$
$Path^{b1} = \{n_{i+2,j}\}.$

For the other best-case paths (Path 2 and Path 3) we can compute a similar equation that yields the same response time.
Evaluating the equation for the Path 4 taken by the target,
$t_{b2}^d = t^d(n_{i,j}) + \sum_{k=1}^{5} t_2^p(n_{i+k,j+k}) + t_3^p(n_{(i+5,j+5)}, b2).$
$Path^{b2} = \{n_{i,j}, \sum_{k=1}^{5} n_{i+k,j+k}\}.$

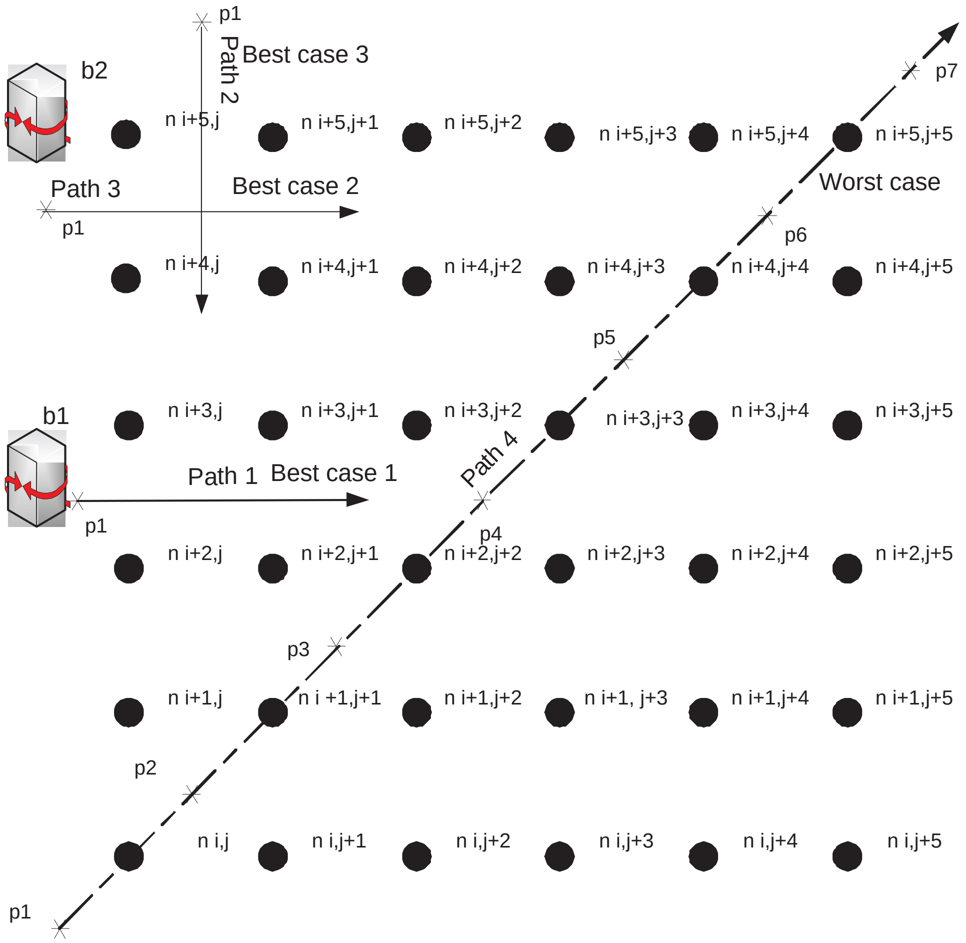

Figure 3.4. Base stations at northwest corner and midwest.

Generalizing the above equation we have,

$$t^d_{b2} = t^d(n_{i,j}) + \sum_{k=1}^{\sqrt{N}-1} t^p_2(n_{i+k,j+k}) + t^p_3(n_{(i+5,j+5)}, b2).$$

$$Path^{b2} = \{n_{i,j}, \sum_{k=1}^{\sqrt{N}-1} n_{i+k,j+k}\}.$$

Having a base station only at one corner does not always provide a Having two base stations, one at the north west corner and other at the middle west of the network does not provide a lesser lower bound on the response time for different paths of the target. It also provides a high upper bound for certain paths of the target. Thus a better choice would be having the other base station at the south east corner in place of mid west of the grid.

Case II(b): Base stations at northwest and southeast corner of the grid.

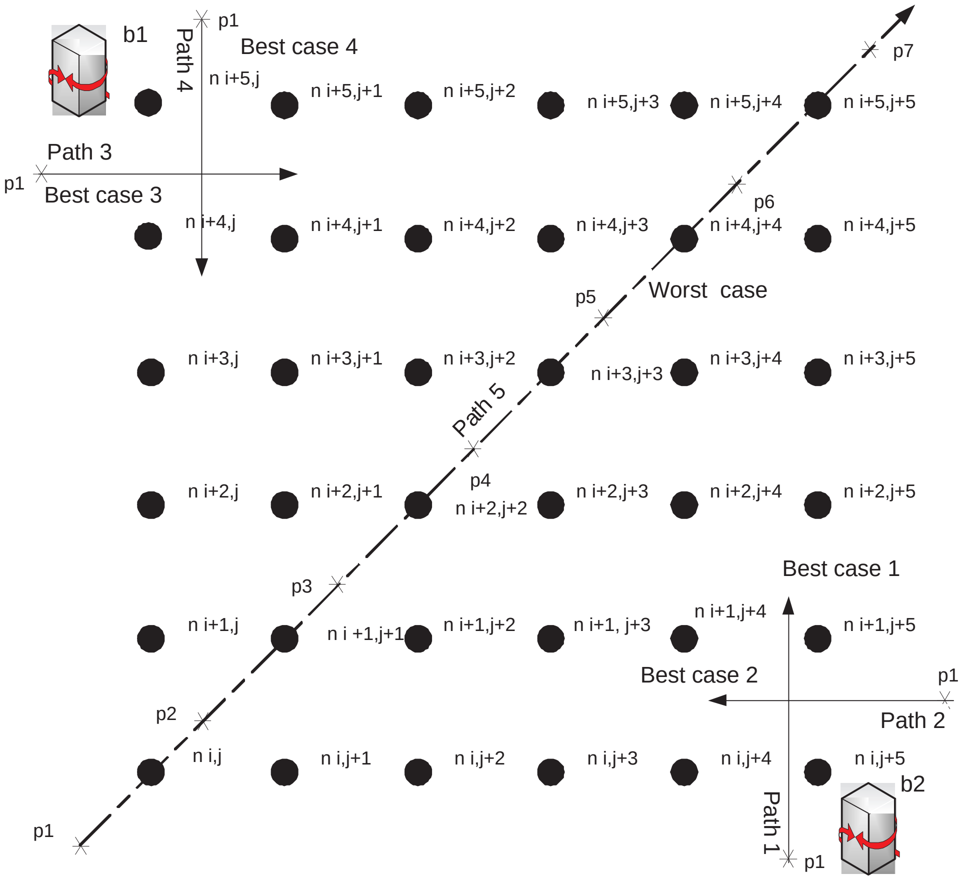

Figure 3.5. Base stations at northwest and southeast corner.

