

Z-PATH TRAJECTORY MECHANISM FOR MOBILE BEACON-ASSISTED
LOCALIZATION IN WIRELESS SENSOR NETWORKS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Computer Science)

Faculty of Computing
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OCTOBER 2014

To my wife Marjan, for her endless support, love and encouragement and to my lovely son Barbod, for his patience.

ACKNOWLEDGEMENT

This thesis is the result of around four years research that has been done since I came to Universiti Teknologi Malaysia. By that time, I have worked with a great number of people and it is a pleasure to convey my gratitude to them all in my humble acknowledgment.

First of all, I owe my loving thanks to my wife, Marjan, on her constant encouragement and love I have relied throughout my time at the Academy. I am indebted a lot to my lovely son, Barbod. He was divested of having me beside many times during my study. I am also deeply grateful to my father and my mother for their compassion, unconditional and emotional support throughout my study.

I wish to express my warm, sincere thanks and my deep gratitude to my supervisor Prof. Dr. Abdul. Samad Ismail. His understanding, encouraging and guidance have provided a good basis for the present thesis.

Finally I would like to give a special thanks to Professor Eryk Dutkiewicz from Wireless Communication and Networking Laboratory, Macquarie University, Sydney, Australia for providing me the guidance and valuable knowledge in wireless networks.

ABSTRACT

A wireless sensor network consists of many sensors that communicate wirelessly to monitor a physical region. In many applications such as warning systems or healthcare services, it is necessary to enhance the captured data with location information. Determining the coordinates of the randomly deployed sensors is known as the problem of localization. A promising solution for statically deployed sensors is to benefit from a mobile beacon-assisted localization. The main challenge is planning an optimum path for the mobile beacon to ensure the full coverage, increase the accuracy of the estimated position and decrease the required time for localization of resource-constrained sensors. So, this research aims at developing a superior trajectory mechanism for mobile beacon-assisted localization to help unknown sensors to efficiently localize themselves. To achieve this purpose; first, a novel trajectory named *Z-path* is proposed to guarantee fully localized deployed sensors with higher precision since the path reduces collinear beacon positions and promises shorter localization time; second, *Z-path* transmission power adjustment scheme named *Z-power* is developed to dynamically and optimally adjust the transmission power for a reliable transmission while conserving the energy consumption for localization by mobile beacon and unknown sensors; third, *Z-path* obstacle-handling trajectory mechanism is designed to improve the effectiveness of the proposed path toward obstacles which obstruct the path. Finally, the proposed *Z-path* obstacle handling mechanism is integrated with the developed power adjustment scheme to improve the energy efficiency of the designed obstacle tolerance mechanism. The performance of the proposed trajectory is evaluated by comparing the efficiency with five benchmark trajectories in terms of localization success, accuracy, energy efficiency, time and ineffective position rate, which is a newly introduced metric by this research to measure the collinearity of the trajectories. Simulation results show that *Z-path* has successfully localized all 250 deployed sensors with higher precision by at least 5.88% improvement than Localization with a Mobile Anchor based on Trilateration (LMAT) trajectory and 58% improvement than random way point. It also serves as a benchmark path with 93 ineffective positions per node localization as compared with LMAT as a second efficient path by 100 collinear positions and faster trajectory for localization. Furthermore, results revealed that *Z-power* accomplishes better performance in terms of energy consumption as an average 34% for unknown sensors and 25% for mobile beacon than *Z-path*. In case of obstacle tolerance mechanism, it ensures higher localization performance in terms of accuracy, time and success around 37.5%, 13% and 11% respectively, as compared to *Z-path* at the presence of obstacles. The handling mechanism integrated with the power control scheme has reduced energy consumption and improved ineffective position rate compared with *Z-path* handling trajectory by 35.7% and 54.4%, respectively.

