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WIRELESS SENSOR NETWORKS MUTUAL POLICY FOR POSITION PROTECTION

Ahmed Irmayyidh MUTAR

Master Thesis

Supervisor
Asst Prof. Dr. Sefer Kurnaz

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WIRELESS SENSOR NETWORKS MUTUAL POLICY FOR POSITION PROTECTION

by

Ahmed Irmayyidh MUTAR

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Asst. Prof. Dr. Sefer KURNAZ

Supervisor

Thesis Defense Jury Members:

Asst. Prof. Dr. Sefer KURNAZ	School of Engineering and Natural Sciences, Altinbas University	____________
Asst. Prof. Dr. Oguz KARAN	School of Engineering and Natural Sciences, Altinbas University	____________
Prof. Dr. Adem KARAHOCA	Faculty of Engineering and Architecture, MEF University	____________

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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Ahmed Irmayyidh MUTAR

DEDICATION

First and foremost, I would like to thank Allah Almighty for giving me the knowledge, ability and opportunity to undertake this research study and to persevere and complete it satisfactorily . Heartfelt thanks goes to my father and my mother. Every success is a direct consequence of their influence in my life and their love. At the end I have to mention my brother and sister for their support and love .

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All praises is to ALLAH Subhanahu wa ta'ala for bestowing me with health, opportunity, patience, and knowledge to complete this research. May the peace and blessings of ALLAH Subhanahu wa Ta'aala be upon Prophet Muhammad (Sallallahu alayhi wa sallam).

My profound gratitude goes to my supervisor Asst. Prof. Dr. **SEFER KURNAZ**, for his invaluable guidance, excellent supervision, continuous encouragement and constant support in making this research possible. His cooperation, tolerance, constructive criticism and useful suggestions have been of immense encouragement to me and enabled me to develop a deeper understanding of this research. I also thank Dr. Alaa Hamid Mohammed I sincerely thank him for the time spent in proofreading and correcting my mistakes.

Finally, I extend my gratitude to all those who were directly or indirectly involved by either encouraging, praying and offering constructive advice in this thesis.

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ABSTRACT

WIRELESS SENSOR NETWORKS MUTUAL POLICY FOR POSITION PROTECTION

MUTAR, Ahmed Irmayyidh

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The usage of K-anonymity to preserve location privacy for wireless sensor network (WSN) monitoring systems, where sensor nodes operate together to notify a server with anonymous shared positions. That k-anonymous position is a coated region with at least k people. However, we identify an attack model to show that overlapping aggregate locations remain privacy-risk because the enemy can infer certain overlapping areas with persons under k who violate the privacy requirement for anonymity. Within this paper we suggest a mutual WSN privacy protocol (REAL). Actual needs sensor nodes to arrange their sensing areas separately into a variety of non-overlapping, extremely precise anonymous aggregate positions. We also developed a state transfer framework, a locking mechanism and a time delay mechanism to address the three main REAL challenges, namely self-organisation, shared assets and high precision. We equate REAL 's output with current protocols through virtual experiments. The findings demonstrate that REAL preserves the privacy of sites, offers more precise question answers and decreases connectivity and device expense.

KEYWORDS: Wireless sensor network, REAL, Optimum, Antenna, 3D diagrams.

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LIST OF ABBREVIATIONS

CDR	Cup-to-Disc Ratio
DR	Diabetic Retinopathy
DRIVE	Digital Retinal Images for Vessel Extraction
MESSIDOR	Methods to Evaluate Segmentation and Indexing
OD	Optic Disc
STARE	Structured Analysis of the Retina

1. INTRODUCTION

1.1 INTRODUCTION

The advancement of remote sensor advances has added to the formation of numerous applications like security, biometrics, and situating frameworks for situating administrations, including military applications. The position management service involves device sensor localization and receives personal location information from each sensor node. On the other hand, the intruder could even misuse the location data obtained from a distrustworthy server to assume personal data. Consequently, during the monitoring stage supervised people may have privacy threats.

The Type K anonymization strategy can be used to address some privacy threats. Basically, k-secret hides the role of the individual like most other K-1 individuals by making that place similar to everyone else in the masked area. The masked area of wireless sensor networks (WSNs) is the k-anonymised aggregate location (WSNs). A area of anonymity P is referred to as a masking zone Ma with N number of citizens surrounding an area that is not overlapping The N of which Ma was identified hereafter as P = (Ma, N).

In survey, medicinal uses and voting data, for instance, K-anonymity was taken advantage of. K-anonymised attributes are framework sets that, in conjunction with other distinguishing characteristics, differentiate between each set of k-1sets. The principle of place-based implementations interprets K-anonymity as a hazard such that a query area attacker model can not discern the source of the query area because it is more than 1/k likely to surpass K1 of other customers. A major part of the current study is seen in Figure 1. A customer sends details about his region and answers questions from a secure source to the anonymiser In this method. The anonymizer extracts the customer's registration id and then modifies its area by means of a masking procedure. Masking theory protects the exact location of the requesting client, using an anonymous geographic region k (ASR or K-ASR), with at least k1 other clients. The masking principle (K-ASR or ASR). Now, the anonymizer sends space to the server, which responds to the anonymizer with a collection of results that matches the query criteria for all possible ASP objects. In this scenario, the server may be hacked, i.e. an opponent may discover all the queries obtained by the server.

A field monitoring scheme may be found in a shopping center to assist customers in supplying various helpful resources, for example when evaluating a particular application scenario.

a. Mass applications: Measurement of N individuals in a certain area.

b. Security measure: Warning if a pre-defined limit reaches the amount of persons in an area.

c. Asset Management: If the quantity of individuals in a zone is not exactly the set worth, you can finish on the homes at house.

The reciprocity property describes spatial k-anonymity as a prerequisite to determine total positions. Thus, in a masked sector, individuals transmit the same secretly placed aggregates. However, location monitoring applications are generated in sensor networks in peer-to-peer contact networks to avoid the masked field of aggregate positions from satisfying the interactive properties because a sensor node can have more than one location. Subsequently, their mysterious territory additionally battles to guard its position. Figure 1 shows an insurance break case where three sensor hubs are shaped to know the specific include of individuals in the region 1, region 2 and passage in their location zone.

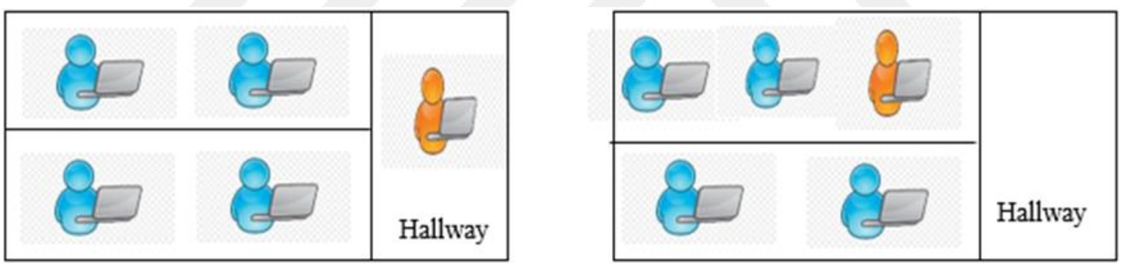

Figure 1.1: A security breach issue (a) At time t n (b) At time t (n+1).

Figure 1. The usage of three sensor nodes in room 1 and 2 as well as the amount of people in the building detector area[10] was an indication of a lack of privacy. No matter the hidden k = 3:(1) device administrator on time n (Fig. 1a), the three sensor nodes are computed in a clustered location by [11]. For example, the k-anonymity level of the system administrator is k=3

1. Three sensor nodes at the time tn will generate anonymous aggregates (Figure 1a).

$$P1^{th} = \left(Ma1^{th} = \{Area\ 1, Area\ 2\}, N1^{th} = 4\right),$$

$$P2^{th} = \left(Ma2^{th} = \{Area\ 2, \text{Hallway}\}, N2^{th} = 4\right),$$

$$P3^{th} = \left(Ma3^{th} = \{Area\ 3, \text{Hallway}\}, N3^{th} = 3\right)$$

In Area 1, Area 2 and Corridor, p, q, and r are respectively three people. We are able to perform linear equations,

$$p + q = 4,$$

$$a + z = 3,$$

$$b + z = 3.$$

As $P1^{tn}$, $P2^{tn}$, $P3^{tn}$ do Not complying with reciprocity property, that is, there will be superposition between certain entities, therefore, upon deduction of the line equations above, can be said to be in Zone 1, when the enemy hears two people, two people in Zone 2 and one on the street in some cases.

2. The three node sensors report during the interval tn+1 (Figure 1b).

$$P1^{th+1} = \left(Ma1^{th+1} = \{Area\ 1\}, N1^{th+1} = 3\right),$$

$$P2^{th+1} = \left(Ma2^{th+1} = \{Area\ 2, \text{Hallway}\}, N2^{th+1} = 5\right)$$

$$P3^{th+1} = \left(Ma3^{th+1} = \{Area\ 1, \text{Hallway}\}, N3^{th+1} = 3\right)$$

Thus, when evaluating the above example, the opponent does not conclude any individual at a defined interval tn+1 in Corridor, three individuals in Region 1 or 2. Working with Chris' relevant data, the tracker understands that Chris has entered Zone 1 on Tn + 1, which expands the Pacific course, from everywhere the area in areas two spots. Here, Chris is a non-identified individual who first stood idle as Figure 1 indicates. In the hallway Such a decrease in details may lead to privacy risks. For instance, when an individual attends a shopping centre, the facting information may include precise details.

1.2 PROBLEM STATEMENT

The improvement of remote innovation has prompted the advancement of a wide scope of utilizations for efficient administrations like security, biometric, and space frameworks. The position management service involves device sensor localization and receives personal location information from each sensor node. On the other hand, the intruder could even misuse the location data obtained from a distrustworthy server to assume personal data. Consequently, during the monitoring stage supervised people may have privacy threats..

1.3 OBJECTIVES

The objectives of this thesis can be represented as :

- To study Anonymity of K True aggregate positions have improved position management services if the server can measure the amount of people spread over an aggregate spectrum roughly.
- To ensure anonymity A privacy algorithm that masks details about the position is programmed.
- To enhance the efficiency of local services and thus boost their specificity, by reducing the areas of these aggregated locations.

1.4 PROJECT SCOPE

The thesis scope will be concentrating on three main factors which are embodied as follows:

i. We aspire to An examination of privacy hazards for position tracked sensor networks.
ii. We propose to maintain confidentiality a privacy algorithm is designed that masks position details.

1.5 THESIS OUTLINE

Chapter 1 provides information on project design. this input optical fiber , and impact of transmit power, problem statement, in addition to, study the objective of this project and scopes.

Chapter 2, we first introduce the principles and mathematical analysis for low-complexity DBP, Optical Fiber Link , Linear Fiber Impairments where the current system is not the DM (NDM) S-SMF links and are moving closer to the EDC for optimum performance. In addition to the linear low, in reality, is a non-linear optical fibers. The loss, dispersion, PMD and nonlinearity polarities but, at the same parameters used for the analysis of real fiber in comparison with the opposite characteristics can be used to model fabricated fiber. In addition to, to analyise Signal Propagation in the Fiber for Chromatic dispersion. Finaly compare according the Previous Studies.

Chapter 3, describe the adaptive PMD theory created due to propagating signal on the fiber birefringence is the major effects: a) continuous-wave. First, the principles of both schemes are labeled, and the numerical expressions for the original filter bandwidth estimation are resulting. Second, we developed the theory of PMD short. PMD and the stochastic nature of the mechanism on the basis of physical nonlinearity example helps us to understand the negative impact on reimbursement schemes.

Chapter 4, I demonstrate our proposed nonlinear noise estimation model for optical networks. First, the principle of the proposed fast AWGN for post-FEC BER. Second, I analyze and discuss the various aspects of Performance analysis verification based on DBP-based CD/NL-C, which includes the effect of span length, the required number of channel combination terms, the required sampling rate when evaluating the integration, and computational complexity..

Chapter 5, I summarize the thesis for conclusion and discuss some instructions for future work.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The concerns relevant to privacy are known as middleware layers of localized surveillance systems. Through our extensive knowledge, M. Spreitzer and M. Theimer have learned to produce this idea. In this way, every consumer has a reliable customer service agent who serves as a mediator and collects data from a large variety of sensors and gives device access to this knowledge.

Any judgments on access management are focused on the data of the policies governed by data security.

Myles and associates, for example, routinely prepare a function server identified from verified computer sets, which allow privacy techniques to test XML-coded applications for user applications' access. In a policy-oriented background, Duri and colleagues have recommended that sensor knowledge be guarded. It is designed to play the in-car machine as a trustful instrument in automotive computer science. Hengartner and Steenkiste's work indicate that the access control information regulate either geographic or place methodologies, both mechanisms have the capacity to address disputes between several other policies. The concepts of mobile network strategy are proclamated by Snekkeness. These concepts promote access management to resolve issues such as pace of area, time of response and request as well as entity recognition.

In addition, as a matter of accordance with the privacy policies, the network operator often tries to create confidence entre people. And the data obtained cannot be guaranteed against other possible threats by the network provider.

The Confidentiality Tool offers an option for retaining strategies that seek to acquire awareness by personalizing information before it is published. Only that. In the automotive telematics domain Gruteser and Grunwald[7] evaluated the possibility of anonymizing complete positions in locations. Beresford and Stajano[8] ideally determine, in view of Successful Bat, secrecy approaches to a robust indoor scheme after development. These methods deal with the problem of determining exactly area information which enable users to know their identity or to track developments continuously.

In a sensor network, the Cricket Location-Support System [9] consolidates protection issues. This device comprises a series of signal inserts that determine on their correct location by radio or ultrasound indications in the reich of transmission and reception of signals. As compared to previous systems, including the Active Badge[10][11], consumer security is enhanced since the specifics of the user's status will initially be decided by the system itself. The owner maintains therefore the right to decide who will send the material. And then consumers don't need to believe the sensor fully. It needs the consumer to maintain a system which is cozy in building comparison points and the right tool to give the customer management decisions (on a decent interface) or to have a response to another reliable individual.