In Fig. 3.5, two base stations are considered to be present at the extreme ends of the network. The location of the base stations $b1$ and $b2$ is respectively given as,
n$_{(i+5,j)}$ and n$_{(i,j+5)}$.
Hence for the Path 1 of the target, the time to detect by the base station, b2, obtained from uniform sampling points of the sensing interval is given as,
$t^d_{b2} = t^d(n_{i,j+5}) + t^p_3(n_{(i,j+5)}, b2)$.
$Path^{b2} = \{n_{i,j+5}\}$.

Also for the other best-case paths (Path 2, Path 3 and Path 4) we can compute a similar equation that yields the same response time.
Now, evaluating for the worst-case path (Path 5) of the target we have the following equation,
$t^d_{b1} = t^d(n_{i,j}) + \sum_{k=1}^{5} t^p_2(n_{i+k,j+k}) + t^p_3(n_{(i+5,j+5)}, b1)$.
$Path^{b1} = \{n_{i,j}, \sum_{k=1}^{5} n_{i+k,j+k}\}$.

Generalizing the above equation we have,
$t^d_{b1} = t^d(n_{i,j}) + \sum_{k=1}^{\sqrt{N}-1} t^p_2(n_{i+k,j+k}) + t^p_3(n_{(i+5,j+5)}, b1)$.
$Path^{b1} = \{n_{i,j}, \sum_{k=1}^{\sqrt{N}-1} n_{i+k,j+k}\}$.

Having base stations at the extreme ends does not provide a significant improvement on the response time as compared to two base stations, one at the north west corner and other at the middle west of the grid. Thus a better choice would be having the other base station at the center of the network, in place of south east corner.

Case II(c): Base stations at northwest corner and center of the grid.

In Fig. 3.6, one base station on the extreme end helps in reducing the lower bound on the response time for specific paths of the target. Having another base station at the center pro-

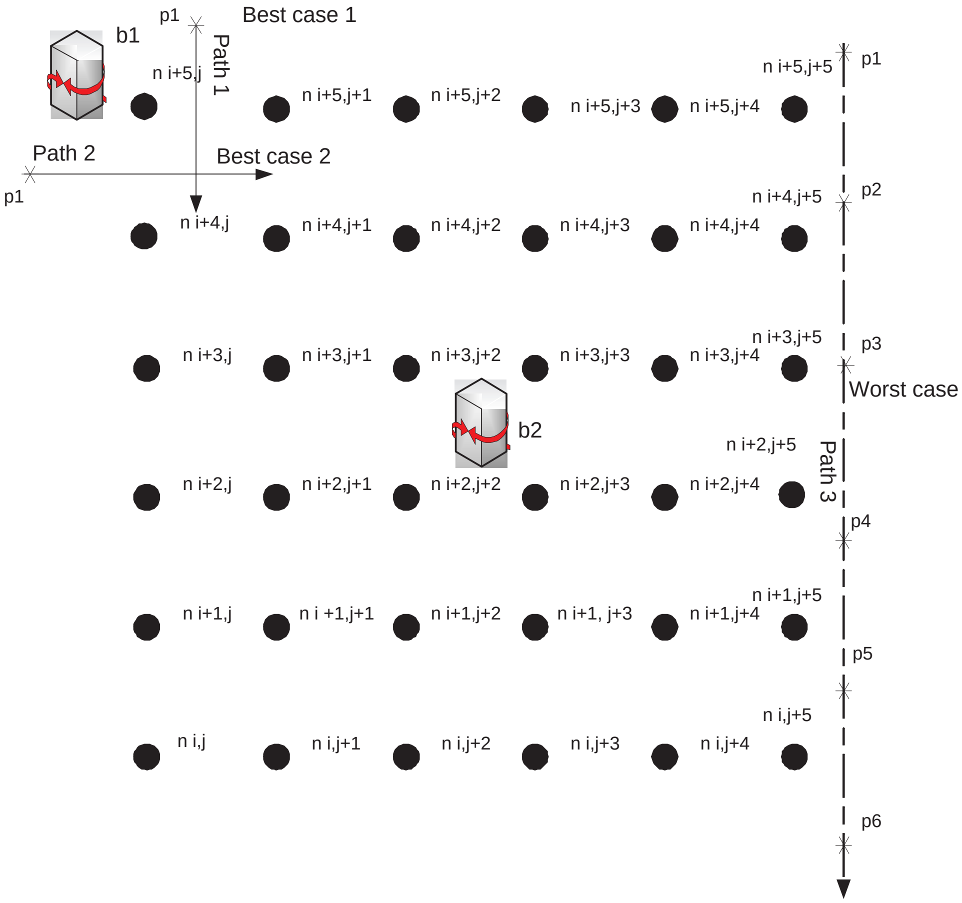

Figure 3.6. Base stations at northwest corner and center.

vides for limits on the upper bound on the response time. The locations of the base stations $b1$ and $b2$ is respectively given as,

n$_{i+5,j}$ and $\frac{n_{i,j}+n_{(i+5,j+5)}}{\sqrt{2}}$

For the Path 1 of the target, the time to detect by the base station $b1$ is given as follows,

$t^d_{b1} = t^d(n_{i+5,j}) + t^p_3(n_{(i+5,j)}, b1)$.

$Path^{b1} = \{n_{i+5,j}\}$.

Also, for the other best-case path (Path 2) we can compute a similar equation that yields the same response time.