ABSTRAK

Rangkaian penderia tanpa wayar terdiri daripada berbilang penderia yang berkomunikasi secara tanpa wayar untuk mengawasi satu kawasan fizikal. Dalam banyak aplikasi seperti sistem amaran atau perkhidmatan kesihatan, adalah perlu untuk menambah baik data yang diperolehi dengan maklumat lokasi. Penentuan koordinat penderia yang ditebar secara rawak dikenali sebagai penyetempatan. Satu penyelesaian kepada tebaran penderia statik ini ialah dengan memanfaatkan penyetempatan bantuan bikon bergerak. Cabaran utama ialah merancang laluan optimum untuk bikon bergerak supaya liputan sepenuhnya boleh dijamin, mempertingkatkan ketepatan kedudukan yang dianggarkan dan mengurangkan masa yang diperlukan dalam proses penyetempatan pada penderia yang mempunyai sumber terhad. Oleh itu, penyelidikan ini bermatlamat untuk membangunkan mekanisme trajektori baik untuk penyetempatan berbantuan-bikon bergerak bagi membantu penderia tak-diketahui lokasi untuk menentukan kedudukannya dengan cekap. Untuk mencapai matlamat ini; pertama, trajektori asli yang dinamakan sebagai *Z-path* dicadangkan untuk menjamin penyetempatan penderia dengan ketepatan tinggi kerana laluan ini mengurangkan kedudukan kolinear bikon dan menjanjikan masa penyetempatan yang lebih pendek; kedua, skema pelarasan kuasa penghantaran *Z-path* yang dinamakan sebagai *Z-power* dibangunkan supaya kuasa penghantaran dapat dilaraskan secara dinamik dan optimum untuk penghantaran yang boleh diharapkan di samping penjimatan penggunaan kuasa untuk penyetempatan bikon bergerak dan penderia yang tidak diketahui; ketiga, trajektori pengendalian halangan *Z-path* direka bentuk untuk mempertingkat kebolegunaan menghadapi halangan dalam laluan. Akhirnya, pengendalian penghalang *Z-path* yang dicadangkan diintegrasikan dengan skema pelarasan kuasa untuk mempertingkat kegunaan kuasa mekanisme toleransi penghalang. Prestasi laluan trajektori yang dicadangkan dinilai dengan membandingkan kecekapan dengan lima penanda aras trajektori iaitu kejayaan penyetempatan, ketepatan, kecekapan tenaga, masa dan nisbah kedudukan tak berkesan, iaitu metrik yang baru diperkenalkan untuk mengukur kolineariti trajektori. Keputusan simulasi menunjukkan *Z-path* berjaya menyetempat semua 250 penderia yang diletak dengan peningkatan ketepatan sekurang-kurangnya 5.8% berbanding *Localization with a Mobile Anchor based on Trilateration* (LMAT) trajektori dan 58% berbanding *random way point*. Ia juga menjadi laluan penanda aras dengan 93 kedudukan tak berkesan berbanding LMAT dengan 100 kedudukan kolinear dan trajektori yang lebih pantas untuk penyetempatan. Tambahan lagi, keputusan menunjukkan *Z-power* berprestasi lebih baik dari segi penggunaan tenaga iaitu secara purata 34% untuk penderia tak diketahui dan 25% untuk bikon bergerak berbanding *Z-path*. Dalam kes mekanisme toleransi penghalang, ia menjamin prestasi penyetempatan yang lebih baik dari segi ketepatan, masa dan daya jaya sebanyak 37.5%, 13% dan 11% setiap satunya berbanding *Z-path* dengan kehadiran penghalang. Mekanisme pengendalian yang disepadukan dengan skema kawalan kuasa telah mengurangkan penggunaan tenaga dan mempertingkat nisbah kedudukan tak berkesan berbanding trajektori pengendalian *Z-path* sebanyak 35.7% dan 54.4% setiap satunya.

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LIST OF ABBREVIATIONS

AoA	–	Angle of Arrival
APT	–	Accuracy-Priority Trilateration
BRF	–	BReadth-First
BTG	–	BackTracking Greedy
CDL	–	Color-theory-based Dynamic Localization
CM	–	Connectivity Metric
DFT	–	Depth-First Traversal
DGL	–	Distributed Grid-based Localization
DREAMS	–	DeteRministic dynamic bEAcon Mobility Scheduling
E-CDL	–	Enhanced Color-theory-based Dynamic Localization
EMAP	–	Extended Mobile Anchor Point
GPS	–	Global Positioning System
IMCL	–	Improved Monte Carlo Localization
LMAT	–	Localization algorithm with a Mobile Anchor node based on Trilateration
MAC	–	Medium Access Control
MAL	–	Mobile-Assisted Localization
MANET	–	Mobile Ad hoc Network
MEMS	–	Micro-Electro-Mechanical System
MCL	–	Monte Carlo Localization
MBC	–	Monte Carlo Localization Boxed
NAV	–	Network Allocation Vector
RF	–	Radio Frequency
RGB	–	Red-Green-Blue
RWP	–	Random Way Point
RSS	–	Received Signal Strength
RSSI	–	Received Signal Strength Indicator