2.2 OVERVIEW OF ROUTING STRATEGIES

During the management of network demand and the need to improve the energy consciousness protocol in all wireless network ports, problems are found as a consequence of inhibited supplies of energy and bandwidth. Study is based on the energy-efficient MAC protocol[4], the awareness of the power level of the equipment and difficulties of the stumbling cycle to strengthen and expand the monitoring of power in the wireless sensor network. Moreover, the network layers have been identified conveniently to match effective network routes by secure data exchange to maximize the network's lifetime.

The routing of wireless sensor networks has been developed to have many different roles connected to ad hoc networks or modern contacts [5]. The following characteristics are listed for wireless sensor networks:

1. Due to the vast number of sensor nodes it is not advisable to build the wireless sensor network with a robust IP addressing arrangement. (However, certain software of IPv6 technology nowadays have IP addresses and systems for such applications can be purchased for both the wireless IP and RF functions).
2. The created data are greatly deployed since such sensors could be positioned in the same area and collect similar data. It may also serve to minimize energy consumption in the wireless sensor network by disconnecting additional or redundancy wishes to improve bandwidth usage.
3. For a wireless network of sensors, the control of the receiver (transmitter and receiver), the amount of data transmission and the storage space are compulsory considerations.

These alterations analyze new protocols, improve existing protocols, and mold researchers and enterprises to solve wireless network-related problems. These protocols are modified according to the architectural necessities and the features of the wireless sensor node along with their implementations. Although some protocols are designed on the basis of flow consistency, they may be categorized as hierarchical, data entered or location based.

2.3 PROTOCOL DATA CENTRIC

To overcome this challenge, it is known that data transmission in a wireless network and various energy-aware routing protocols or algorithms has difficulties. These routing protocols may usually be separated into two groups, data center or central. If you think of a data center[5][6] system by means of metadata debate or defined data to eliminate layered data sent to improve energy efficiency for the remainder of your life. In Kulik et al. [7], numerous communications, including the "3-stage" data-centric rule set, have been used by ADV, REQ and DATA to transfer data through nodes intermediately. Empirical studies have been used to assess what form of packet dissemination method a wireless network can use to capture a specified set of laws. These are regarded as the unicast multi-store or WSN transmission single-hop.

2.4 PROTOCOL LOCATION–BASE

For the most part, wireless sensor network routing technology finds the role or positioning of sensor mote data available for the measurement of space in 2 separate nodes to infer power consumption. Take an example: a single query can be sent to the recognized section to identify the published area by means of sensor capability, thus dramatically decreasing transmitted knowledge matched to a broadcast call to be transmitted to the whole networks. If we put this in a certain context, the field or function referred to as algorithms enable localization knowledge to transfer the details to the required segment rather than the configuration. The MTN is a protocol that is most often employed in positions-based technologies (MECN). In a low power global positioning system in a wireless sensor network, this sort of network produces and supports low power (GPS).

2.5 ROUTION HERARCHICAL

In this system, only routers or terminal devices within the sector or area of each router are accessible data; other regions and routers are therefore not data available. Therefore, the routing system sets aside single details for various places in its routing table. By utilizing a multi-Hop communication with an explicit cluster or field, the rule to move herearchical information would reduce energy consumption by minimizing the amount of data transmitted through the wireless network via the acting accumulation and combinations. Sample hierarchical routing network with numerous regions as shown in figure 2.1.

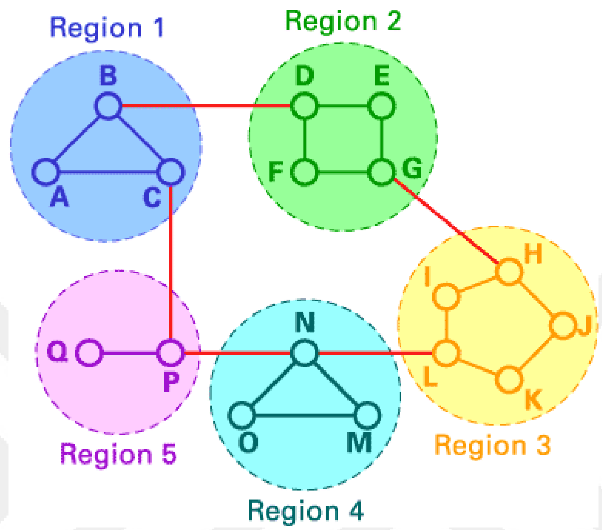

Figure 2.1: Hierary, different areas routing network.

Figure 2.1 sends it to mount B if Node A looks for data packets to some potential node in area or zone 2 (node F, node E, node D , node G). If we can see, maps may be potted using such data sending, but the quality of set-up progresses. The picture demonstrates hierarchical routing demonstrations for two stages. Then we will still see if the network is complex or smaller by level three or level four.

The table below (Table 2.1) illustrates the difference [4] in life, scalability, strength and the dispersion of data in the wireless sensor network of the numerous routing protocols. Through studying this we understand that hierarchical approaches tactically minimize scalability and resources in a WSN.

Table 2 1: Routing Protocol Compares.

	Hierarchical	Location Based	Data Centric
Lifespan	Good	No	Limited
Scalability	Long	Long	Long
Data Diffusion	Yes	No	No
Power usage	High	Limited	Limited

2.6 STUFF INSERT (IOT) AND WSN THINGS

More than a decade earlier, tech investigators invented the word Internet of Things (IoT), but has recently become omnipresent in its background. Some believe that IoT would influence the way computer network/sensor networks are utilized for at least 5 or 5 decades, although others accept that IoT is just disinformation that does not effect people's daily lives.

2.7 WHERE ARE IOT??

The Internet of Things ensures that a network computer can gather or feel data in anywhere and then exchange the data collected over the Internet anywhere various relaxing resolutions can be used and administrated. Nearly anywhere could now be found Internet of Stuff. There are available industry programs, home automation, building automation, medical and military applications, etc.

2.8 ACTOR RELOCATION

Actor relocation problem focuses on minimizing the total distance moved by the ac- tors to establish a communication network among them. To enable communication, actors need to stay within the transmission range (distance up to which it can com- municate directly) of each other. Figure 2.1 shows when actors cannot communicate and Figure 2.2 shows when can they communicate with each other. Figure 2.3 shows a connected inter-actor network. An actor failure can cause the loss of multiple inter- actor communication links and may partition the network if alternate paths among the affected actors are not available. Such a scenario will hinder the actors' com- munication capabilities and cause the failure of WSAN. Therefore, it is necessary to maintain a connected inter-actor network at all times.

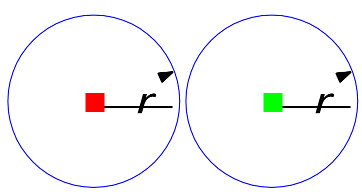

Figure 2 1: Two actors that cannot communicate with each other.

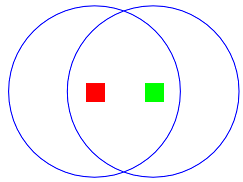

Figure 2 2: The two actors can communicate with each other.

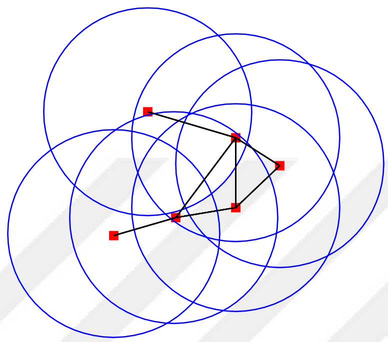

Figure 2 3: A connected WSAN. Even though two actors do not directly communicate with each other, they can do so through other actors in the network.

2.9 LITERATURE REVIEW

Most of the research work done on actor relocation problem focuses on developing an algorithm or heuristic to establish a communication network among actors. Melodia et al. [2005] presents a coordination framework for WSAN to decide which actors should respond to an event in a particular region. In this work, they considered inter-actor connectivity in the context of actor placement ignoring potential breaks in the network connectivity. Wang et al. [2005] studied sensor relocation in mobile sensor networks (which is similar to actor relocation problem), and developed an algorithm for relocating mobile sensors in a timely, efficient, and balanced manner, and at the same time maintaining the original sensing topology as much as possible. In their algorithm, sensor relocation consists of two phases: the first phase is to find the redundant sensors in the sensor network; the second phase is to relocate them to the target location. In their model, they did not consider connectivity of the whole network.

Abbasi et al. [2007] considered the problem of relocating the actors to establish an inter-actor communication network while minimizing the total traveling distance and therefore reducing the energy overhead of the actors. They developed a heuris- tic approach called Distributed Actor Recovery Algorithm(DARA) which opts to efficiently restore the connectivity of a partitioned inter-actor network. Basu et al. [2004] studied the configuration of an ad-hoc network that can tolerate failures while allowing recovery. They developed algorithms for achieving bi-connectivity. In the bi-connectivity problem it is required to have at least two different paths between any two sensors.

It is not hard to see the importance of maintaining a connected WSAN consider- ing the various application areas of sensors such as habitat monitoring and military services(see Section 1.1). To enable rapid response to potential natural disaster or enemy threat immediately it is crucial to have a continuous and reliable communi- cation between the nodes of a WSAN. As the nodes of a network can randomly fail, we should be prepared to relocate sensors and actors to re-establish connectivity in the most efficient way. In this study, mixed integer programming model for relocat-ing actors to establish single-connectivity1 and bi-connectivity2 using the concepts of adjacency matrix from graph theory are developed.

In the rest of the chapter, problem description and then model notation are ex- plained. Next the mathematical models developed to solve single-connectivity and bi-connectivity are explained. Finally, this chapter is concluded with numerical re- sults and conclusions section.

2.10 PROBLEM DESCRIPTION

Suppose that we are given a WSAN with n actors and let $A = \{1,2, \dots, n\}$ be the set of indices of indices of these actors. Let $P_i = \begin{bmatrix} P_i^1 \\ P_i^2 \end{bmatrix}$ be the position coordinates and r_i be the transmission range of actor $i, i \in \{1,2, \dots, n\}$. Our goal is to relocate actors in the WSAN network using as little total travel distance as possible to restore connectivity when the inter-actor network is partitioned due to a failure of an actor. To gain some insight into the problem, consider the simple WSAN shown in Figure 2.4, which consists of two actors, indexed by 1 and 2. Where, P^1 and P^2 denote the original coordinates of actors, $x^1 and\ x^2$ denote the decision variables (i.e., coordinates of the actors after relocating). The transmission range of both actors is equal to r. As can be seen in the figure, the distance between the two actors is given by:

$$d = \|p^1 - p^2\| = \sqrt{(P_1^1 - p_2^2)^2 + (P_2^1 - p_2^2)^2}$$

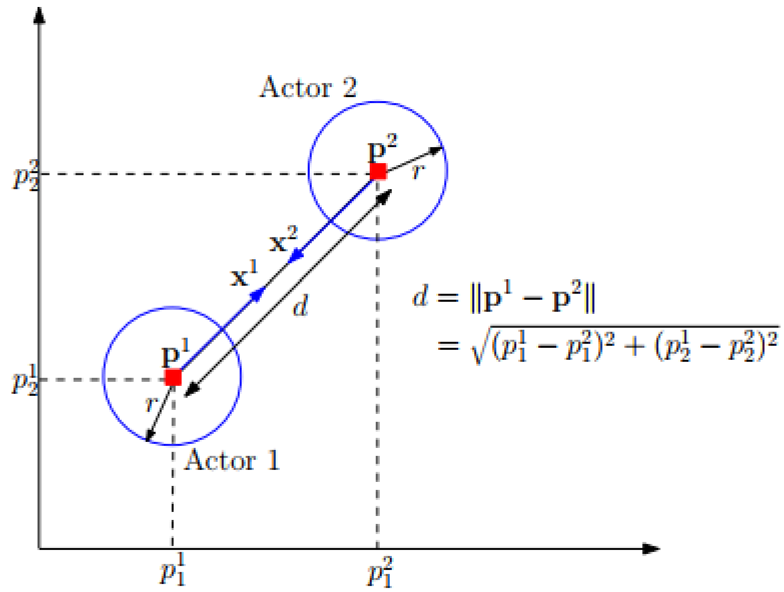

Figure 2 4: A simple WSAN consisting of two actors.

The optimal relocation problem for this simple WSAN is given by:

$$\min_{x^1,x^2} \|X^1 - P^1\| + \|X^2 - P^2\|$$

$$subject\ to\ \|X^1 - X^2\| \leq r$$

of actor 1 and actor 2, respectively.

It can be readily shown that the optimal relocation strategy is.

- If $\|P^1 - P^2\| <= r$, then $(x^1)^* = P^1$ and $(x^2)^* = P^2$ (i.e., we do not need to move the actors if they are already communicating with each other),
- If $\|P^1 - P^2\| > r$, then

$$(X^1)^* = P^1 + \lambda\,(P^2 - P^1)\left(1 - \frac{r}{\|P^2 - P^1\|}\right)$$

$$(X^2)^* = P^2 + (1 - \lambda)(P^1 - P^2)\left(1 - \frac{r}{\|P^1 - P^2\|}\right),$$

where $\lambda = [0, 1]$ (i.e., if the actors are outside of their respective transmission ranges, all we need to do is to move them towards each other along the line connecting them so that the distance between them becomes equal to r).

2.10.1 A Mixed-Integer Formulation

Let $X_i = \begin{bmatrix} x_i^1 \\ x_i^2 \end{bmatrix}$ be the position coordinates of actor$i, i = \{1,2,\dots,n\}$, after it is relocated.

The total distance traveled by all the actors during the relocation is given by

$$\sum_{i=1}^{n} \|X_i - P_i\| = \sum_{i=1}^{n} \sqrt{(x_i^1 - P_i^1)^2 + (x_i^2 - P_i^2)^2},$$

where $\|.\|$ is the Euclidean distance.

Let for all $i, \iota \in$ A, $i \neq j$,

$$y_{ij} = \begin{cases} 1, \text{if actor i can communicate directly with actor j (i.e.,} \left\|X^i - X^j\right\| & \leq r_i \\ 0, otherwise. \end{cases}$$

Here, transmission ranges of all sensors are assumed to be same, i.e., $r_i = r_j$, therefore $y_{ij} = y_{ji}$.