Evaluating for the worst-case path (Path 3) of the target we have the following equation,

$t^d_{b2} = t^d(n_{i+5,j+5}) + \sum_{k=0}^{4} t^p_1(n_{i+k,j+5}) + t^p_3(n_{(i,j+5)}, b2)$.

$Path^{b2} = \{n_{i+5,j+5}, \sum_{k=0}^{4} n_{i+k,j+5}\}$.

Generalizing the above equation we have,

$t^d_{b2} = t^d(n_{i+5,j+5}) + \sum_{k=0}^{\sqrt{N}-2} t^p_1(n_{i+k,j+5}) + t^p_3(n_{(i,j+5)}, b2)$.

$Path^{b2} = \{n_{i+5,j+5}, \sum_{k=0}^{\sqrt{N}-2} n_{i+k,j+5}\}$.

But this case can be improvised by having three base stations so as to further reduce the lower bound on response time.

Case III(a): Base stations at northwest corner, midwest, and southeast corner of the grid.

In Fig. 3.7, there are three base stations in the network. Locations of the base stations $b1$, $b2$, and $b3$ is respectively given as,

n$_{(i+5,j)}$, $\frac{n_{i,j}+n_{(i+5,j)}}{2}$ and n$_{(i,j+5)}$.

The total time to detect by the base station b2 for the given path (Path 1) of the target is,

$t^d_{b2} = t^d(n_{i+2,j}) + t^p_3(n_{(i+2,j)}, b2)$.

$Path^{b2} = \{n_{i+2,j}\}$.

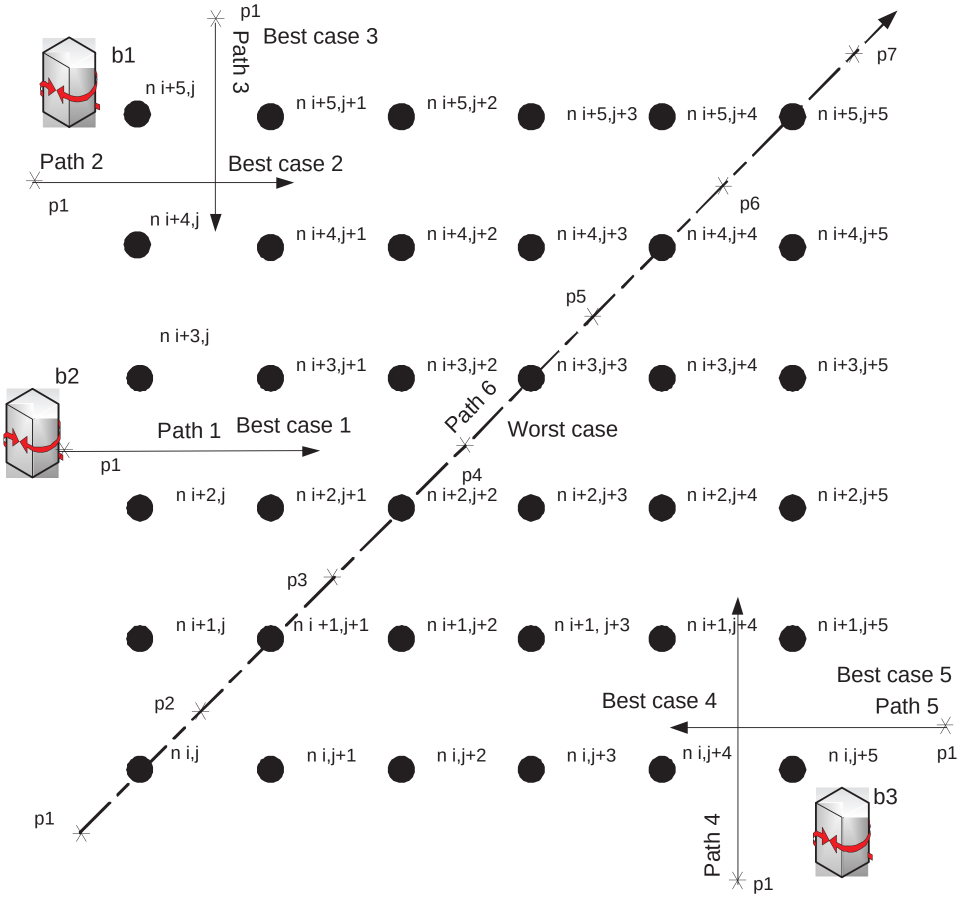

Figure 3.7. Base stations at northwest corner, midwest, and southeast corner.

For the other best-case paths (Path 2, Path 3, Path 4, and Path 5) we can compute a similar equation that yields the same response time.

Now evaluating for the worst-case path (Path 6) taken by the target we get the following equation,

$t^d_{b1} = t^d(n_{i,j}) + \sum_{k=1}^{5} t^p_2(n_{i+k,j+k}) + t^p_3(n_{(i+5,j+5)}, b1).$

$Path^{b1} = \{n_{i,j}, \sum_{k=1}^{5} n_{i+k,j+k}\}.$

Generalizing the above equation we have,

$t^d_{b1} = t^d(n_{i,j}) + \sum_{k=1}^{\sqrt{N}-1} t^p_2(n_{i+k,j+k}) + t^p_3(n_{(i+5,j+5)}, b1).$

$Path^{b1} = \{n_{i,j}, \sum_{k=1}^{\sqrt{N}-1} n_{i+k,j+k}\}.$

This organization of three base stations can be further improvised to reduce the lower bound on response time by having two base stations at the extreme ends of the network and one at the center of the network.

Case III(b): Base Stations at northwest corner, center, and southeast corner of the grid.

In Fig. 3.8, the locations of the three base stations $b1$, $b2$, and $b3$ is respectively given as, n$_{(i+5,j)}$, $\frac{n_{i,j}+n_{(i+5,j+5)}}{\sqrt{2}}$ and n$_{(i,j+5)}$.

Hence, the total time to detect by the base station $b1$ for the Path 1 of the target is,

$t^d_{b1} = t^d(n_{i+5,j}) + t^p_3(n_{(i+5,j)}, b1).$

$Path^{b1} = \{n_{i+5,j}\}.$

Also, for the other best-case paths (Path 2, Path 3, and Path 4) we can compute a similar equation that yields the same response time.