SNR	–	Signal-to-Noise Ratio
TDoA	–	Time Difference of Arrival
TEV	–	Temporary Estimation Value
ToA	–	Time of Arrival
TPT	–	Time-Priority Trilateration
TPC	–	Transmission Power Control
WCL	–	Weighted Centroid Localization
WSN	–	Wireless Sensor Network

LIST OF SYMBOLS

P_r	–	Received power
P_t	–	Transmission power
G_t	–	Antenna gain of the transmitting antenna
G_r	–	Antenna gain of the receiving antenna
v	–	Signal velocity
$dist_{ij}$	–	Distance between node i and beacon j
H_c	–	Hop count
d	–	Resolution
l	–	Level of path
l_{p,p_i}	–	Straight line passing through p and p_i
s_i	–	Unknown sensor i
P_{s_i}	–	Position S_i
N_r	–	The number of received beacons
$b_j(x, y)$	–	Beacon coordinates
w_{ij}	–	Weight function of beacon j and sensor i
P_{rr}	–	Packet reception rate
f	–	Frame size
P_{be}	–	Probability of bit error
B_N	–	Noise bandwidth
P_{rec}	–	Reception power
P_n	–	Noise floor
F	–	Noise figure
k	–	Boltzmann's constant
T_0	–	Ambient temperature
P_L^{dB}	–	Power loss
P_{trans}^{dB}	–	Transmission power
$P_L(d)^{dB}$	–	Power loss after the signal propagation through distance d

$P_L(d_0)$	–	Power loss at the reference distance d_0
X_σ	–	Gaussian random variable
γ	–	path loss exponent
σ	–	Standard deviation
L_S	–	Localization success
L_e	–	Average localization error
R_c	–	Communication range
std	–	Standard deviation of noise
m	–	Number of successfully localized sensor nodes
n	–	Total number of unknown nodes
(x_{ei}, y_{ei})	–	Estimated location of unknown sensor s_i
I_P	–	Ineffective position
E_P	–	Effective position
N_p	–	Composition of 3 beacon positions from the received messages
I_{pr}	–	Ineffective position rate
E_{trans}	–	Energy required for transmitting message
E_{travel}	–	Energy required for traveling along the trajectory
N_t	–	Number of transmitted messages
L_{path}	–	Total path length
E_p	–	Energy consumption for traveling per 1 m
P_{rec}	–	Received power
E_{sensor}	–	Energy consumed by unknown sensor
N_r	–	Average number of received messages
L_t	–	Average localization time
$t_{loc(i)}$	–	Completed time of localization
$t_{rec(i)}$	–	Received time of the first beacon message
C_k	–	Vertex k
sq	–	Sub-square
MSG	–	Matrix formed by coordinates of three consecutive received beacons
$\frac{R_c}{d}$	–	Ratio of range to resolution
c'_k/c'_o	–	Span of communication range of mobile beacon centered at c_k/c_o
PS	–	Primary state
$N_{(c_k)}$	–	sensors neighbored with the mobile beacon at position c_k

PS_{rec}	–	Set of receiver sensors in the primary state
MS	–	Middle state
MS_{rec}	–	set of receiver sensors in the middle state
$R_{c(MS)}$	–	Transmission radius of middle state
$D_{main-sq}$	–	Diagonal of the main square
SS	–	Secondary state
SS_{rec}	–	Set of receiver sensors in secondary state
D_{sq_k}	–	Diagonal of the various sub-squares
c_k^{behind}	–	Latter beacon position which left behind before obstacle detection