Using the ideas from the Traveling Salesman cut-set formulation; a straightforward formulation can be written as follows:

Min $\sum_{i=1}^{n} \left\|x^i - p^i\right\|$

subject to $\left\|X^i - X^j\right\| \leq r_j y_{ij} + M\left(1 - y_{ij}\right), \forall i, j \in A, i \neq j$

$\sum_{i \in S} \sum_{j \notin S} y_{ij} \geq 1, \forall S \subset A, S \neq \emptyset,$

$x^i \in R^2, \quad i \in A,$

$y_{ij} \in \{0,1\}, \quad i, j \in A, \quad i \neq j,$

where the constraint (2.2) determine whether an actor communicates directly with another actor; constraint (2.3) enforce that every possible partition of the network by nodes is connected with at least one node outside of the partition and M is a large positive number. Unfortunately, the number of constraints in this formulation is non-polynomial (there are 2n−1 constraints in equation (2.3). Therefore, we need a more tractable formulation.

2.10.2 Using Powers of the Adjacency Matrix to Ensure Connativity.

Definition 1 (Adjacency Matrix). Let Y be the adjacency matrix after the actors are relocated.

$$\mathbf{Y} = \begin{bmatrix} y_{11}(1) & y_{12}(1) & \cdots & y_{1n}(1) \\ y_{21}(1) & y_{22}(1) & \cdots & y_{2n}(1) \\ \vdots & \vdots & y_{ij}(1) & \vdots \\ y_{n1}(1) & y_{n2}(1) & \cdots & y_{nn}(1) \end{bmatrix}$$

Definition 2 (Walk). A walk is an alternating sequence of vertices and edges, begin- ning and ending with a vertex. A graph is said to be connected if each pair of vertices is joined by a walk (Biggs [1993])

Theorem 1. The (i, j) entry of the kth power of the adjacency matrix Y is Yk, which equals to the number of walks of length(at-most k steps) between actor i to actor j .

Proof. Refer to Pemmaraju and Skiena [2003]

Corollary 1. A WSAN with n actors is connected if and only if

$$\left[\mathbf{Y}^{n-1}\right]_{ij} \geq 1, \quad i \in \{1, 2, \ldots, n\}, \; j \in \{1, 2, \ldots, n\}.$$

Proof. Where, [Yn−1]ij is (n − 1)th power of Adjacency Matrix Y. Therefore, the value of (i, j) entry of [Yn−1]ij will be at most equal to (n − 1) walks. From the definition of Walk, if there exists a walk between two vertices, then they both are connected. Therefore, if every entry in [Yn−1]ij is greater than 1, which means there exits at least one walk between i and j, then WSAN is connected

Motivated by Corollary 1, an alternative nonlinear mixed-integer programming formulation can be written as:

$$\begin{aligned}
\min \quad & \sum_{i=1}^{n} \|\mathbf{x}_i - \mathbf{p}_i\| \\
\text{subject to} \quad & \|\mathbf{x}_i - \mathbf{x}_j\| \leq r_j \; y_{ij}(1) + M(1 - y_{ij}(1)), \quad \forall i, j \in \mathcal{A},\; i \neq j, \\
& \left[\mathbf{Y}^{n-1}\right]_{ij} \geq 1, \quad i \in \{1, 2, \ldots, n\},\; j \in \{1, 2, \ldots, n\}. \\
& \mathbf{x}_i \in \mathbf{R}^2, \quad i \in \mathcal{A}, \\
& y_{ij}(1) \in \{0, 1\}, \quad i, j \in \mathcal{A},\; i \neq j.
\end{aligned}$$

Letting, for all i, j ∈ A, i *f*= j, and k ∈ {1, 2, . . . , n − 1},

$$y_{ij}(k) = \begin{cases} 1, & \text{if actor } i \text{ and actor } j \text{ can communicate using at most} \\ & k \text{ intermediary steps,} \\ 0, & \text{otherwise,} \end{cases}$$

An equivalent formulation is obtained:

$$
\begin{aligned}
\min \quad & \sum_{i\in\mathcal{A}} \|\mathbf{x}_i - \mathbf{p}_i\| \\
\text{s.t.} \quad & \|\mathbf{x}_i - \mathbf{x}_j\| \le r_j\ y_{ij}(1) + M(1 - y_{ij}(1)), \quad \forall i,j \in \mathcal{A},\ i \ne j, \\
& y_{ij}(k) \ge y_{il}(k-1)y_{lj}(1), \quad \forall i,j,l \in \mathcal{A},\ i \ne j \ne l, \\
& \qquad\qquad k \in \{2,3,\ldots,n-1\}, \\
& y_{ij}(k) \le \sum_{l\in\mathcal{A}\setminus\{i,j\}} y_{il}(k-1)y_{lj}(1), \quad \forall i,j \in \mathcal{A},\ i \ne j, \\
& \qquad\qquad k \in \{2,3,\ldots,n-1\} \\
& y_{ij}(n-1) \ge 1, \quad \forall i,j \in \mathcal{A},\ i \ne j, \\
& \mathbf{x}_i \in \mathbf{R}^2, \quad \forall i \in \mathcal{A}, \\
& y_{ij}(k) \in \{0,1\}, \quad \forall i,j \in \mathcal{A},\ i \ne j,\ k \in \{1,2,\ldots,n-1\},
\end{aligned}
$$

Here, objective function (2.11) minimizes the total distance moved by the actors from their initial positions. Constraint (2.12) determine whether an actor communi- cates directly with another actor; the constraints (2.13)–(2.15) capture multiplcation of adjacency matrix and ensure connectivity. Constraints (2.13) and (2.14) make sure that yij(k) = 1, when there exists a path from one actor to another actor through a neighbor actor within the k-th step. Finally, constraint (2.15) is needed to confirm that all nodes are connected in at most (n − 1) steps.

The constraints (2.13)-(2.14) involve multiplication of binary variables, which is non-linear and therefore are difficult to handle. We can linearize these constraints by defining the following additional variables, for all i, j, l ∈ {1, 2, . . . , n}, i *f*= j, and k ∈ {2, 3, . . . , n − 1},

$$
v_{ilj}(k) = \begin{cases} 1, & \text{if actor } i \text{ and actor } j \text{ can communicate through actor } l \\ & \text{within exactly } k \text{ steps,} \\ 0, & \text{otherwise.} \end{cases}
$$

Using these variables, we obtain the following formulation, which is equivalent to the formulation (2.11)-(2.17):

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{n} \|\mathbf{x}_i - \mathbf{p}_i\| \\
\text{s.t.} \quad & \|\mathbf{x}_i - \mathbf{x}_j\| \le r_j\, y_{ij}(1) + M(1 - y_{ij}(1)), \quad \forall i, j \in \mathcal{A},\ i \ne j, \\
& v_{ilj}(k) \le y_{il}(k-1), \quad \forall i, j \in \mathcal{A}, i \ne j, \text{ and} \\
& \qquad \forall l \in \mathcal{A}, l \ne i, l \ne j,\ \forall k = \{2, 3, \ldots, n-1, \} \\
& v_{ilj}(k) \le y_{lj}(1), \quad \forall i, j \in \mathcal{A}, i \ne j, \text{ and} \\
& \qquad \forall l \in \mathcal{A}, l \ne i, l \ne j,\ \forall k = \{2, 3, \ldots, n-1\}, \\
& v_{ilj}(k) \ge y_{il}(k-1) + y_{lj}(1) - 1, \forall i, j \in \mathcal{A}, i \ne j, \text{ and} \\
& \qquad \forall l \in \mathcal{A}, l \ne i, l \ne j,\ \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(k) \ge v_{ilj}(k), \quad \forall i, j \in \mathcal{A}, i \ne j, \text{ and} \\
& \qquad \forall l \in \mathcal{A}, l \ne i, l \ne j,\ \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(k) \le \sum_{l \in \mathcal{A} \setminus \{i,j\}} v_{ilj}(k), \quad i, j \in \mathcal{A}, i \ne j,\ \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(n-1) = 1, \quad \forall i, j = \mathcal{A},\ i \ne j, \\
& \mathbf{x}_i \in \mathbf{R}^2, \quad \forall i \in \mathcal{A}, \\
& v_{ilj}(k) \in \{0, 1\}, \quad \forall i, j, l \in \mathcal{A}, i \ne j \ne l,\ \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(k) \in \{0, 1\}, \quad \forall i, j \in \mathcal{A}, i \ne j,\ k = \{1, 2, \ldots, n-1\},
\end{aligned}
$$

In the above formulation, constraints (2.20) - (2.22) make sure that vilj(k) = 1 if yil(k − 1) and ylj(1) are both equal toJ1J, and if any one of these variables equals to J0J then vilj(k) will become equal to J0J. Constraints (2.24) and (2.25) make sure that yij(k) = 1, if vilj(k) = 1 (for any in l ∈ A). Constraint (2.25) make sure that every element in yij(n − 1) is equal to J1J, this confirms that actor i is connected to actor j (∀i, j ∈ A).

In this formulation the objective function (2.18) and the constraints (2.19) involve Euclidean distance calculations and therefore they are nonlinear. Next, approxima- tion scheme used to linearize Euclidean norms in our model is explained.

2.11 A POLYGON APPROXIMATION SCHEME

A vector's Euklidean norm (i.e. lenght) is equivalent to the radius of the smallest circle centered at the root of the vector as a whole. One approximation to the Euclidean norm can be obtained using the concepts explained in Earl and D'Andrea [2007], by replacing this circle with a regular polygon centered at the origin, as shown in Figure 2.5. In this approximation scheme, the Euclidean norm of a vector is approximated by the apothem3 of the smallest polygon containing the entire vector. Let s be the number of sides of the polygon used in the approximation. Then;

$$\mathbf{a}^h = \begin{bmatrix} \cos\left(\frac{2\pi h}{s}\right) \\ \sin\left(\frac{2\pi h}{s}\right) \end{bmatrix}$$

represents the normal vector to side h, h ∈ {1, 2, . . . , s}

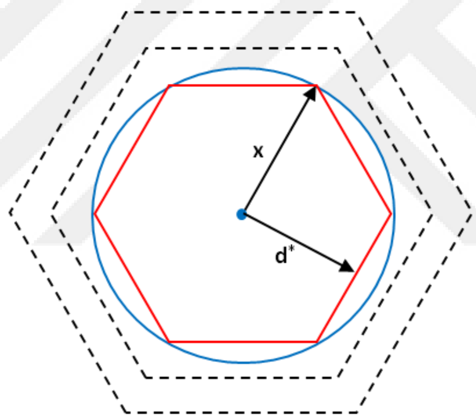

Figure 2 5: replacing a vector with a normal polygon for the smallest circle.

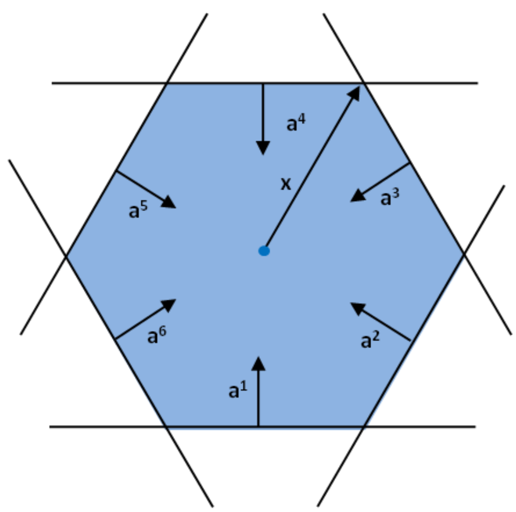

Figure 2 6: Inside of a polygon as a feasible region

By considering the inside of a polygon as the feasible region (see Figure 2.6), the problem of finding the apothem of the smallest polygon containing a vector x can be easily modeled as a linear programming problem (LP):

$$\begin{aligned} \min_{d} \quad & d \\ \text{subject to} \quad & \left(\mathbf{a}^{h}\right)^{\mathsf{T}}\mathbf{x} \leq d, \quad h \in \{1, 2, \ldots, s\} \\ & d \geq 0. \end{aligned}$$

Here, d is the apothem of a smallest circle that can cover the given vector x. Since apothem of a circle is smaller than radius of circle, there is a slight margin of error in the feasible region. Which is approximately equal to the difference between area of circle and area of the polygon with apothem d∗, where d∗ is the optimal solution of the model given above ((2.29) - (2.31)). In Figure 2.7, Jmaximum percent errorJ vs. Jnumber of sides of the polygonJ is plotted using equation (2.32). From the figure it is evident that as the number of sides polygon increase, percentage of error decreases exponentially and for polygons with more than 30 sides, the error is negligible.

$$\text{Maximum Percent Error}(s) = \frac{\text{Area of Cirle}(r)\text{ - Area of Polygon}(s)}{\text{Area of Circle}(r)}$$

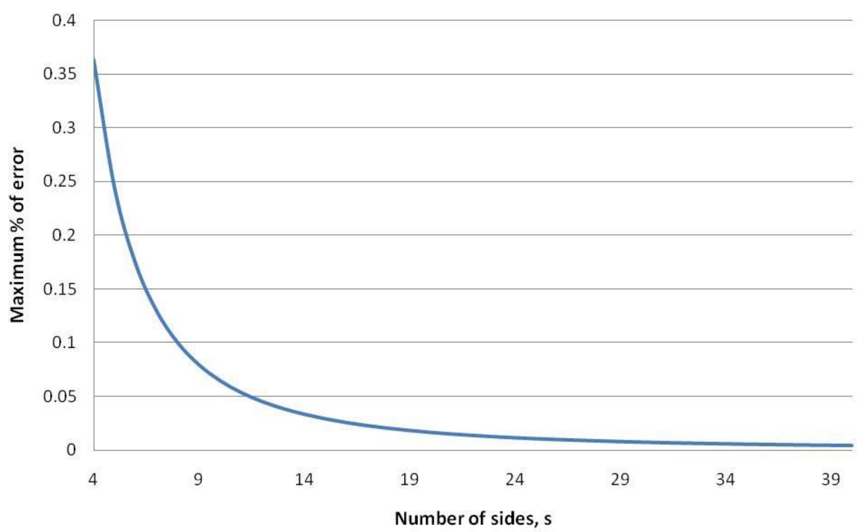

Figure 2 7: The percent area of a circle that is outside of a polygon contained in the circle as a function of the number of sides of the polygon.