Evaluating for the worst-case path (Path 5) of the target yields the following equation,

$t^d_{b3} = t^d(n_{i+5,j+5}) + \sum_{k=0}^{4} t^p_1(n_{i+k,j+5}) + t^p_3(n_{(i,j+5)}, b3).$

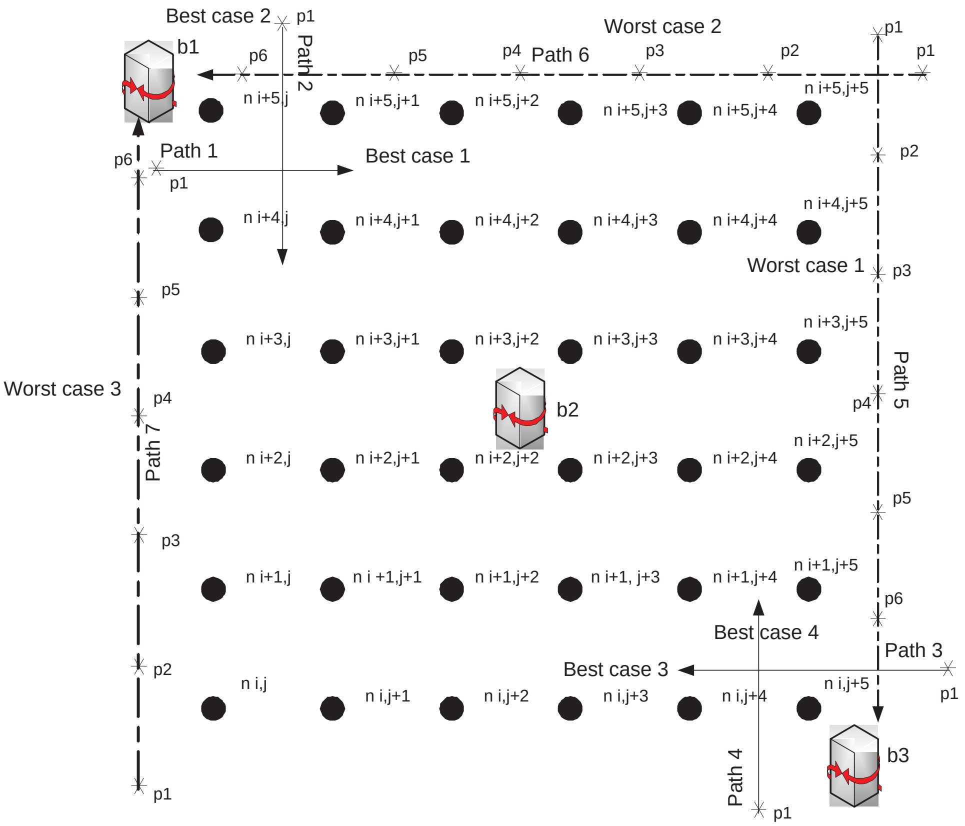

Figure 3.8. Base stations at northwest corner, center, and southeast corner.

$$Path^{b3} = \{n_{i+5,j+5}, \textstyle\sum_{k=0}^{4} n_{i+k,j+5}\}.$$

Generalizing the above equation we have,

$$t^d_{b3} = t^d(n_{i+5,j+5}) + \textstyle\sum_{k=0}^{\sqrt{N}-2} t^p_1(n_{i+k,j+5}) + t^p_3(n_{(i,j+5)}, b3).$$

$$Path^{b3} = \{n_{i+5,j+5}, \textstyle\sum_{k=0}^{\sqrt{N}-2} n_{i+k,j+5}\}.$$

Similarly we can obtain equations for the other worst-case paths (Path 6 and Path 7) taken by the target.

This organization of three base stations is a better solution to having all the three at the extreme ends, as in the latter case, the upper bound on response time increases. However this solution can further be improved by having four base stations, each at the corner of the grid.

Case IV: Base stations at northeast, southeast, northwest, and southwest corners of the grid.

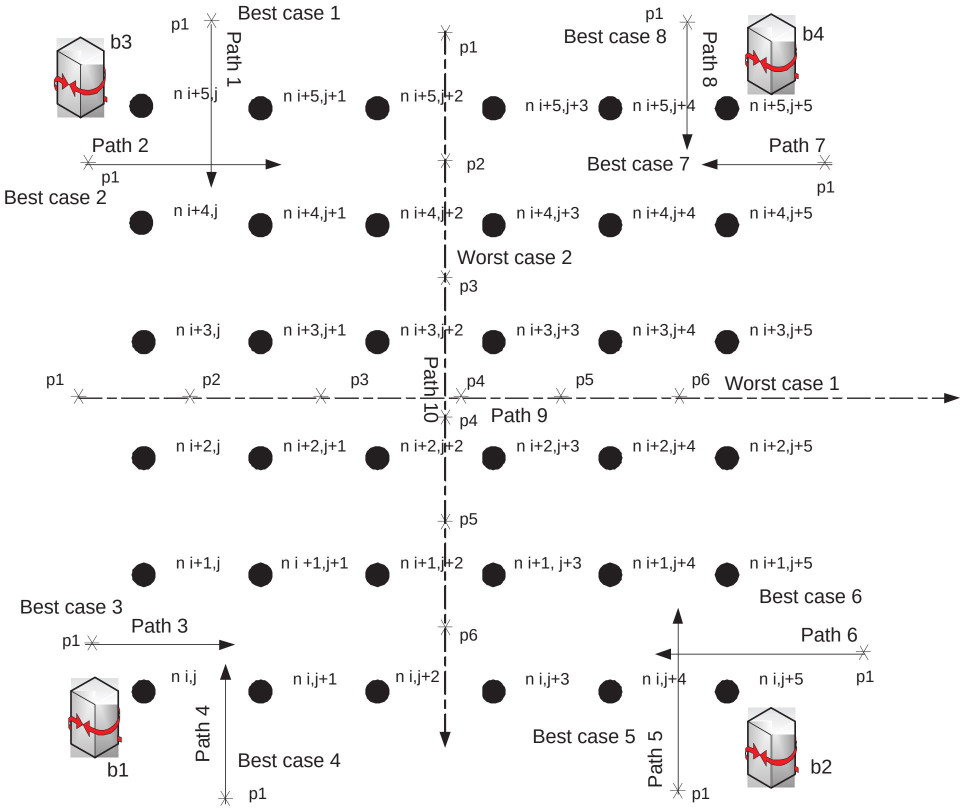

Figure 3.9. Base stations at northeast, southeast, northwest, and southwest corners.