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CHAPTER 1

INTRODUCTION

1.1 Overview

A Wireless Sensor Network (WSN) is formed by many resource constraint sensors communicating among them wirelessly to monitor a physical region. Application scenarios of WSNs cover a wide spectrum of areas including military, health, environment monitoring, household and commercial (Akyildiz *et al.*, 2002; Borges *et al.*, 2014; Karray *et al.*, 2014; Deif and Gadallah, 2014). Some of the military applications of WSNs are enemy reconnaissance and attack detection, and battle damage assessment. In the health area a typical crucial application of sensor networks is to support the elderly. Forest fire detection, monitoring disaster area, and target or animal tracking are few examples of environmental monitoring applications of WSNs. In these scenarios, just to mention a few, the reported event is meaningful and can be responded to only if the event position is known. Thus, the collected data must be tagged with the location information where the data is attained. The process of determining physical coordinates of a sensor node or the spatial relationships among objects is known as localization (Mao *et al.*, 2007; Amundson and Koutsoukos, 2009; Han *et al.*, 2011a; Gu *et al.*, 2013).

Global Positioning System (GPS) is a commonly used and precise method for localization (Qu and Zhang, 2011; Drawil *et al.*, 2013). Unfortunately, the GPS solution for WSN is neither cost-effective nor energy-efficient. Additionally, the

deployment-ability of sensor nodes which are equipped with GPS may be reduced due to the increased size. Finally, these GPS-equipped sensors have limited applicability because GPS works only in an open field (Bulusu *et al.*, 2000; Bours *et al.*, 2014). Localization algorithms can relieve the problem where they are able to estimate the location of sensors by using the position information of some portions of sensors. Generally, these small proportion of location-aware sensors (either equipped with GPS or installing at a fixed position) are called *beacons*. The rest of the sensors that need to be localized are called *unknown nodes*.

WSNs can also be applied for missions where human operation is impossible (e.g., under the ocean). So, installing beacon nodes in a predetermined location is often infeasible. This means that, beacon nodes equipped with GPS receivers must be employed for localization. Another observation is that the precision of the localization increases with the number of beacons (Bulusu *et al.*, 2000; Savvides *et al.*, 2001), but they increase the energy consumption and the overall cost of the WSN (Popescu *et al.*, 2012; Yaghoubi *et al.*, 2014; Popescu *et al.*, 2014).

Considering all the aforementioned problems, the motivation behind this research is to investigate how a single mobile beacon can be employed as an alternative solution to localize the entire network.

Since the accuracy provided by the localization algorithms is the most critical issue, higher precision should be considered by the promised solution (Xu *et al.*, 2013; Zheng *et al.*, 2014). Comparatively, localization through the use of a mobile beacon is inherently more accurate and cost-effective than localization using static beacons (Sichitiu and Ramadurai, 2004; Ssu *et al.*, 2005; Lee *et al.*, 2009). The mobile beacon travels around the region of interest where unknown sensor nodes are deployed and transmits the beacon messages which include its location information (Ou and He, 2011).

Taking advantages of such a mobile beacon in location estimation is of importance. Since mobile beacon-assisted localization algorithms offer significant practical benefits, a fundamental issue is finding an optimum path for mobile beacon trajectory to take advantage of such an architecture. Consequently, the mobile beacon-assisted localization problem is limited to finding an optimum beacon trajectory (Tang and Zhong, 2012; He *et al.*, 2013). To mitigate this problem, various properties of an optimum trajectory of the mobile beacon node need to be investigated.

A carefully selected deterministic trajectory can guarantee that all the unknown sensors receive beacon messages and obtain estimation for their positions, as the basic condition. On the other hand, traveling along a poor trajectory may cause certain unknown sensors not to be localized due to being far away from the trajectory. The discussed limitations lead the research to the design and development of an optimized trajectory mechanism for mobile beacon assisted localization in WSN to improve the overall performance of the localization.

1.2 Background

There has been a large body of research on localization for wireless sensor networks over the last decade. Most existing localization schemes for WSNs are classified based on a key classification into two main groups: range-based or range-free. Range-free techniques only use connectivity information between sensors and beacons. Bulusu *et al.* (2000), He *et al.* (2003) and Niculescu and Nath (2003b) proposed some range-free methods. Range-based techniques use distance or angle estimates for localization, such as methods proposed by Priyantha *et al.* (2000), Bahl and Padmanabhan (2000) and Niculescu and Nath (2003a). Although it is a comprehensive categorization of localization algorithms, it is not distinct enough for further research in the presence of mobile beacon nodes and mobile sensor nodes. In

a wide range of applications, a fully static network is not realistic. One solution is to let localization algorithms benefit from node mobility. To capture this possibility, this research reclassifies localization methods with respect to the mobility state of beacons and sensor nodes, as shown in Figure 1.1.