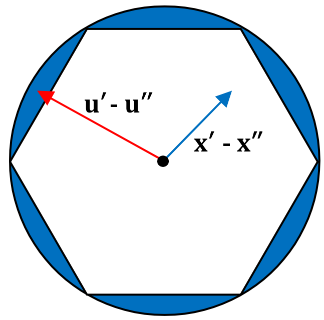

Figure 2 8: Approximation for checking whether the distance between two vectors is less than a certain value.

In order to check whether the distance between two vectors, say xJ and xJJ, is less than a certain value, say r, a similar approximation scheme can be used for finding the largest polygon inside of a circle with radius r as shown in Figure 2.8. The apothem of this polygon is equal to r cos π . The problem of determining whether the distance between xJ and xJJ is less than r can be modeled as an integer programming problem:

$$
\begin{aligned}
\max_{y} \quad & y \\
\text{subject to} \quad & (\mathbf{a}^h)^{\mathsf{T}}(\mathbf{x}' - \mathbf{x}'') \leq \left(r \cos\left(\frac{\pi}{s}\right)\right) y + M(1-y) \\
& y \in \{0, 1\},
\end{aligned}
$$

where M is a very large number. Inequality (2.19) forces y to be J0J, if the distance between xJ and xJJ is greater than J1J. If the optimal solution y∗ = 1 then it infers that the distance between xJ and xJJ is less than r. Otherwise, it infers that the distance is greater than r.

Using the approximation schemes, the formulation given in (2.18) - (2.28) can be linearized as follows:

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{n} d_i \\
\text{subject to} \quad & \left(\mathbf{a}^h\right)^{\mathsf{T}}\left(x^i - \mathbf{p}^i\right) \le d_i, \quad \forall i \in \mathcal{A}, \forall h = \{1, 2, \ldots, s\}, \\
& \left(\mathbf{a}^h\right)^{\mathsf{T}}\left(\mathbf{x}^i - \mathbf{x}^j\right) \le \left(r_j \cos\left(\frac{\pi}{s}\right)\right)\ y_{ij} + M(1 - y_{ij}), \\
& \qquad \forall i, j \in \mathcal{A},\ i \ne j, \forall h = \{1, 2, \ldots, s\}, \\
& \text{[Equations (2.20) - (2.28)]} \\
& d_i \ge 0, \quad \forall i \in \mathcal{A}.
\end{aligned}
$$

Here (2.36) and (2.37) are used to linearize the objective function (2.18) and the constraint set (2.37) is used to linearize the inequality (2.19).

2.12 NUMERICAL RESULTS FOR SINGLE CONNECTIVITY

To test optimization algorithm given in Section 2.4, different set of unconnected WSAN to relocate them to establish connectivity is considered. In the first set of experiments 5 actors are used, the coordinates and the transmission ranges of which are shown in Figure 2.9. Table 2.1 lists the initial coordinates of these actors. Note that, in these networks the transmission ranges of all the actors are chosen to be equal to two units. Therefore, actors 2, 3 and 4 are connected, while 4 and 5 are not connected. Note that, the solution of this small problem can easily be determined, therefore this example is used to validate the optimization model.

Table 2 2: Coordinates of the actors shown in Figure 2.9

Actor i	1	2	3	4	5
p_i^1	-2	0	2	3	6
p_i^2	2	0	0	0	0

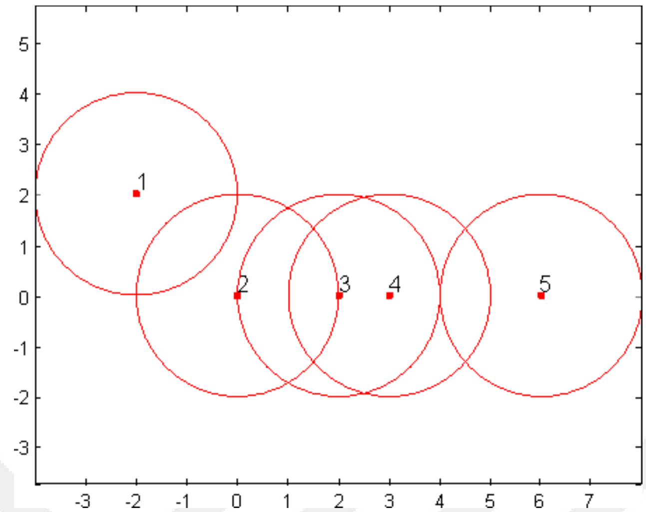

Figure 2 9: Initial Position of the given 5 actors.

In order to form a connected inter-actor network all the actors should be connected directly or indirectly. The intuitive solution of this problem is to move either actor 1 or actor 2 along the straight line joining the positions of these two actors, (see Figure 2.4). We cannot move actor 2, since it gets disconnected from actor 3, so we should move actor 1 till it reaches the transmission range of actor 2

In this solution, the distance moved by actor 1 will be,

$$d_1 = \sqrt{(-2-0)^2 + (2-0)^2} - 2 = 0.828$$

The new position of actor 1 is,

$$X_1 = \left(\frac{-2*2+0*0.828}{2.828}, \frac{2*2+0*0.828}{2.828}\right) = (-1.414, 1.414)$$

Similarly, the closest actor to 5 is actor 4. Therefore, the distance it moves is,

$$d_5 = \sqrt{(6-3)^2 + (0-0)^2} - 2 = 1$$

New position of actor 5 would be,

$$x_5 = \left(\frac{3*1+6*2}{3}, \frac{0*1+0*2}{3}\right) = (5,0).$$

Note that, we can also move actor 4 by one unit instead of moving actor 5, since actor 4 will be still connected to actor 3. But, the total distance moved by the actors will be the same.

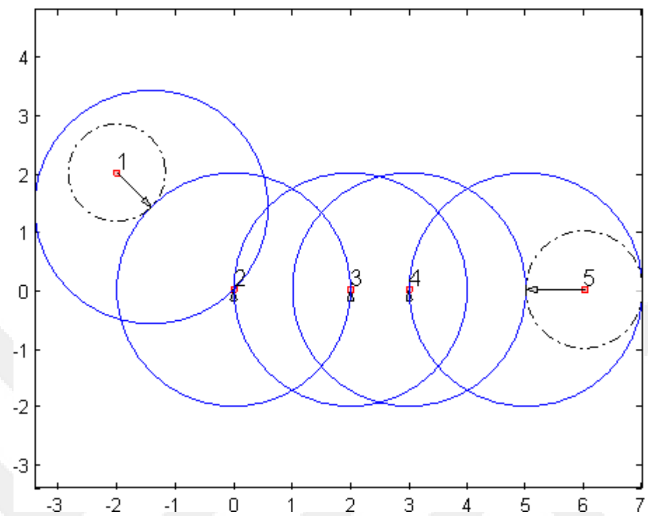

Figure 2 10: Optimal relocation positions of the given actors.

Figure 2.10 shows the optimal relocation positions for the actors. Here, straight circles represent the transmission range of the corresponding actors and arrows show the direction in which actors have been relocated. And, dotted circles are used to represent the Euclidean distance that the actors moved in this solution. To validate the model given in Section 2.4, the model for the 5-actors problem is coded in AMPL and obtained the results using CPLEX solver.

For the polygon approximation, polygons with 8, 10, 12 and 20 sides are used. The results obtained for each of these experiments are shown in Figure 2.11 - 2.14 and their respective solutions are shown in Table 2.3.

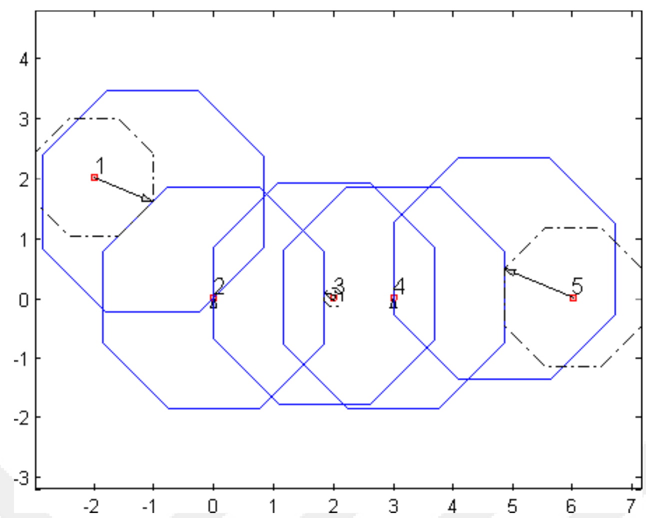

Figure 2 11: Relocation Position for 8-Sided Polygon.

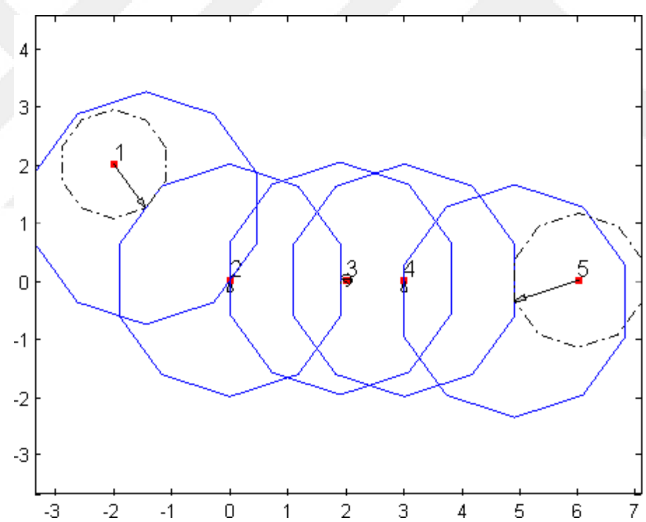

Figure 2 12: Relocation Position for 10-Sided Polygon.

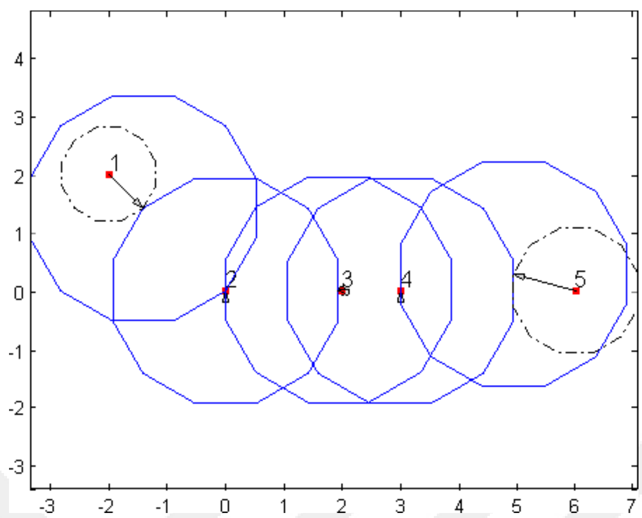

Figure 2 13: Relocation Position for 12-Sided Polygon.

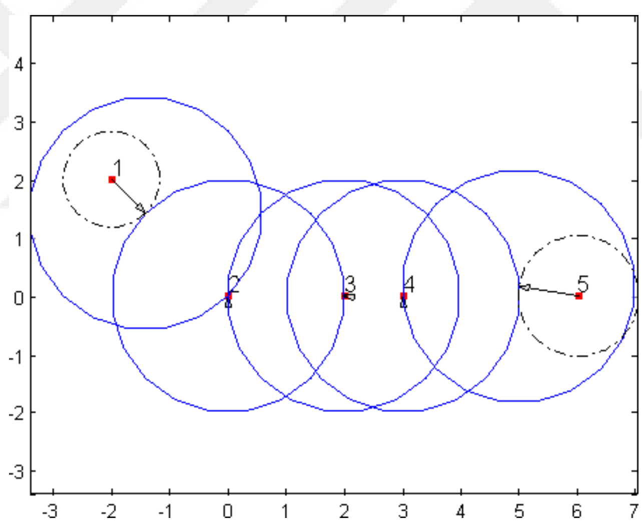

Figure 2 14: Relocation Position for 20-Sided Polygon.

Table 2 3: Optimal positions and n-sided regular polygon solutions for 5 actors single connectivity.

	i	1	2	3	4	5	
Initial Position	p_i^1	-2.00	0.00	2.00	3.00	6.00	
	p_i^2	2.00	0.00	0.00	0.00	0.00	
Optimal Solution	p_i^1	-1.41	0.00	2.00	3.00	5.00	
	p_i^2	1.41	0.00	0.00	0.00	0.00	
	d_i	0.83	0.00	0.00	0.00	1.00	
	EDM	0.83	0.00	0.00	0.00	1.00	$\sum EDM = 1.83$
8-Sides Polygon	p_i^1	-1.02	0.00	1.85	3.00	4.85	
	p_i^2	1.59	0.00	0.06	0.00	0.48	
	d_i	0.98	0.00	0.15	0.00	1.15	
	EDM	1.06	0.00	0.16	0.00	1.24	$\sum EDM = 2.47$
10-Sides Polygon	p_i^1	-1.45	0.00	1.90	3.00	4.90	
	p_i^2	1.24	0.00	0.03	0.00	-0.36	
	d_i	0.89	0.00	0.08	0.00	1.10	
	EDM	0.94	0.00	0.10	0.00	1.20	$\sum EDM = 2.24$
12-Sides Polygon	p_i^1	-1.41	0.00	1.93	3.00	4.93	
	p_i^2	1.41	0.00	0.02	0.00	-0.29	
	d_i	0.80	0.00	0.07	0.00	1.07	
	EDM	0.83	0.00	0.07	0.00	1.11	$\sum EDM = 2.00$
20-Sides Polygon	p_i^1	-1.41	0.00	2.00	3.00	4.98	
	p_i^2	1.41	0.00	0.00	3.00	0.16	
	d_i	0.82	0.00	0.03	0.00	1.02	
	EDM	0.83	0.00	0.03	0.00	1.03	$\sum EDM = 1.86$

In these figures straight polygons represent the approximate transmission ranges of actors, dotted line polygons are used to approximate Euclidean distance moved by the actors denoted by di. From these figures it is evident that the actors are moving to the corner of either the straight polygon or the dotted polygon. This is due to the well known result in linear programming which states ”If an optimal value exists then the value must occur at one or more of the corner points of a feasible region (Luenberger and Ye [2008])”. In Figure 2.14, polygons with 20 sides/edges are used, therefore they look like circles. From the solutions shown in the Table 2.3, it is evident that as the number of sides of the polygons increase the solution obtained is improving and getting closer to the optimal solution of the original nonlinear model.