Referring to Fig. 3.9, having four base stations at the extreme corners of the network decreases the overall lower bound on the response time. The location of the four base stations $b1$, $b2$, $b3$, and $b4$ is respectively given as,

n$_{(i,j)}$,n$_{(i,j+5)}$,n$_{(i+5,j)}$, and n$_{(i+5,j+5)}$.

The total time required to detect by the base station $b1$ for the Path 3 of the target is,

$t^d_{b1} = t^d(n_{i,j}) + t^p_3(n_{(i,j)}, b1)$.

$Path^{b1} = \{n_{i,j}\}$.

Also, for the other best-case paths (Path 1, Path 2, Path 4, Path 5, Path 6, Path 7, and Path 8) we can compute a similar equation that yields the same response time.

Now, evaluating for the worst-case path (Path 9) of the target we get the following equation,

$t^d_{b4} = t^d(n_{i+2,j}) + \sum_{k=1}^{5} t^p_1(n_{i+2,j+k}) + t^p_3(n_{(i+2,j+5)}, b4)$.

$Path^{b1} = \{n_{i+2,j}, \sum_{k=1}^{5} n_{i+2,j+k}\}$.

Generalizing the above equation we have,

$t^d_{b4} = t^d(n_{i+2,j}) + \sum_{k=1}^{\sqrt{N}-1} t^p_1(n_{i+2,j+k}) + t^p_3(n_{(i+2,j+5)}, b4)$.

$Path^{b1} = \{n_{i+2,j}, \sum_{k=1}^{\sqrt{N}-1} n_{i+2,j+k}\}$.

Generalizing the above equation we have,

Similarly we can obtain equations for the other worst-case path (Path 10) taken by the target. But having all the four base stations only at the extreme ends increases the upper bound on the response time. Therefore a better solution to this is adding an additional base station at the center of the network.

Case V: Base stations at northeast, southeast, northwest, southwest, and center of the grid (optimal).

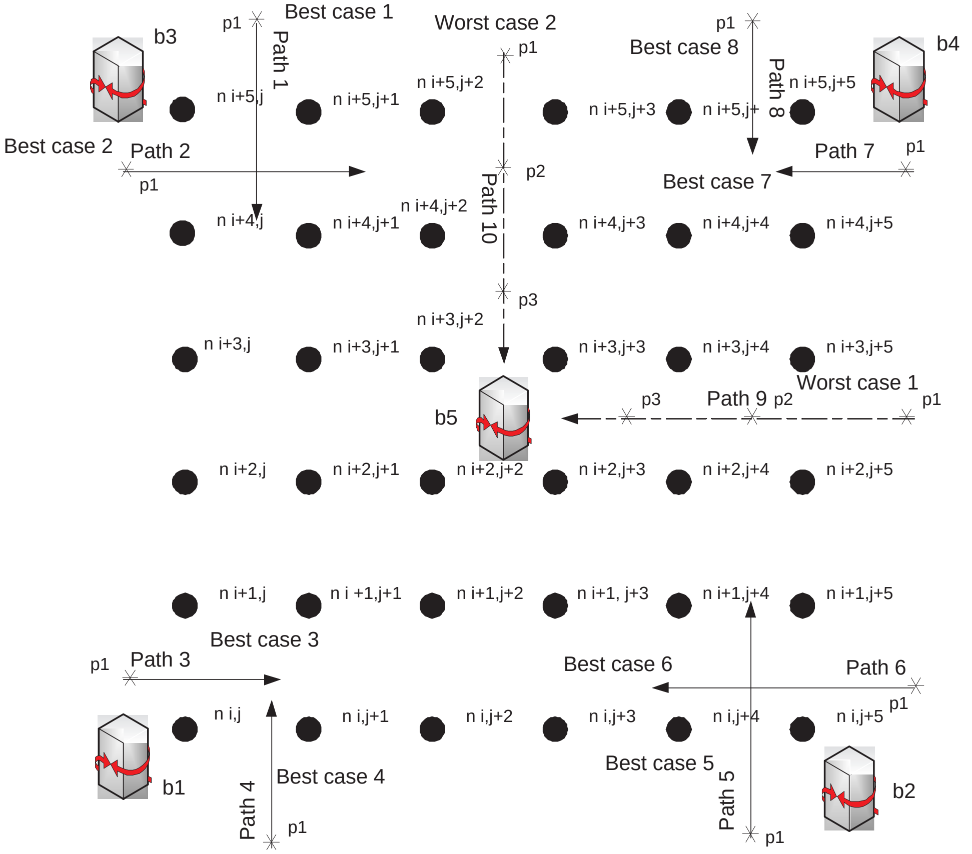

Figure 3.10. Base stations at northeast, southeast, northwest, southwest and center (optimal).

Referring to Fig. 3.10, having five base stations reduces both the upper and lower bound on the response time. The location of the five base stations $b1$, $b2$, $b3$, $b4$, and $b5$ is respectively given as,

n$_{(i,j)}$,n$_{(i,j+5)}$,n$_{(i+5,j)}$,n$_{(i+5,j+5)}$, and $\frac{n_{i,j}+n_{(i+5,j+5)}}{\sqrt{2}}$.

The total time required to detect by the base station $b1$ for the Path 3 of the target is,

$t^d_{b1} = t^d(n_{i,j}) + t^p_3(n_{(i,j)}, b1)$.

$Path^{b1} = \{n_{i,j}\}$.

Also, for the other best-case paths (Path 1, Path 2, Path 4, Path 5, Path 6, Path 7 and Path 8) we can compute a similar equation that yields the same response time.

Now, evaluating for the worst-case path (Path 9) of the target we get the following equation,

$t^d_{b5} = t^d(n_{i+2,j+5}) + \sum_{k=3}^{4} t^p_1(n_{i+2,j+k}) + t^p_3(n_{(i+2,j+3)}, b5)$.

$Path^{b5} = \{n_{i+2,j+5}, \sum_{k=3}^{4} n_{i+2,j+k}\}$.

Generalizing the above equation we have,

$t^d_{b5} = t^d(n_{i+2,j+5}) + \sum_{k=3}^{\sqrt{N}-2} t^p_1(n_{i+2,j+k}) + t^p_3(n_{(i+2,j+3)}, b5)$.

$Path^{b5} = \{n_{i+2,j+5}, \sum_{k=3}^{\sqrt{N}-2} n_{i+2,j+k}\}$.