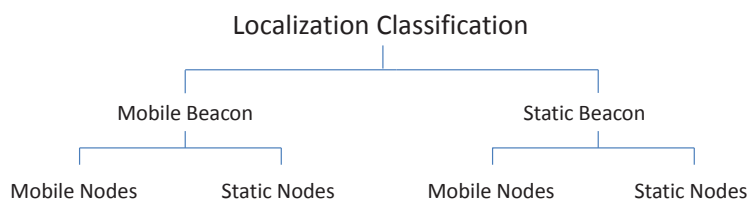


Figure 1.1: Localization classification (based on mobility feature)

As illustrated in this figure, localization methods can be classified into four groups: (1) static beacons and static nodes such as the methods proposed by Mao *et al.* (2007), Han *et al.* (2011a) and Patwari *et al.* (2003); (2) static beacons and mobile nodes such as the schemes proposed by Bulusu *et al.* (2000); (3) mobile beacons and static nodes, as proposed by Sichitiu and Ramadurai (2004), Ssu *et al.* (2005), Chen *et al.* (2010), and (4) mobile beacons and mobile nodes like the methods proposed by Hu and Evans (2004) and Baggio and Langendoen (2008).

This research focuses on the category of mobile beacons with static sensor nodes, because this kind of localization promises a wide spectrum of application scenarios. An example can be a military application or a monitoring task like fire detection, where sensor nodes are dropped from a plane on land, and transmitters are attached to soldiers or animals acting as mobile beacons. Localization studies with mobile beacons generally focus on two major problems, proposing an efficient localization algorithm and developing an optimum mobile beacon movement strategy. Sections 1.2.1 and 1.2.2 briefly survey representative methods for both issues.

1.2.1 Mobile Beacon, Static Nodes Localization Algorithms

A key paper presented by Sichitiu and Ramadurai (2004), has localized static nodes based on the RSSI of a mobile beacon and Bayesian inference. The paper employed statistical principles for processing the received information from mobile beacon, instead of imposing geometrical constraints. The major drawback of the scheme is its relatively high computation complexity which increases energy consumption. Ssu *et al.* (2005) proposed a prior method for localization of static sensor nodes with four mobile beacons. Obstacles in the sensing field are tolerated, although it causes radio irregularity. The major drawback of the mechanism is its long execution time and high beacon overhead. In order to further improve localization accuracy in Ssu's scheme, Lee *et al.* (2009) proposed another geometric constraint-based localization method. Only one mobile beacon moves around the network field. The main drawback of this scheme is increasing location error with longer communication range. Another mobile-beacon assisted localization method has been proposed by Guo *et al.* (2010) which utilizes the geometric relationship of the perpendicular intersection to compute node positions. The design was extended by a new mobile beacon which is made up of a rotating arm and wheels to handle obstacle-resistance problem in the network field. The extended design suffers from the extra cost while it requires the extra hardware. Ou (2011) presented an approach for locating static sensor nodes by means of mobile beacon nodes equipped with four directional antennas. Obstacles were taken into account in the proposed range-free localization method. The method is efficient where the sensor nodes have no specific hardware requirements.

1.2.2 Mobile Beacon Trajectories

The main concern for developing an optimum trajectory for mobile beacon assisted localization is how to find the optimal path for the mobile beacon. Some fundamental properties of an optimum beacon path have been introduced by Sichitiu and Ramadurai (2004). According to Sichitiu and Ramadurai (2004), all unknown

sensors must fully covered by at least three non-collinear beacon messages. Indeed, beacon positions symmetric to a straight line will be equally probable and the unknown node will not be able to determine on which side of the line the node lies. These in-line messages are known as collinear messages and at least one non-collinear beacon message must be received for localization (Sichitiu and Ramadurai, 2004; Huang and Zaruba, 2007; Han *et al.*, 2011b). Several trajectories for mobile beacon assisted localization have been surveyed by Han *et al.* (2011a). Here, a brief review is presented on the existing mobile beacon trajectories for localization.