In the second set of experiments, 4 actors are used which are positioned as shown in Figure 2.15, coordinates of those actors are given in Table 2.4.

Table 2 4: Initial Coordinates of the 4 actors

Actor i	1	2	3	4
p_i^1	0	0	6	6
p_i^2	0	2	2	0

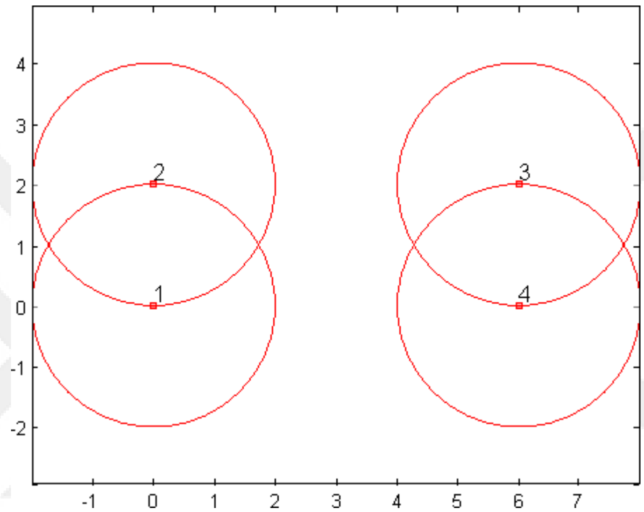

Figure 2 15: Initial positions for the 4 actors

As can be seen in Figure 2.15; in this experiment actors 1 and 2 are connected and so are actors 3 and 4. However, actors 1 and 2 cannot communicate with 3 or 4. One could argue that an intuitive solution for this problem is to move actor 2 and 3 on horizontal line between actors 1 and 4 as shown in Figure 2.16. In this solution the total distance moved will be 5.66. Note that if we chose to relocate actors 1 and 4 on a horizontal line between actors 2 and 3, the total movement distance will still be the same due to the symmetry.

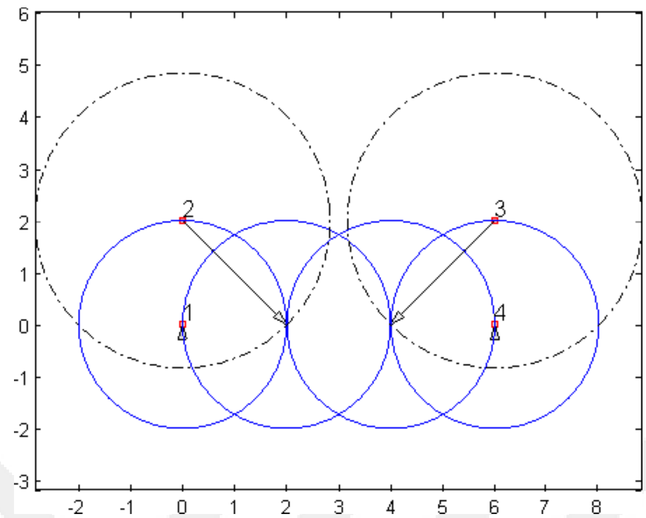

Figure 2 16: Intuitive optimal relocation positions for the given 4 actors

To confirm this intuitive solution, the approximate model ((2.36) - (2.40)) with 32-side polygon is implemented, so that the final solution will be almost equal to the actual optimal solution with negligible approximation error. As discussed earlier, increasing the number of sides of the polygons used for approximation reduces the approximation errors. Again used AMPL with CPLEX solver, to implement this example using the approximate model. A comparison of the intuitive solution and the solution from the approximate model are shown in Table 2.5. The results show that according to the approximate model solution the actors 1 and 4 are moved a little bit in the upward direction. Actors 2 and 3 are moved to get connected along an arc between actors 1 and 4 (see Figure 2.17). The total movement obtained with the approximate model was 4.96 units (significantly lower than intuitive solution which was 5.66 units). This example shows that the optimal solution of the relocation problem can be significantly better than an anticipated solution. Therefore, such optimization models are valuable to build better intuition to design heuristics for large scale problem instances,

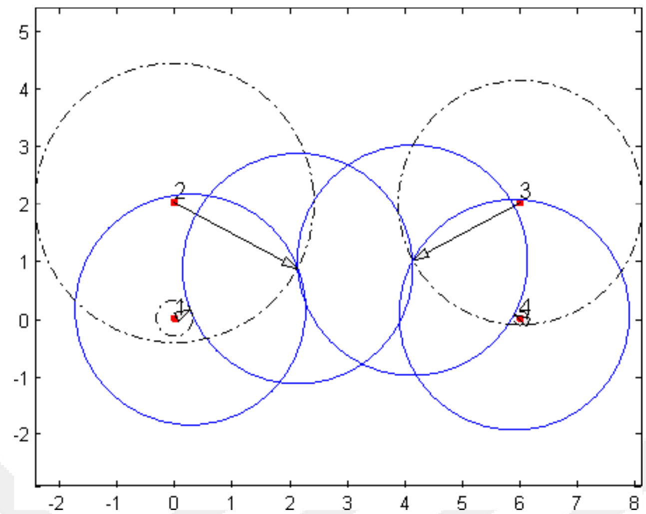

Figure 2 17: 32-Sided polygon relocation position for 4-actors.

Table 2 5: Intuitive and actual relocation positions for the given 4 actor positions

	Initial Position		Intuitive Optimal Solution			32-Sides Polygon Solution		
i	p_i^1	p_i^2	x_i^1	x_i^2	EDM	x_i^1	x_i^2	EDM
1	0.00	0.00	0.00	0.00	0.00	0.27	0.15	0.31
2	0.00	2.00	2.00	0.00	2.83	2.14	0.86	2.41
3	6.00	2.00	2.00	4.00	2.83	4.13	0.99	2.11
4	6.00	0.00	6.00	0.00	0.00	5.89	0.06	0.12
					$\sum EDM = 5.66$			$\sum EDM = 4.96$

2.12.1 Heuristics To Warm Start The Algorithm For Single Con- Nectivity

Large number of binary variables used in the MIP model makes it difficult to solve the relocation problem for larger networks. One way to decrease the solution time of the MIP model is to provide an initial feasible solution to the model. If we can provide a good starting point to the solver, then the MIP model is expected to find the solution for larger networks. To find a good starting point a heuristic method is developed, which finds a feasible solution for the given actors in no time.

2.13 WARM START HEURISTIC

For the WSAN relocation problem the simplest heuristic would be to move all the actors towards the center, but that would be a bad idea since it does not take into account the actor ranges and their positions. Therefore, in order to make it more efficient the following algorithm steps are used, which can reduce the movement of actors while moving them towards the center.

Algorithm Steps

1. Calculate the average of all the actor positions along x and y directions and determine the center of these positions. We'll refer to this points as JCenter PointJ

2. Maintain two data sets, old set and new set. Old set consists of initial actor positions; new set consists of new actor positions. Initially new set is empty.

3. Measure the distance of all the actors from their position to the center point. Rank the actors in the ascending order based on their distances from this point.

4. Select the lowest ranked actor and move it to the center point.

5. Remove the actor in consideration from old set and put it in the new data set, and record its new position coordinates. If old set is empty go to step 7.

6. Measure the distance between the actors in the old data set and actor that was added to the new data set in step 5. Select the closest actor from old data set. If its distance is greater than the transmission range, move it towards the actor from the new data set along the straight line that connects them. If the distance is less than the transmission range, do move the actor and set its new coordinates to be the original coordinates. Go to step 5.

7. Terminate the algorithm.

To realize the heuristic we run it for 13 actors whose positions are shown in Figure 2.18 .The total movement distance obtained with this heuristic was 14.9 units. Figure 2.19 shows the relocation position for the 13 actors. From the figure we can see that the heuristic is first moving the actor that is closest to the center, and then it is moving the actor which is next closest to it, to the boundary of that actor. Thereby, all the actors are moving one after the other to whichever actor it is closest in its new positions until all the actors are connected.

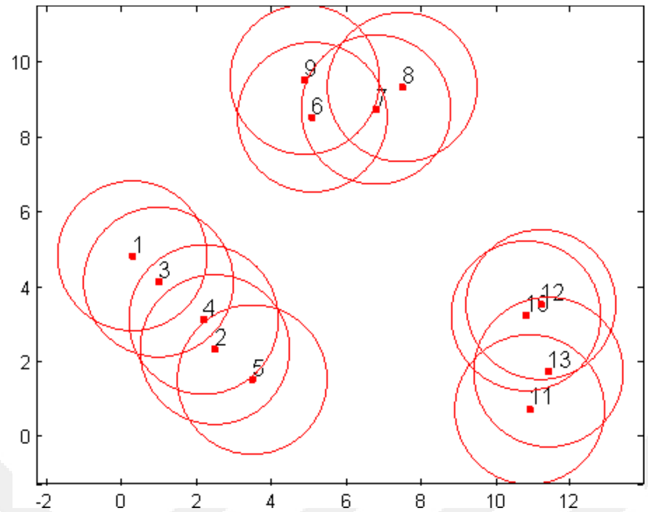

Figure 2 18: Initial Position of 13 actors

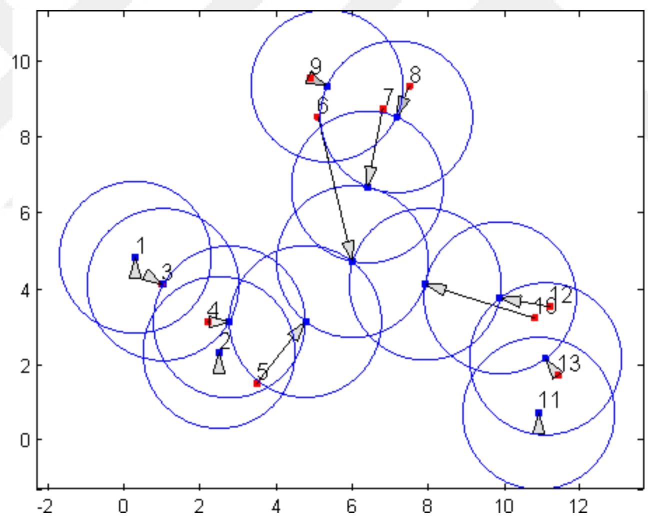

Figure 2 19: Relocation position for 13 actors using the Heuristics

This solution is used to warm start the MIP model for the given 13 actor example, with transmission range approximated by polygons of 12 edges. The optimal solution is shown in Figure 2.20. Table 2.6 shows the initial positions, heuristic solution and approximate optimal solution coordinates for the 13 actor example. From this exam- ple, the total movement distance obtained with heuristics was 14.9 units, whereas the optimal solution was 13.1 units. Even though these values may seem close, the set of actors that were relocated according to heuristic solution was significantly different compared to the set of actors that were relocated in the optimal solution. The exact model could not able to find good feasible solution without warm start, but with warm start it found the optimal solution in approximately 86 hrs with a optimal gap of 0.0096%. However, the Gurobi solver has found the optimal solution within few hrs, but at the gap4 of 75% , and to make sure that it is the best solution (to reach 0% gap) it took lot of time.

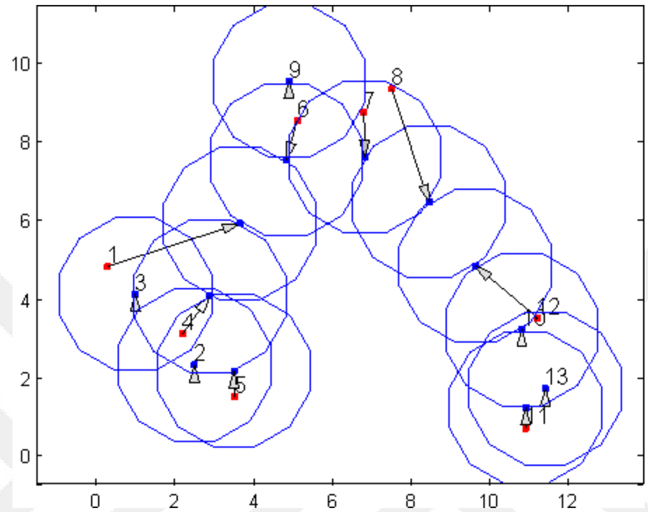

Figure 2 20: Optimal Position of 13 actors

Table 2 6: Initial, Heuristics and Optimal Positions of the 13 actors

	Initial Position		Heuristic Solution			Optimal Solution		
i	p_i^1	p_i^2	x_i^1	x_i^2	EDM	x_i^1	x_i^2	EDM
1	0.3	4.8	0.30	4.80	0.00	3.7	5.9	3.5
2	2.5	2.3	2.50	2.30	0.00	2.5	2.3	0.0
3	1.0	4.1	1.03	4.08	0.03	1.0	4.1	0.0
4	2.2	3.1	2.77	3.10	0.57	2.9	4.0	1.2
5	3.5	1.5	4.77	3.11	2.05	3.5	2.2	0.7
6	5.1	8.5	6.01	4.68	3.92	4.8	7.5	1.0
7	6.8	8.7	6.40	6.65	2.09	6.8	7.6	1.1
8	7.5	9.3	7.16	8.49	0.87	8.4	6.4	3.0
9	4.9	9.5	5.34	9.30	0.48	4.9	9.5	0.0
10	10.8	3.2	7.92	4.09	3.02	10.8	3.2	0.0
11	10.9	0.7	10.90	0.70	0.00	10.9	1.2	0.5
12	11.2	3.5	9.87	3.74	1.34	9.6	4.8	2.1
13	11.4	1.7	11.08	2.13	0.54	11.4	1.7	0.0
					$\sum EDM = 14.91$			$\sum EDM = 13.1$

2.14 BI-CONNECTIVITY FORMULATION IN WSAN

The model given in Section 2.3.1, provides an optimal solution for relocating actors with minimum total movement distance to restore connectivity. However, in certain application domains, i.e. the task carried out by the actors is critical for the success of the whole network, a more robust design may be desirable. For example, having an alternative connection path between any two actors on the network will help to make the network function without any disruption even if one of the actors fails and destroys connectivity. We refer to the problem of finding the new positions of the actors, such that there are at least two disjoint paths (i.e. the paths do not have any actors in common) exists between any two actors as the bi-connectivity problem in WSAN.