Similarly we can obtain equations for the other worst-case path (Path 10) taken by the target. Thus, having five base stations is an optimal network organization, catering to all possible paths taken by the target. But there is always a trade-off between cost and achieving minimal response time. Having at least one base station in excess to the five base stations, in the above organization, is a waste and hence should be discarded.

CHAPTER 4

SIMULATION RESULTS

In order to evaluate the real-time target monitoring we create a grid topology framework described in Section 3.2. We then run simulations for different paths of the target and calculate the average response time. For the simulations, we have taken a grid network of 36 sensors placed at a distance of 100 m from each other. The transmission range is $100\sqrt{2}$ m and sensing range is 100 m. The sensing interval is 0.1 second and target speed is 1250 m/s. Transmission time is is 0.1 second. Activation and Propagation delays are very small and hence assumed to be negligible. We have also catered to all possible directions of the target as indicated by the Fig. 4.1.

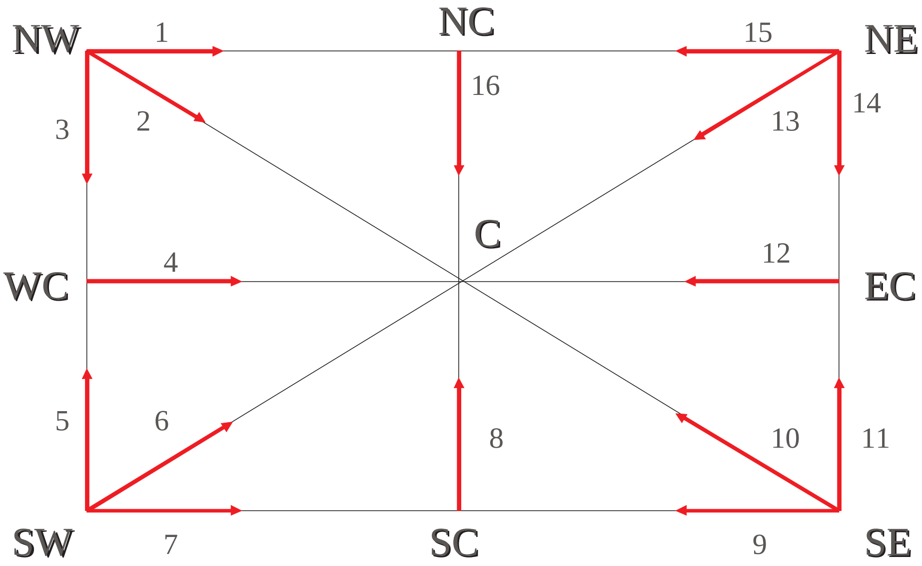

Figure 4.1. Target Directions.

Fig. 4.2 represents the best-case and worst-case paths of the target when non-real time reporting is performed. The graph indicates the best-case and worst-case paths of the target for each base station organization scenario. X-axis label in the graph indicates the placement of base stations in the network.

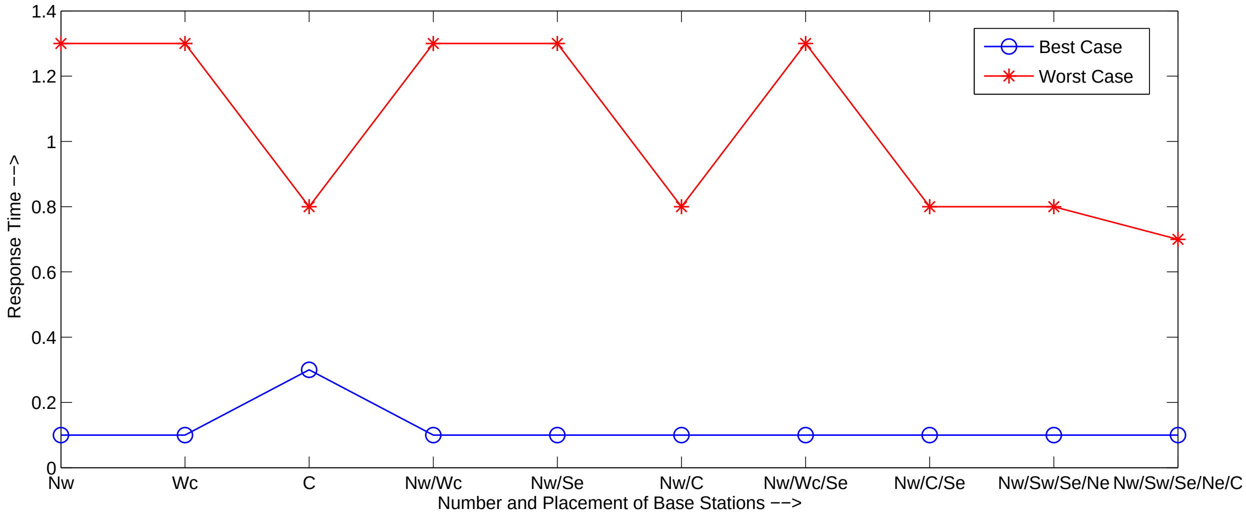

Figure 4.2. non-real time reporting best-case and worst-case.

As seen in Fig. 4.2, the value of best-case for response time is highest when a base station is at the center as compared to all the other cases. This is because for any path taken by the target some minimum hops (two or three) are required to send the data to the base station as the base station is not at the border of the network. However, the value of worst-case for the response time is lower whenever a base station is at the center of the network and is lowest for five base stations, one base station at the each corner and one at the center of the network. The reason is that for any path taken by the target, the center base station lies along the path of the target, and hence reporting of data can be done before the target reaches the border of the network.