Scan, Double Scan, and Hilbert space filling curve are three well-known trajectories proposed by Koutsoukoulas *et al.* (2007). All these path types can successfully achieve higher precision location estimation than Random Way Point (RWP) (Sichitiu and Ramadurai, 2004; Camp *et al.*, 2002). However, their accuracy directly depends on the resolution of the trajectory (the distance between two successive beacon positions). All the above path types can cover the network field, but Scan suffers from collinearity (beacon messages as transmitted by the mobile beacon node when it moves on a straight line). To solve the above problem, Double Scan was proposed to traverse the field along both directions at the expense of doubling the distance. A Hilbert space filling curve was then proposed to reduce the collinearity without significantly increasing the path length, but a new problem arises. Sensors located near the border of the deployment area are not able to estimate their locations. So, coverage is not fully achieved by this approach and error will be increased.

CIRCLES and S-CURVES were proposed by Huang and Zaruba (2007) to reduce the amount of straight lines and mitigate the collinearity problem of trajectory mechanisms. Although they produce the shortest path length amongst other methods, CIRCLES leaves the four corners, uncovered. However, CIRCLES can cope with the problem but at the expense of longer path and as a result, higher energy consumption. A spiral trajectory for mobile beacon was proposed by Hu *et al.* (2008). The trajectory has trivial differences with CIRCLES and effectively solves the collinear problem as well the localization accuracy. However, the trajectory suffers from long path lengths and uncovered areas near the border of the network field.

Han *et al.* (2011b) introduced a trajectory for localization based on trilateration. The mobile beacon moves according to an equilateral triangle to broadcast its current position. The path type successfully copes with the collinear beacons problem but it cannot maintain the trajectory through the whole network field. It causes to increase the localization error on the border of the deployment area. Moreover, the path length traveled by the mobile beacon is long.

Ou and He (2011) have proposed a Scan-based trajectory which can be directly applied to the localization method proposed by Ssu *et al.* (2005) to meet the specific requirements of the localization method. Moreover, the obstacle resistant trajectory has been considered to handle the obstacles where the obstacles can block the mobile beacon trajectory.

Even all the proposed methods make the beacon movement possible along the statically deterministic trajectories without the reference to the actual distribution of the unknown nodes, several real time or dynamic trajectory schemes were introduced by Li *et al.* (2012), Li *et al.* (2008) and Chang *et al.* (2012) to consider the real distribution of the sensor nodes. The major drawback of real time schemes in localization is the high numbers of message exchanges and high energy consumption.

It could be concluded that a considerable research attention has been attracted to designing movement trajectories for mobile beacon-assisted localization, since a carefully designed deterministic trajectory can guarantee the higher performance of location estimation, as opposed to a random movement.

1.3 Problem Statement

A well studied deterministic trajectory for mobile beacon-assisted localization in a real environment is desired to ensure that all the unknown sensors receive sufficient numbers of non-collinear beacon messages for maximum localization precision and minimum energy cost. The existing designed trajectory mechanisms have some limitations which are briefly addressed here. First, accuracy, as the critical goal of localization techniques is not successfully obtained, especially in a real environment. A node is best localized if the trajectory is close to that node since the RSS is higher. But, this property is not sufficient to guarantee the precision of localization because the RSS is dominated by the environmental interference. The signal may also be scattered by the obstacles and thus, increase the estimated error. Accordingly, a reliable channel and radio model is crucially demanded to improve the accuracy of localization, especially at the presence of obstacles. The obstruction in the sensing field cannot be tolerated by most of the trajectories even though the path is blocked by these obstacles. Second, the existing paths left the uncovered area by the mobile beacon in the network field which cause to a lower localization success. Next, collinear beacon messages are a critical issue in the existing trajectories which demands further investigation. These useless messages not only impair the precision of the localization but also increase the time and energy consumption. The above limitations lead this research to address the problem of finding a trajectory mechanism traveled by the mobile beacon in order to localize the statically deployed unknown sensors in real environment with higher precision and lower energy consumption. Considering the stated problem, the research hypothesis can be expressed as follows:

The accuracy and energy efficiency of the location estimation of statically deployed unknown sensors in WSN can be significantly improved if the traveling path of the mobile beacon is planned to pass close to the sensors for transmitting non-collinear beacon messages and further, the optimum transmission power can be achieved.