To solve the bi-connectivity problem an optimal mixed integer linear programming model is developed based on the single connectivity model from Section 2.4. In the bi-connectivity model single connectivity formulation is executed for JnJ times by removing actor i each time,∀i ∈ A. This is done to examine, whether remaining (n − 1) actors will be still connected when an actor fails. Therefore, the resulting formulation is similar to that of single connectivity formulation except that we run it for n times. Equations (2.41) - (2.52) represent the bi-connectivity formulation. The notation used in this formulation is same as the original relocation model except for the additional variable vhilj(k) defined as follows;

$$v_{hilj}(k) = \begin{cases} 1, & \text{if sensor } i \text{ and sensor } j \text{ can communicate through sensor } l, \\ & \text{within } k \text{ steps, when sensor } h \text{ fails,} \\ 0, & \text{otherwise.} \end{cases}$$

$\forall h, i, l, j \in \mathcal{A}, h \neq i \neq j \neq l, \ \forall k = \{1, 2, \ldots, n-1\}$

$$\min \sum_{i=1}^{n} d_i$$

$$\text{s.t. } (a_m)^T (x_i - P_i) \leq d_i, \ \forall i \in A, \forall m = \{1,2, \ldots, s\},$$

$$(a_m)^T (x_i - x_j) \leq \left(r_j \cos\left(\frac{\pi}{s}\right)\right) \ y_{ij}(1) + M\left(1 - y_{ij}(1)\right),$$

$$\forall i, j \in A, i \neq j, \forall m = \{1,2, \ldots, s\},$$

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{n} d_i \\
\text{s.t.} \quad & (\mathbf{a}_m)^{\mathsf{T}}(x_i - \mathbf{p}_i) \leq d_i, \quad \forall i \in \mathcal{A}, \forall m = \{1, 2, \ldots, s\}, \\
& (\mathbf{a}_m)^{\mathsf{T}}(\mathbf{x}_i - \mathbf{x}_j) \leq \left(r_j \cos\left(\frac{\pi}{s}\right)\right) \; y_{ij}(1) + M(1 - y_{ij}(1)), \\
& \qquad \forall i, j \in \mathcal{A}, \; i \neq j, \forall m = \{1, 2, \ldots, s\}, \\
& v_{hilj}(k) \leq y_{il}(k-1), \quad \forall h, i, j, l \in \mathcal{A}, h \neq i \neq j \neq l \text{ and} \\
& \qquad \forall k = \{2, 3, \ldots, n-1\}, \\
& v_{hilj}(k) \leq y_{lj}(1), \quad \forall h, i, j, l \in \mathcal{A}, h \neq i \neq j \neq l \text{ and} \\
& \qquad \forall k = \{2, 3, \ldots, n-1\}, \\
& v_{hilj}(k) \geq y_{il}(k-1) + y_{lj}(1) - 1, \quad \forall h, i, j, l \in \mathcal{A}, \\
& \qquad h \neq i \neq j \neq l \text{ and } \; \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(k) \geq v_{hilj}(k), \quad \forall h, i, j, l \in \mathcal{A}, h \neq i \neq j \neq l \text{ and} \\
& \qquad \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(k) \leq \sum_{l \in \mathcal{A} \setminus \{h,i,j\}} v_{hilj}(k), \quad h, i, j \in \mathcal{A}, h \neq i \neq j, \text{ and} \\
& \qquad \forall k = \{2, 3, \ldots, n-1\}, \\
& y_{ij}(n-1) = 1, \quad \forall h, i, j = \mathcal{A}, \; h \neq i \neq j,
\end{aligned}
$$

The equations in this model are similar to single connectivity model, Equations (2.41)- (2.43) are similar to (2.36) - (2.38) and Equations (2.44) - (2.52) are similar to (2.20) - (2.28), except for their indices.

2.15 NUMERICAL RESULTS FOR BI-CONNECTIVITY

To test the bi-connectivity model, two test problems are designed with three and four actors.

The initial locations of actors for our first test problem is given in Figure 2.21. In this example all actors are connected; however if actor-2 fails then actor 1 and 3 will not be able to communicate. Our aim is to relocate these actors, so that there are at least two unique paths between any two actors. The intuitive solution of this problem would be to move either actor-1 or actor-3 to the coordinate (2,0) with a total movement distance of 2 units. To test the bi-connectivity model, 32-sided polygons is used for Euclidean norm approximation and run the model in AMPL with CPLEX solver. The final positions of the actors obtained in the solution are shown in Figure 2.22. According to this solution, actor-1 is moved towards actor-2 (consistent with our intuitive solution) with a total movement distance of 2.01 units. This difference is caused by the approximation scheme we use for calculating Euclidean distances.

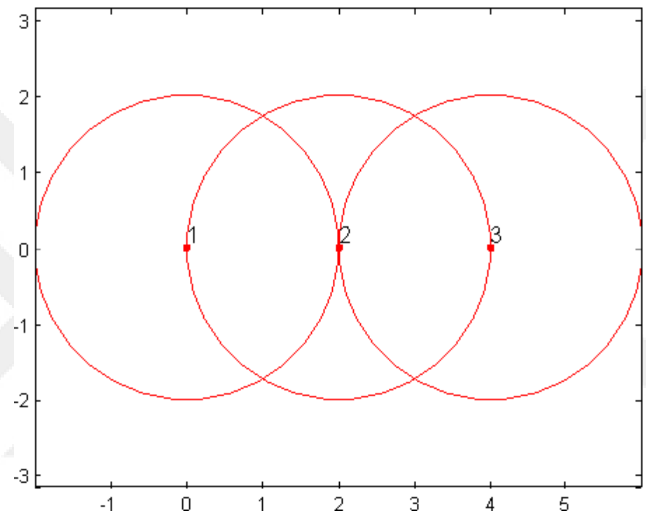

Figure 2 21: Initial position of the actors which are connected

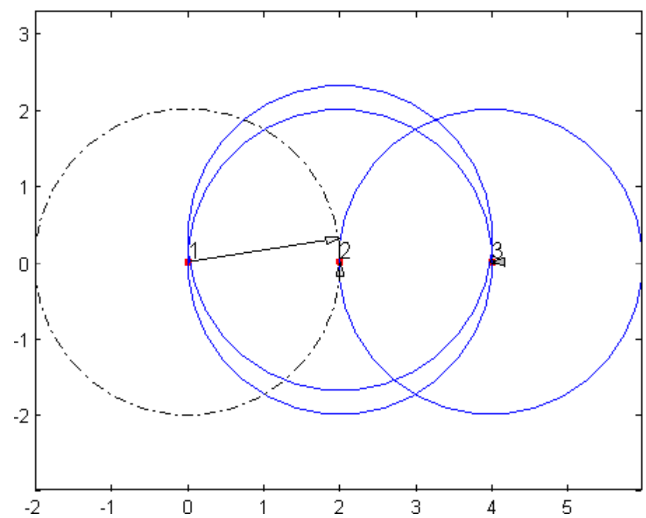

Figure 2 22: Optimal bi-connectivity relocation positions for the actors approximated 32-sides polygon.

For our second test case, a network with 4 actors are used as shown in Figure 2.23, which are positioned in T shape. It can easily be seen from the figure that the network is connected, but if actor-2 fails then the entire network gets disconnected. To find the final positions of actors from the bi-connectivity model 32-side polygons is used for the approximation scheme and run the model in AMPL with CPLEX solver. The results of the bi-connectivity model are shown in Figure 2.24. From the figure, it can easily be seen that if actor-1 fails then actors 2, 3 and 4 are still connected, same is the case for all the actors.

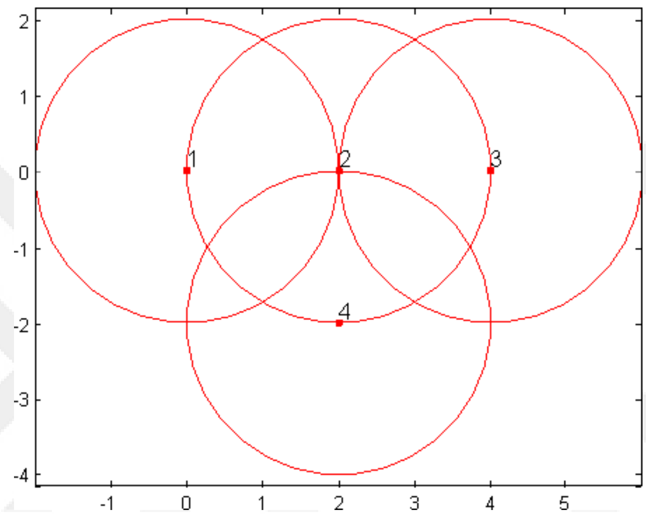

Figure 2 23: Initial position for actors connected in T-shape

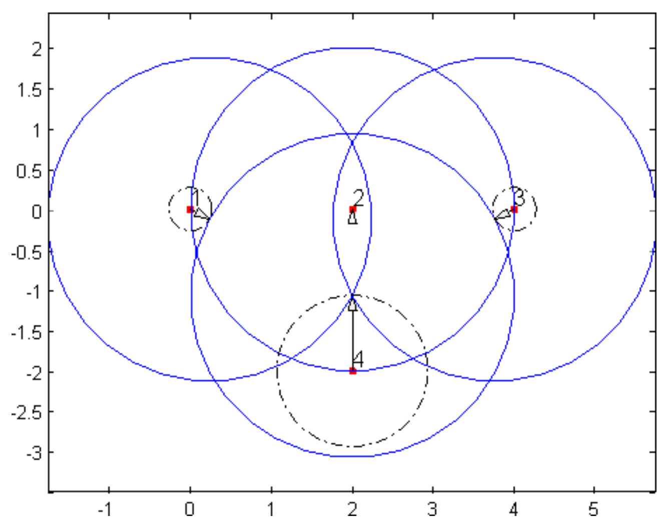

Figure 2 24: Optimal relocation position for actors connected in T-shape

Table 2 7: Initial and optimal relocation positions of the T shape network

	Initial Position		Optimal Solution		
i	p_i^1	p_i^2	x_i^1	x_i^2	EDM
1	0.00	0.00	0.236	-0.13	0.27
2	2.00	0.00	2.00	0.00	0.00
3	4.00	0.00	3.76	-0.13	0.27
4	2.00	-2.00	2.00	-1.07	0.93
					$\sum EDM = 1.47$

2.16 SUMMARY

In chapter 2, we discussed the important an optical fiber is surrounded by a cladding, which cylindrical core waveguide. Glaucoma core index above the light guided by the optical communication such cladding. In addition, this chapter study the important of used Linear Fiber Impairments and nonLinear Fiber. Moreover, this chapter summaries the previous studies compare with the exiciting works.

3. METHODOLOGY

3.1 INTRODUCTION

WSN's are used for a wide variety of applications, such as coverage, localization, tracking, synchronization and data aggregations. Coverage is an important applica- tion among them, as it is a measure of quality of service. The sensor coverage problem focuses on identifying the positions of the sensors, which can observe the surveillance area efficiently and effectively. In order to be efficient, the minimum number of sen- sors should be installed. To be effective, sensors should be positioned in such a way that every point in the surveillance area will be covered by at least one sensor.

3.2 SENSOR COVERAGE PROBLEM IN WSN

Consider a network of wireless sensors deployed in a rectangular area A. Let ri denote the sensing range of sensor i in the network. In this scenario, we consider the sensor coverage issue to cover the continuous area A, thus minimizing the total number of sensors in the network. Any of the sensor coverage optimization methods discretized Region A and solved an integer programming model to locate the sensors. The real challenge cannot be approached simply discretely since the field is constantly regarded. We built a bi-level algorithm that runs in two steps, the master problem and the subproblem in the rest of the chapter, so we could find the optimal deployment strategy for a continuous area. We first discrete region A and use the master problem to find the limited number of sensors that cover all the discrete points in the field. Then, we run the sub-issue to locate a point in the continuous field not supplied by sensors centered on the master problem solving. Every time the master problem finds locations of the op-time sensor the subproblem is run to check whether any unveiled points occur in the continuous region A. When an open point is located, a number of distinct points representing region A are applied to the original set, which are used to run the master problem. The two are working before the root dilemma is inviolable. The inability of the sub issue means that in the continuous area A, there are no uncovered points remaining. It must be remembered that the sensors are positioned in a continuous region in the master issue and that an uncovered point from the continuous region is observed in the secondary level. The method suggested in this chapter thus overcomes the limitations of discretizing regions A.

Then, in each process of the algorithm we have the descriptions of algorithmic measures and optimisation process runs.

3.2.1 The Bi-level Algorithm

We run the master problem and the sub-problem until the sub-problem is invalid. The following are the phases of this algorithm:

1. Initialization

(a) Randomly select a discrete point from region A.

(b) Set iteration count $t = 1$

2. Iteration t

(a) Master − Problem : Run the master-problem, find the minimum number of sensors and their locations to cover all the points in P , where P is points set to be covered in region A.

(b) Sub − problem : Run the sub-problem to find an uncovered point u in region A. Where the sensors positioned according to the master-problem.

(c) If the sub-problem is feasible, then set $P = P \cup \{u\}$ and go to step (2a). Else, terminate and return the most recent solution of the master-problem.