Fig. 4.3 represents the average response time for 36 different paths of the target simulated for each base station organization scenario. We have simulated 36 different target paths by

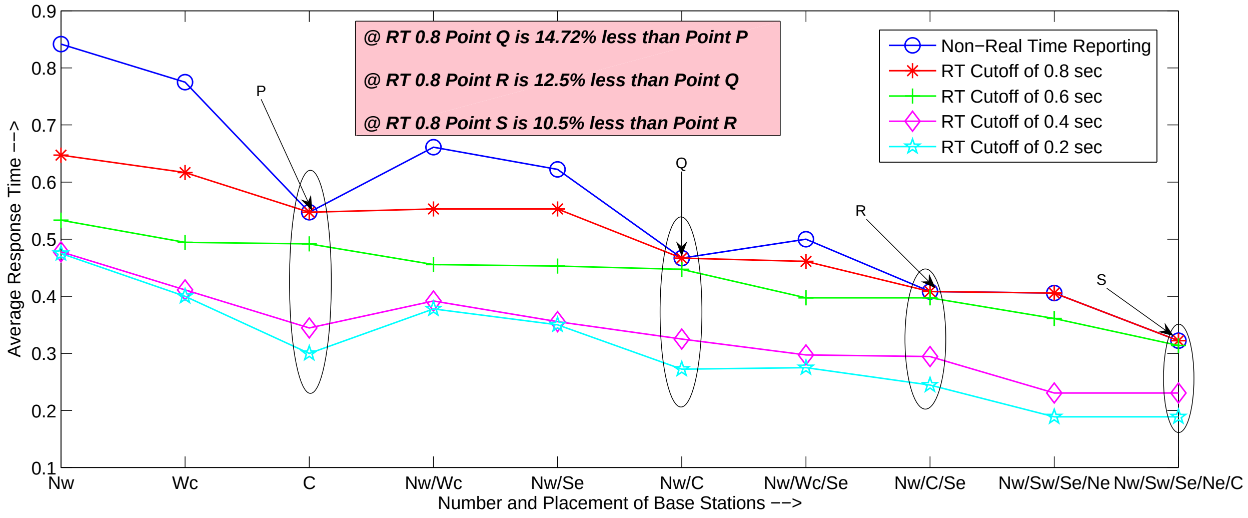

Figure 4.3. Average Response Time.

considering all the target directions stated in Fig. 4.1 at some angle.

We observe from the graph that non-real time reporting has the highest response time as compared to real-time reporting. Also, as the response time deadline decreases the average response time also decreases.

Considering the same plot from the perspective of the number of base stations used in the wireless sensor network. We can see that placing a base station at the center provides substantial reductions on the response time. Increasing the number of base stations further reduces the response time. Consider the graph for response time deadline of 0.4 seconds, we see that the average response time for a single base station at the center is lower than placing two base stations (one at the north west corner and other at the mid west of the grid). This clearly proves that just increasing the number of base stations is not a solution to reduce on the response time, we also need to optimally place them in the network. Also, we can observe that for response time deadline of 0.8 seconds, point Q is 14.72% less than point P and point R is 12.5% less than point Q. This clearly indicates that having a single base station at the center provides for maximum reductions on response time and adding any more base stations provides further reductions. Similarly, point S is 10.5% less than point R. Having five base stations (one at each corner and one at the center of the grid), provides the best response time.

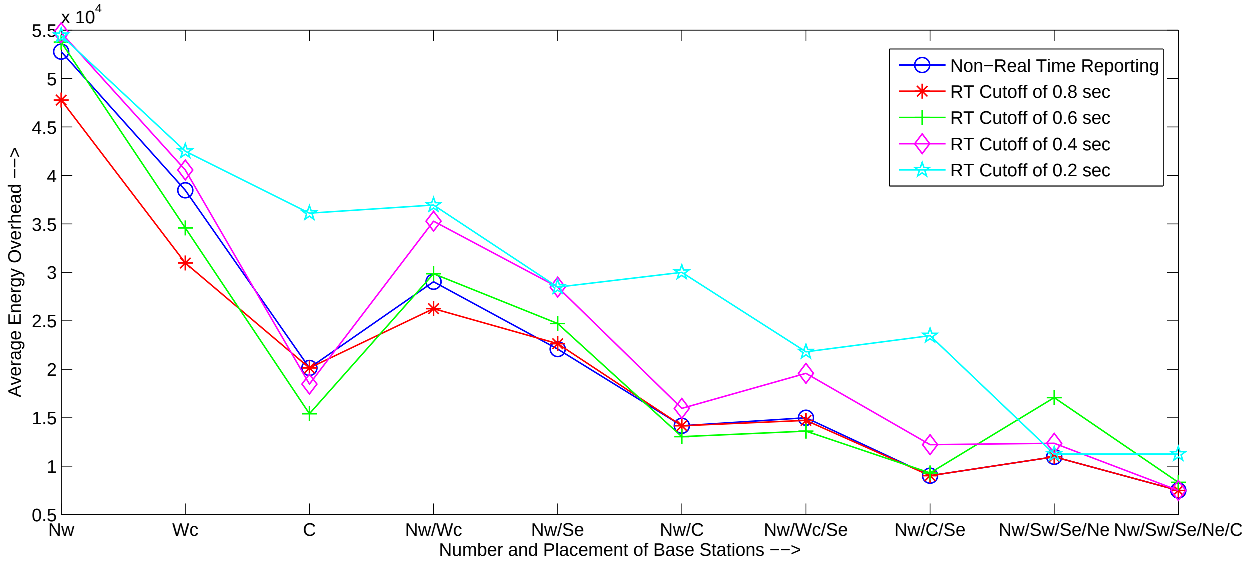

Figure 4.4. Average Energy Overhead.

Fig. 4.4 illustrates the energy overhead involved at each node for non-real time reporting, real-time reporting and the different base station organizations. As can be seen for non-real time reporting graph the average energy overhead per node is comparatively high as compared to real-time reporting with a response time deadline of 0.8 seconds. This is because the target paths that do not have base station in their direction involve an substantial energy overhead for independently sending the data to the base station. This overhead is reduced by performing real-time reporting where sending of data to the base station can happen before the target actually reaches the border of the network. However, it is interesting to note that the energy overhead keeps on increasing as we further reduce the response time deadline. This is because as we reduce the response time deadline, the time to perform target tracking and reporting of sensed data to the base station, also reduces. This clearly indicates that we need to perform tracking and reporting of the target cooperatively until a break way point after which target sensing continues independently and data is reported to the base station independently ensuring real-time monitoring. Also, we can observe that having optimal base station organization and increasing the number of base stations together, helps in substantial reduction in the average energy overhead. Thus, minimizing energy overhead results in increasing network lifetime. However, increasing only the number of base stations without their optimal placement in the network increases the energy overhead, as can be seen in Fig. 4.4. Also it is interesting to note that, except for response time deadline of 0.2 seconds, the energy overhead is high for a network having four base stations at the borders of the network as compared to having three base stations with one of them at the center. This is because, in the former case, for most paths taken by the target, the reporting of data to the base station requires more hops as the base stations are placed at the borders of the network. Moreover, decreasing the response time deadline beyond a certain point (consider response time deadline of 0.2 seconds) increases the energy overhead even when a base station is at the center of the network.