1.4 Research Questions

The above research hypothesis leads to address the following research questions:

- i. How to significantly improve the accuracy of the location estimation of statically deployed unknown sensors in WSNs using a mobile beacon assisted localization?
- ii. How to optimize the consumed energy of both mobile beacon and unknown sensors while the mobile beacon is traveling along the predefined movement pattern without incurring the obtained location precision?
- iii. How to handle the possible deficiency of the trajectory in the presence of obstacles in real environment so as to increase localization success and accuracy?
- iv. How to test the validity and efficiency of the developed trajectory mechanism, the proposed power adaptive scheme and the obstacle handling trajectory mechanism, as compared with the existing proposed trajectories in terms of accuracy, collinearity, success, energy efficiency and time.

1.5 Aim

This research aims at designing and evaluating a superior trajectory mechanism for mobile beacon assisted localization to help statically deployed unknown sensors to localize themselves with higher precision, shorter localization time, least possible collinear positions and lower energy consumption for both obstacle-free and obstacle-presence environments.

1.6 Objectives

The following objectives are specified to optimize a movement trajectory for mobile beacon assisted localization in WSNs, as the goal of the research:

- i. To design and evaluate a superior trajectory mechanism for mobile beacon to enhance unknown sensors localization which are statically deployed through WSNs in order to minimize the localization error while obtaining minimum number of collinear messages through shorter localization time.
- ii. To design and evaluate a transmission power adjustment scheme for the trajectory proposed in (i) towards achieving a power conservation trajectory mechanism.
- iii. To design and evaluate an obstacle-handling trajectory support for the proposed trajectory mechanisms in (i) and (ii) towards improving the usefulness of the localization technique at the presence of obstacles in the real environment.

1.7 Scope

The scope of this research has following assumptions and limitations:

- i. The large amount of unknown sensor nodes are deployed randomly. The sensors are static and silent while do not transmit any messages for localization.
- ii. A single mobile beacon is employed to help localization. The mobile beacon obtains its position coordinates via a Global Positioning System (GPS) which

is equipped. The mobile beacon traverses through the network with different moving speed.

- iii. The mobile beacon travels along a deterministic trajectory and broadcasts its current location at the predefined positions to help localization. The boundaries of the field are known by the mobile beacon.
- iv. The mobile beacon-assisted sensor localization is able to adjust its output power during localization.
- v. Both obstacle-free and obstacle presence environments are considered by this research. In obstacle presence environment, 10% of the network field is covered by obstacles.
- vi. The mobile beacon is able to detect unknown obstacles within its communication range while it is equipped with a compass.

1.8 Significance of the Study

Localization, with a high degree of precision, is an essential service for WSN and demands a significant improvement since it is a critical requirement for different applications and services. Employing a single mobile beacon to assist localization is promising while it is both energy efficient and cost effective. The beacon traverses around the network field and transmits its location information to cover the area and help localizing unknown sensors which are statically deployed. However, the main problem is how to find an optimum movement trajectory to benefit from the mobile beacon location information to successfully and precisely localize the unknown sensors. A carefully designed trajectory ensures all the unknown sensors are able to receive sufficient, highly precise and non-collinear beacon messages while keeping shorter time for location estimation. This research can assure a superior trajectory mechanism to assist the unknown sensors to localize themselves precisely, energy efficiently, successfully and timely.

1.9 Research Contributions

As stated above, the aim of the research is to significantly improve the efficiency of localization problem using a single mobile beacon messaging its location information into static unknown sensors. Therefore, the research targets to design and develop an optimized trajectory mechanism for mobile beacon assisted localization in WSNs. So, the following contributions are achieved.