Figure 3.1 - Figure 3.5 shows how the bi-level algorithm works on a simple example. Here, circular dots represent discrete points in set P , square dots represent locations of the sensors and circles surrounding them represent their sensing ranges. Figure 3.1 shows that initially a point is selected in region A. Figure 3.2 shows that after running the master problem a sensor is placed to cover the point given in region A.

Figure 3.3, shows that sub problem found a new point which is not covered in region A. From Figure 3.4, we can see that the initial position of the sensor is adjusted to cover the two points according to the intersection of those points using MCLP approach. Figure 3.5, show the final solution obtained with the bi-level algorithm in which all the points in the continuous region A are covered.

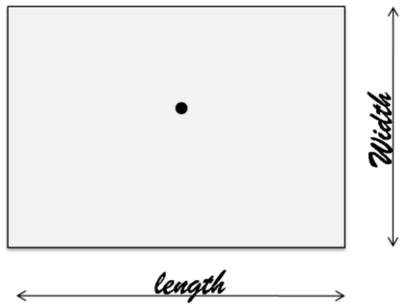

Figure 3 1: Randomly selected point in the given Surveillance area.

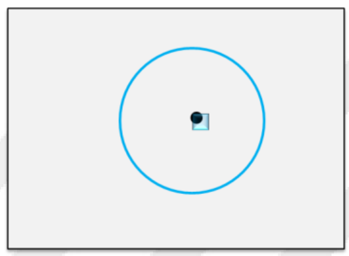

Figure 3 2: A Sensor is selected to cover the uncovered point

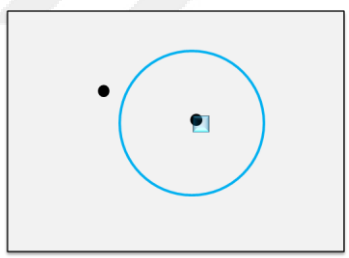

Figure 3 3: New uncovered point is found

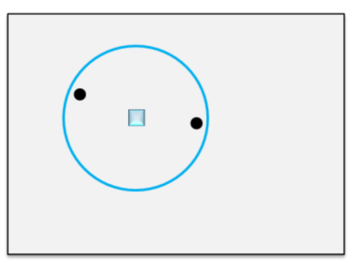

Figure 3 4: Sensor position is modified to cover the two points

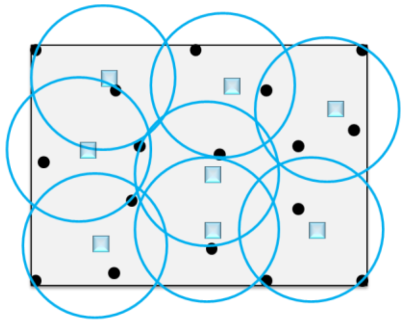

Figure 3 5: All the Points which represent the surveillance area are covered.

3.2.2 Master-Problem

We find the minimum number of sensors required to cover a certain range of distinct points in the key problem. The formulation of this dilemma is noted and optimised in the following:

Parameters:

- N : Maximum number of sensors to be deployed. We assume that there is a large number of sensors available and the subset of these sensors are to be selected to cover the finite set of discrete points
- Tp : Total number of points that need to be covered
- P = {pj, j ∈ {1, 2, ..., Tp}} : Discrete points set to be covered from region A
- M : A very large number

Decision Variables:

- $\mathbf{x}_i$: Final position of the sensor $i, i \in \{1, 2, ..., N\}$
- $y_{ij} = \begin{cases} 1, & \text{if sensor } i \text{ covers point } j \\ 0, & \text{otherwise} \end{cases}$
  $i \in \{1, 2, ..., N\}, j \in \{1, 2, ..., T_p\}$.
- $z_i = \begin{cases} 1, & \text{if sensor } i \text{ is used} \\ 0, & \text{otherwise} \end{cases}$

The Model:

$$\begin{aligned}
\min \quad & \sum_{i=1}^{N} z_i \\
\text{s.t.} \quad & \|\mathbf{x}_i - \mathbf{p}_j\| \leq r \cdot y_{ij} + M(1 - y_{ij}), \quad \forall i \in \{1, 2, \ldots, N\}, \\
& \qquad \forall j \in \{1, 2, \ldots, T_p\}, \\
& \sum_{i=1}^{N} y_{ij} \geq 1, \quad \forall j \in \{1, 2, \ldots, T_p\} \\
& y_{ij} \leq z_i, \quad \forall i \in \{1, 2 \ldots N\}, \forall j \in \{1, 2, \ldots, T_p\} \\
& y_{ij}, z_i \in \{0, 1\} \qquad \forall i \in \{1, 2, \ldots, N\}, \forall j \in \{1, 2, \ldots, T_p\}
\end{aligned}$$

Objective function (3.1) minimizes the total number of sensors to be installed. Constraint (3.2) verifies if sensor xi is capable to cover point pj. Constraint (3.3) checks if every point in the region is covered by at least one sensor. Constraint (3.4) makes sure if a point is covered by a sensor, then that sensor is selected to install.

The model given above selects the sensor positions from the continuous region A, to cover the points set of lj. However, it is shown in Church and ReVelle [1974], that in order to find the solution that may be some of the optimal positions of sensors to cover a discrete set of points, we only need to inspect a finite set of critical points rather than searching the whole region. Therefore mixed integer model is replaced by MCLP problem discussed in Church and ReVelle [1974], since its solution matches with at least one optimal solution. Next, we will explain the details of finding intersection points of the circles and mixed integer model which identifies the minimum number of sensors to deploy using the critical points. These critical points are defined to be the intersection points of the circles drawn with a radius r centered at point pj. If the circle drawn is not intersecting with any other circle then critical point of that circle is point pj itself.

Finding Critical/Intersection Points:

Here, we will explain how to find intersection points of two circles, if they intersect with each other. In Figure 3.6, two circles centered at p1 and p2 are shown. In this figure r1 and r2 represent the radii of these circles and ip1 and ip2 denote the critical points i.e. intersection points of the circles. We use the approach explained by Darby [2009] to calculate the coordinates of the critical points ip1 and ip2 as follows:

- ipc : center point of ip1 and ip2
- h : distance between ip1 and ipc
- a : distance between p1 and ipc
- b : distance between p2 and ipc
- dx : difference in the x-coordinates of points p1 and p2
- dy : difference in the y-coordinates of points p1 and p2
- d : distance between points p1 and p2 (i.e. d = (a + b))

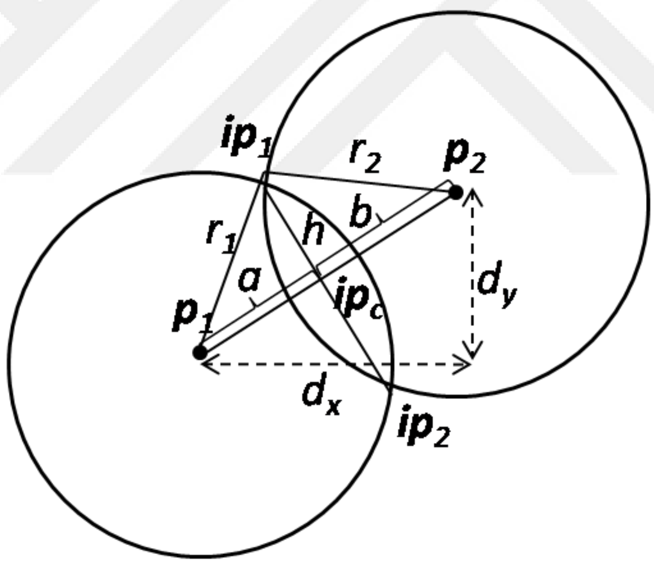

Figure 3 6: Critical points of circles centered at p1 and p2

Intersection Point 1:

$$ip_1^1 = p_1^1 + (a \cdot d_x - h \cdot d_y)/d$$

$$ip_1^2 = p_1^2 + (h \cdot d_x + a \cdot d_y)/d$$

Intersection Point 2:

$$ip_2^1 = p_1^1 + (a \cdot d_x + h \cdot d_y)/d$$

$$ip_2^2 = p_1^2 + (-h \cdot d_x + a \cdot d_y)/d$$

Using the above equations, we find intersection points for the given points set. From these intersection points, we can identify the minimum number of sensors to cover the region A using the following mixed integer formulation,

Parameters:

- Tp: Total number of points to be covered in region A

- Tc: Total number of critical points available for selection

- $c_{ij} = \begin{cases} 1, & \text{if sensor at critical point } i \text{ can cover point at location } j \\ 0, & \text{otherwise} \end{cases}$

  where, $i \in \{1, 2, ..., T_c\}$ and $j \in \{1, 2, ..., T_p\}$

Decision Variable:

- $z_i = \begin{cases} 1, & \text{if a sensor is placed at critical point } i \\ 0, & \text{otherwise} \end{cases}$

$$T_n = \min \quad \sum_{i=1}^{T_c} z_i$$

$$\text{subject to} \quad \sum_{i=1}^{T_c} c_{ij} \cdot z_i \geq 1, \qquad \forall j \in \{1...T_p\},$$

3.3 DESIGN METHODOLOGY

The software has been launched for paper creation. Figure 2 in the stream table displays the whole scheme and software steps. This paper needs research, programming and configuration as appropriate. With a summary of the planned solution and with the date of implementation of the job plan in the journal, this region will be finished.

3.4 METHODOLOGY PROPOSED

This chapter republishes the cluster's realities (Figure 2), on models of protection and communication systems.

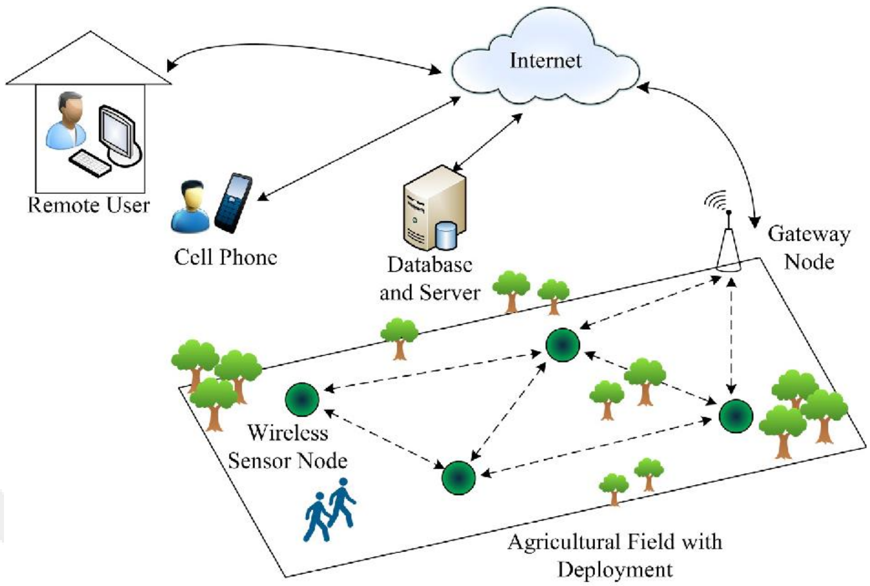

Figure 3 7: Architecture of REAL System.

Problem: Consider k anonymous (a1,a1,a2,....am) a sequence of motion elements that does not detect anything in d1,d2, Set of sensing nodes (n 1, n2).

3.5 SENSOR NODE INITIALISATION

They cannot move other than routing paths in the deployment of a sensor node, i.e. they would remain permanent, but they are susceptible to alterations due to node malfunction at any time. Figure 3 shows the sensor node trigger during each monitoring period in which each sensor node warns the area and determines the number of N individuals in its detecting area at each detection point. These sensor nodes design sensing areas in a not protected region and separately define the system status [12]

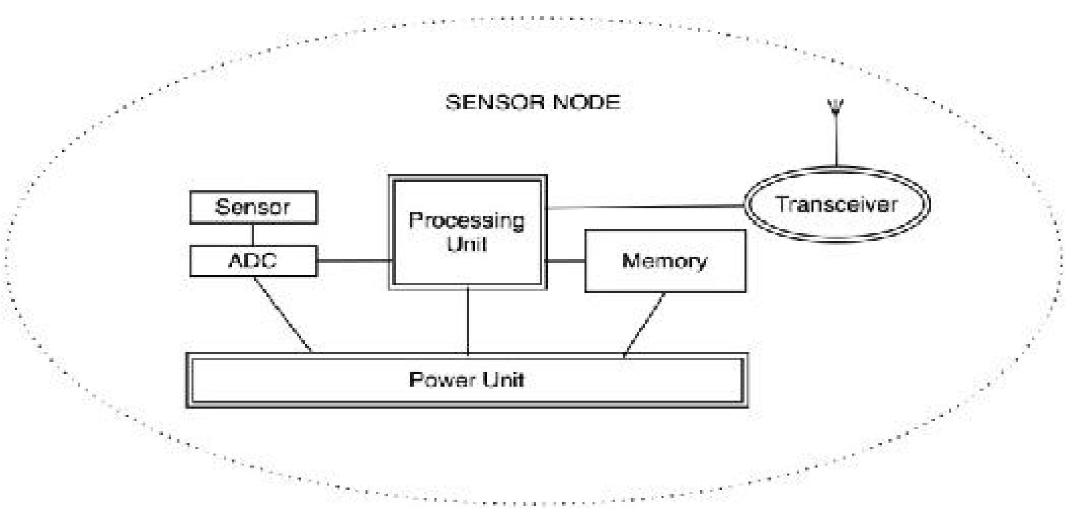

Figure 3 8: Initializing Diagram Node Sensor

4. SIMULATIONS RESULTS

4.1 OVERVIEW

We describe an intruder model, output indicators and measured methods in this section.

Intruder model: The adversary lists the amount of objects resident in a detection region utilizing the accumulated positions of the sensor nodes to determine the protection of Actual protocol in relation to privacy. If the opponent cannot deduce the detection area item count, location-based data for this component cannot be deduced. Centered on Gaussian elimination called LU decomposition, a basic model for solving a series of linear equations is used as an intruder model.

Methods calculated: Our research documents subsequently the framework conventions applied.

Alternative A sensor automatically collects neighbors and generates a combined position.

Goddamn it. The sensor scans for neighbors with the most products and forms an aggregate role autonomously.