Fig. 4.5 illustrates the average blocking probability defined as the number of failed paths to the number of target paths simulated. Failed paths are those target paths that could not be tracked within the specified response time deadline. The total number of paths simulated for each base station organization were 36.

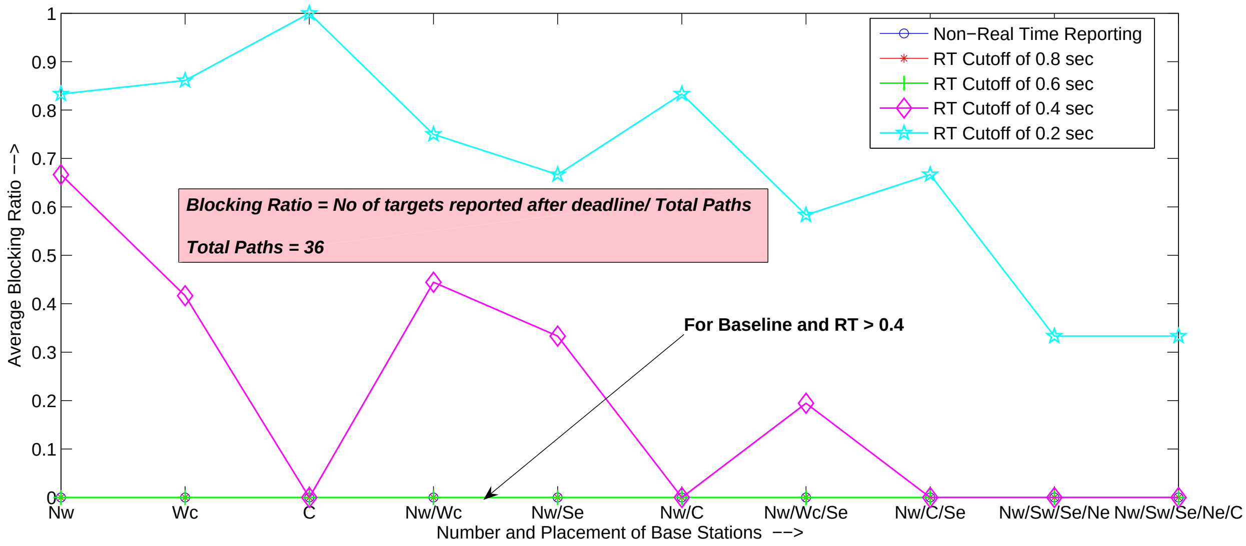

Figure 4.5. Average Blocking Probability.

From the figure, we see that all paths taken by the target get tracked for non-real time reporting, response time deadline of 0.8 seconds, and response time deadline of 0.6 seconds, for any kind of a base station organization. But as the response time deadline keeps decreasing there are certain paths that cannot be tracked for specific base station organizations. The graph for response time deadline of 0.4 seconds indicates that blocking ratio is high for non-optimal base station placement and the average blocking probability decreases with optimal placement of base stations. We observe that we can avoid blocking of any target path by having a base station at the center of the network. Interestingly for the response time deadline of 0.2 seconds, the blocking ratio is highest when we have a single base station at the center. This is because for any kind of path taken by the target some minimum hops are required to send the data to the base station, which are greater then the response time deadline (0.2 seconds). Thus any kind of a path taken by the target cannot be tracked in this kind of base station organization with a response time deadline of 0.2 seconds. In general, the blocking ratio keeps decreasing as we keep increasing the number of base stations and placing at least one base station at the center of the grid.

Hence, for any kind of a topology, we can reduce on the response time by placing a single base station at the center of the network. We can further add base stations depending on the cost factor involved. Incorporating a response time deadline helps in additional response time reductions.

CHAPTER 5

CONCLUSION

In this report, we proposed coordinated activation and reporting to provide real time target monitoring in wireless sensor networks. We verified that the simulation results closely match to the equations stated in Section 3.2. Simulation results show that response time is highest when non-real time reporting is performed (i.e. data is send to the base station only when the target reaches the border of the network). This not only increases the response time to the base station but also increases the energy overhead per node. By incorporating a response time deadline we can help reduce the response time and also the energy overhead per node. By carefully selecting the number and the location of base stations, we can provide minimal blocking probability. This implies tracking and reporting is performed coordinately until the response time deadline is not exceeded, after which tracking continues independently and data is reported to the base station independently within the response time deadline. We have observed that reducing the response time deadline beyond a certain point increases the energy overhead substantially and results in a high blocking probability. This is due to the fact that tracking and reporting are no longer performed coordinately.
An important area of future work is looking at more energy-efficient target monitoring. This has be can achieved by having only alternate border nodes in the network to be active.

As nodes are arranged in a grid pattern and have overlapping sensing range, the target always gets detected as soon as it enters the network even with alternate border nodes active.

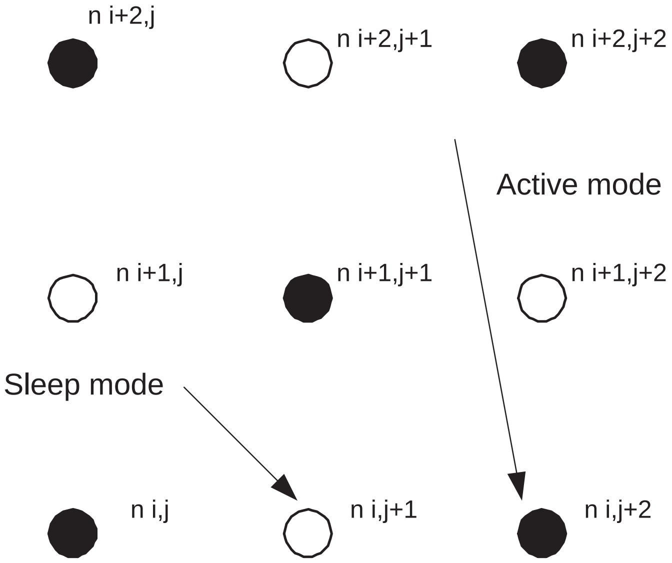

Figure 5.1. Alternate border nodes active.

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