- i. A superior trajectory mechanism for mobile beacon assisted localization named *Z-path* to assist unknown sensors location estimation successfully, accurately and timely.
- ii. A critical metric named Ineffective Position Rate to analyze the effectiveness and efficiency of movement trajectories for mobile beacon assisted localization in terms of the ratio of collinearity.
- iii. A reliable and realistic wireless channel and radio model in order to transmit a beacon message for localization through the network.
- iv. An optimum transmission power adjustment scheme named *Z-power* to minimize the required power for a reliable transmission of beacon messages by the mobile beacon traveling along *Z-path* trajectory mechanism.
- v. A novel mathematical definition for theoretically analysis the relation between the distance of sender and receiver with the required optimum transmission power of the mobile beacon assisted localization traveling along a static trajectory.
- vi. An obstacle-handling trajectory mechanism to further enhanced the effectiveness and efficiency of the proposed trajectory mechanism in an environment where the path is obstructed by the obstacles.

1.10 Thesis Organization

The thesis contains 7 chapters organized as in Figure 1.2.

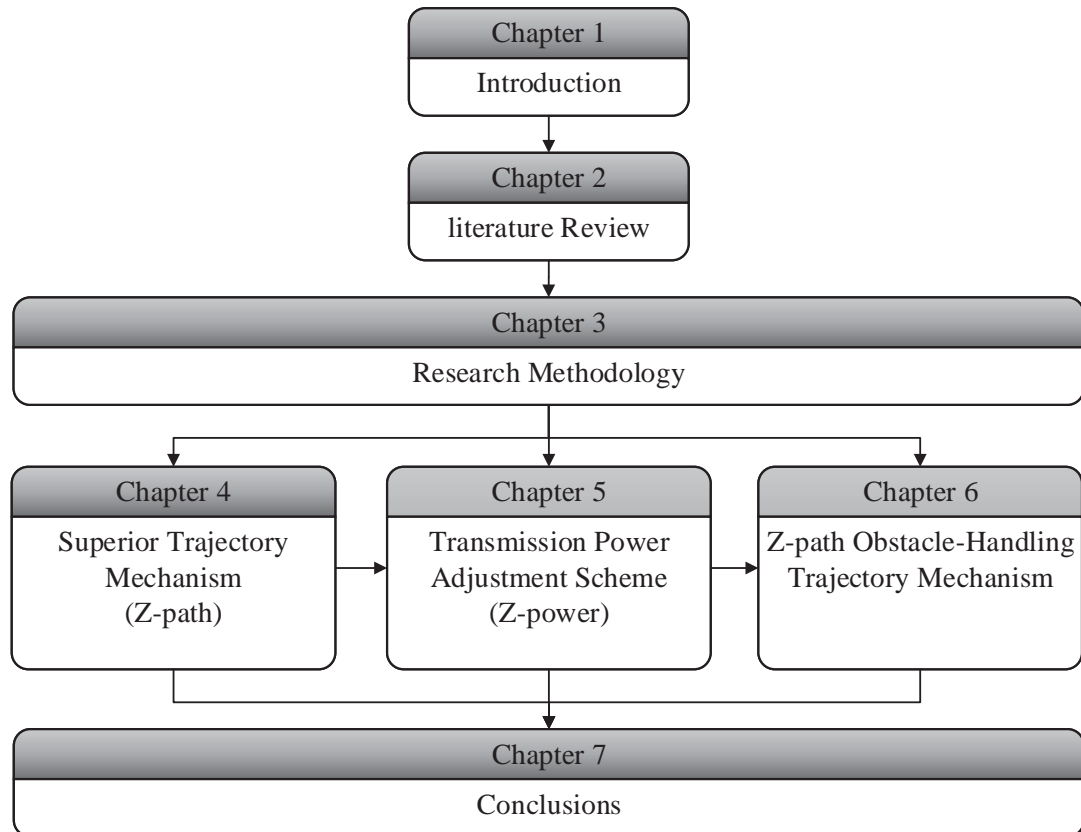


Figure 1.2: Thesis organization

Chapter 1 introduces the research study. Chapter 2 provides the extensive literature review related to this research. Chapter 3 presents the methodology adopted in this research. Chapter 4 explains the design and development of a superior trajectory mechanism for mobile beacon-assisted localization in WSN named *Z-path*. Chapter 5 addresses the design and development of *Z-path* transmission power adjustment scheme. Chapter 6 is dedicated to design and development of *Z-path* obstacle handling trajectory mechanism. Chapter 7 concludes the thesis by a summary of contributions and presents the possible future directions.

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