CasperSmall The coating region of Greedy is optimized iteratively on the basis of coordination between sensor nodes until the negligible possible dimension is reached. In TinyCasper obviously:

1. A sensor node n expands the overlapping region Check for aggregate site S with core in s and maximal distance from sensor nodes in masked field Ma.
2. In the position search field, sensor nodes interact to collect data on area identification and object count.
3. Calculation expenses are minimized using Modeling Strategies.

REAL: In conjunction with the state transition, time delay and lock feature, Sensory nodes arrange their sensors in a variety of non-overlapping areas in a total of anonymous positions.

Metrics of performance: four metrics are added.

1) Attack success rate: the versatility of k-anonymity agreements to the intrusion model is calculated in this protocol. Let N be the total number of detection areas, and n be the total detection areas with less k elements according to the intruder model. Therefore, n/N is calculated as the ratio of successful attacks.
2) Question Answer Error: This strategy considers the closeness of the inquiry answers and the precision of the gatherings. Utilizing the space diagram, C is the quantity of articles

saw in the inquiry space and C is the quantity of items saw toward the start of the question space If C> 0, the blunder of wrong reaction.

3) In the event that C> 0, the response to the inquiry | Listed - c |/C; Otherwise, the mistake is recorded.

4) Average message count: That is information expense analysis. It is provided for each reporting period by a description of messages received by each sensor node.

5) Average execution time: The calculation costs for each sensor node are calculated as a variable for each reporting cycle of a global location.

4.2 WSN ANIMATOR ATTACK

Owing to the amount of job and the load in the node and the repeat length of 1 μ, which can cause a network bottleneck, kernel load delays transmission and reception over time.

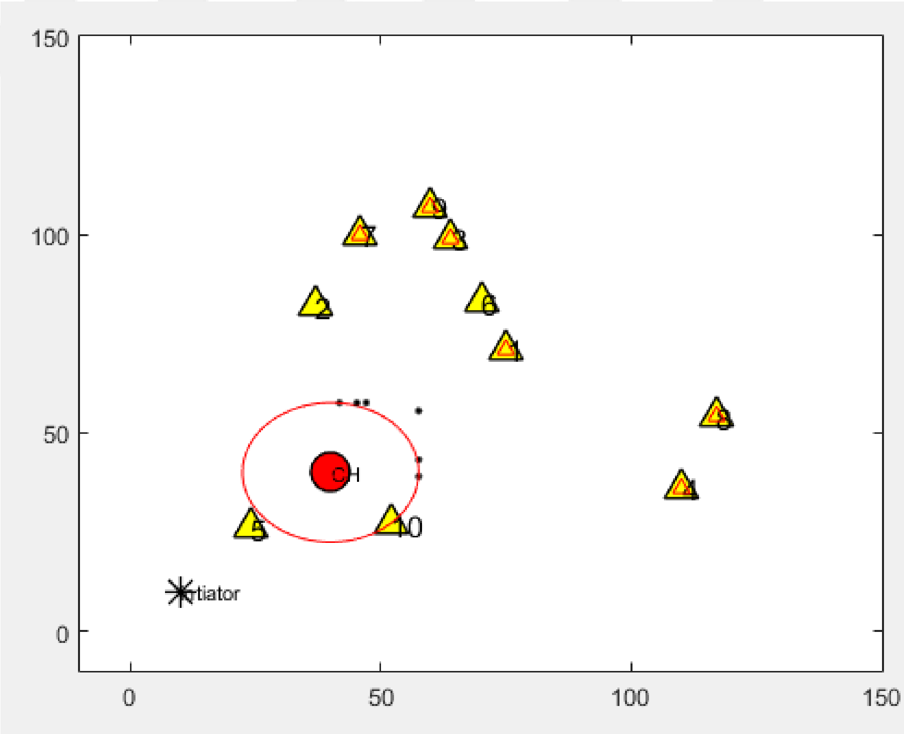

Figure 4 1: Send the node an attack.

It's 120 seconds of attack. The Node's Reaction.

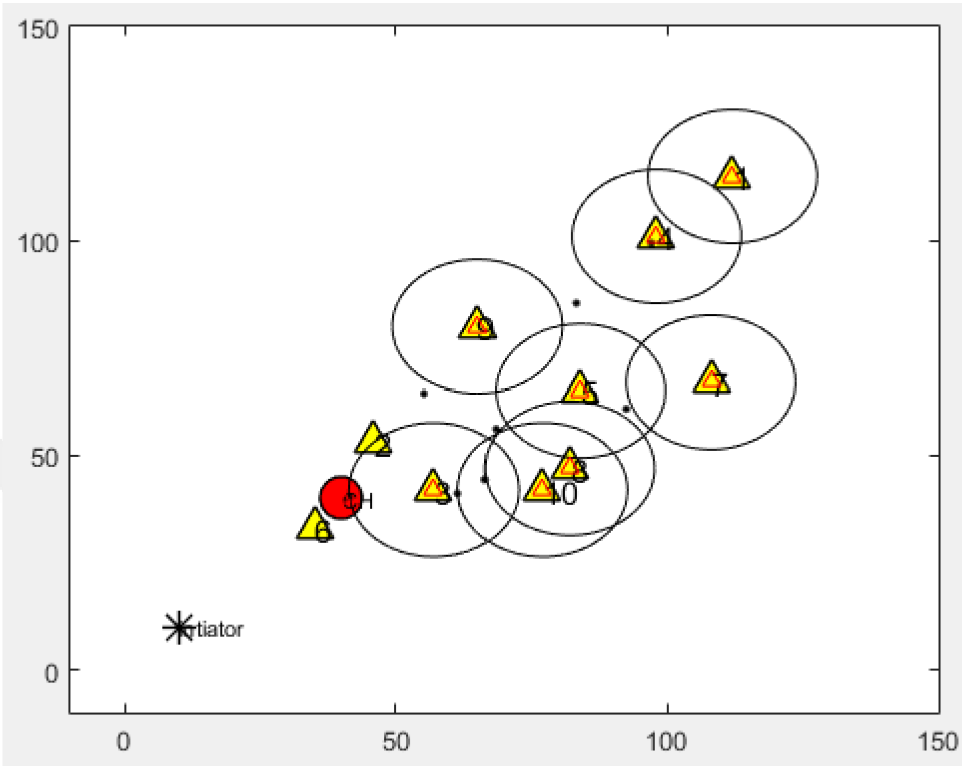

Figure 4 2: Get attack on the server.

You return many nodes to a server which are the time calculation server for the attack.

4.3 WSN RATIO SIGNAL TO NOISE

It brought about a trial that found a nearby connection between's coupling insights and sign to-commotion markers. I just utilized a Gaussian clamor correlation marker since I don't have WSN signals. Remember that the sign and sound itself impact the communication yet you need to give a thought of what you are hanging tight for [14]. The even dark tissue line addresses an estimation of 0.9958, while the vertical red tissue line addresses the 20.44 dB trial of the SNR.

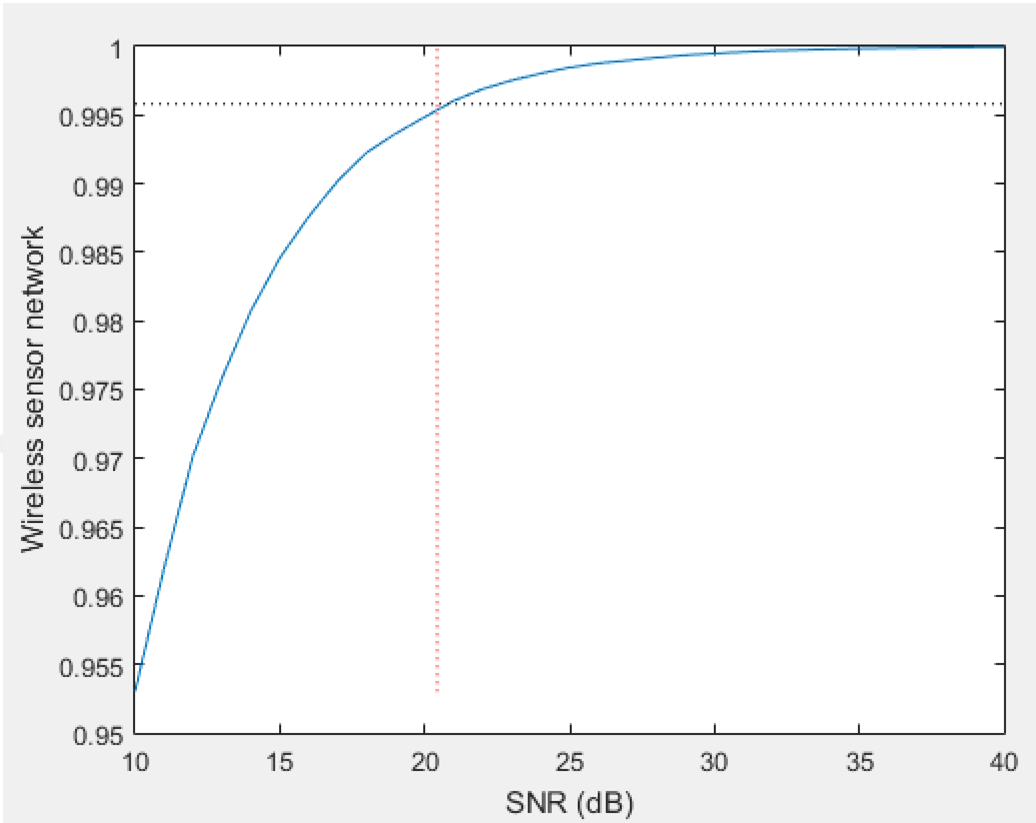

Figure 4 3: Network SNR Wireless Sensor.

The bit error rate is specified basically as the amount of incorrect bits over the total number of passed bits. There is also a very important factor when measuring the sum, such as the degree of bit errors. The graph for wrong bits produced between the node and the drain during data transmission. It is observed that with the distance between 10 and 45 m, the numbers of wrong bits decrease. The meaning of incorrect bits for the distance of 10 m is just 137 bits and for 4516 m rises.

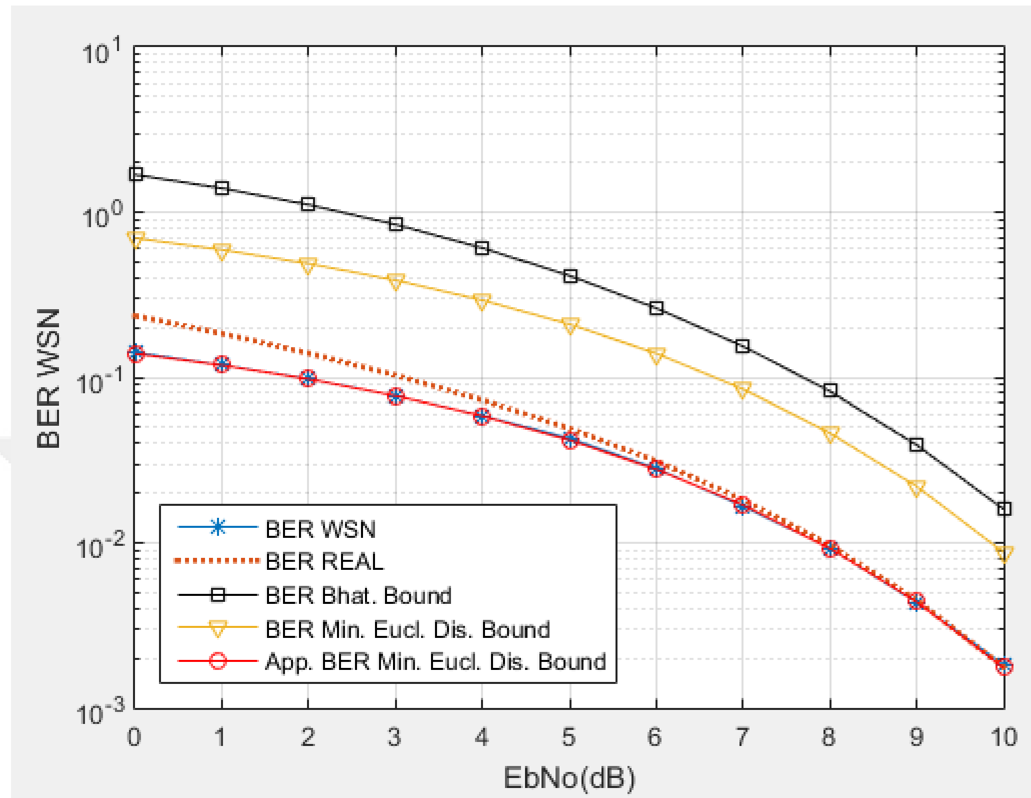

Figure 4 4: Network BER Wireless Sensor.

4.4 SUMMARY

In this section, for chapter summary the simulation results, approaching the capacity of the simulation results of the nonbinary codes for the code on the basis of speed compared to other metrics depend on the results obtained. Indeed, according to the changes in the channel, this is an accurate predictor of performance, the mutual information of the codes shown in experiments with the club. Such pre-BER and pre-FEC SER as shown uncoded norms required. GMI also not nonbinary codes, but the short-term with the Code Modulation binary soft decision FEC continues to be a good indicator. We further use of the codes used in optical communication, however, is known to be the case for the FEC schemes, mass necessary to be discussed

5. CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

In order to preserve privacy, Actual protocol proposes to include location tracking services within Wireless Sensor Networks. To solve this failure, the Actual protocol produces uncomplicated aggregate positions that obey the principle of reciprocity. A method of state change aims at self-organizing, delaying to increase the precision of the overall position and the blocking mechanism to safe contact. Two examples, i.e. 30 x 30 mall sensor nodes, and 10 x 10 sensor nodes used in a health control setting, are seen to have simulated effects. The findings demonstrate clearly that Actual guarantees anonymity in the position and delivers correct questions in both cases with lower contact and device costs.

5.2 FUTURE WORK

Even though the models developed for relocation of actors in WSAN and coverage of sensors in WSN are optimal, there are issues with the solving time of the models. To overcome these problems, we are planning to further research on methods to make our model more efficient and also to develop heuristics whose solution is near to the optimal solution.

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