

LB/NO 2/33/09

DATABASE CORRELATION FOR GSM LOCATION IN OUTDOOR AND INDOOR ENVIRONMENTS

A dissertation submitted to the
Department of Electronic and Telecommunication Engineering,
University of Moratuwa
in partial fulfilment of the requirements for the
degree of Master of Science in Telecommunication Engineering

LIBRARY
UNIVERSITY OF MORATUWA, SRI LANKA,
MORATUWA



By
University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk
B.D.SHASHIKA LAKMALI

Supervised by: Professor Dileeka Dias

621.38 "08"
621.39 (043)

Department of Electronic and Telecommunication Engineering,
University of Moratuwa, Sri Lanka

February 2008

University of Moratuwa



92929

92929

92929

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

Name of Candidate: B D Shashika Lakmali
Date: 26th February 2008

I endorse the declaration by the candidate.

UOM Verified Signature

Name of the Supervisor : Professor Dileeka Dias



CONTENTS

Declaration	i
Abstract	v
Dedication	vi
Acknowledgement	vii
List of Figures	viii
List of Tables	x
List of Principal Symbols	xiii
1. Introduction	1
1.1 Motivation	1
1.2 Objectives and Scope	4
1.3 Structure of Thesis	4
2. Statement of the Problem	6
2.1 Preliminaries	6
2.2 Problem Identification	6
3. Background	8
3.1 Overview of Cellular Positioning	8
3.1.1 Positioning Parameters	8
3.1.2 Positioning Technologies	12
3.1.3 Performance Measures	15
3.2 Basics of GSM	16
3.2.1 GSM Network Architecture	17
3.2.2 GSM Air interface	18
3.3 Survey of Previous Work	19
4. Proposed Methodology	23
4.1 Background for Database Correlation	23
4.2 Fingerprint Collection	24
4.2.1 Outdoor Fingerprint Collection	24
4.2.2 Indoor Fingerprint Collection	27
4.3 Positioning methodology	28
4.3.1 Effect of the number of measurements	29

4.3.2 Fingerprint Filtering	30
4.3.3 Fingerprint Matching Techniques	32
4.3.3.1 Deterministic Algorithms	33
4.3.3.2 Probabilistic Algorithms	37
4.3.4 Location Estimation Method	42
4.4 Database Preparation	44
5. Measurement Trial	47
5.1 Equipment	47
5.2 Outdoor Measurement Trials	48
5.3 Indoor Measurement Trials	50
5.3.1 Building 1	51
5.3.2 Building 2	53
6. Results and Analysis	55
6.1 Results of Outdoor Positioning	55
6.1.1 Results of Urban Trial	57
6.1.1.1 Nearest Neighbor (NN) approach	57
6.1.1.2 Weighted k Nearest Neighbor (WkNN) approach	58
6.1.1.3 Comparison	60
6.1.2 Results of Suburban Trial	62
6.1.2.1 Nearest Neighbor (NN) approach	62
6.1.2.2 Weighted k Nearest Neighbor (WkNN) approach	63
6.1.2.3 Comparison	65
6.1.3 Results of Rural Trial	67
6.1.3.1 Nearest Neighbor (NN) approach	67
6.1.3.2 Weighted k Nearest Neighbor (WkNN) approach	69
6.1.3.3 Comparison	71
6.2 Results of Indoor Positioning	73
6.2.1 Results of Building 1	75
6.2.1.1 Deterministic Approach	76
6.2.1.1.1 Nearest Neighbor (NN) approach	76
6.2.1.1.2 Weighted k Nearest Neighbor (WkNN) approach	77

6.2.1.2 Probabilistic Approach	80
6.2.1.3 Comparison	81
6.2.2 Results of Building 2	82
6.2.2.1 Deterministic Approach	83
6.2.2.1.1 Nearest Neighbor (NN) approach	83
6.2.2.1.2 Weighted k Nearest Neighbor (WkNN) approach	84
6.2.2.2 Probabilistic Approach	87
6.2.2.3 Comparison	88
6.3 Analysis and Evaluation	89
7. Conclusion and Future Work	93
7.1 Conclusion	93
7.2 Future Work	94
References	96



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Abstract

Accurately estimating the location of a Mobile Station is a key requirement to effectively provide a wide range of Location Based Services over mobile network. Since the mobile phone has become a common device in today's society, location based services are very popular among cellular subscribers. Hence developing cellular positioning techniques has been a key research problem and numerous localization solutions have been proposed. These include technologies such as Cell ID, angle and time of arrival methods and fingerprinting methods.

This thesis presents fingerprinting based positioning techniques suitable for different outdoor and indoor environments. Thus multiple positioning techniques are proposed, implemented and evaluated for different environments. Three outdoor trials in areas falls under urban, suburban and rural areas and two indoor trials in two multi storey buildings were used for evaluation. The ultimate solution proposed in this thesis is not a single positioning technique; rather it presents several positioning techniques that achieve optimum performance in each test environment.



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

This thesis proposes a novel fingerprint collection process for outdoor positioning and introduces a more accurate correlation algorithm. This thesis reports 67% positioning error as 112 m, 299 m and 221 m for urban, suburban and rural areas respectively. Experimental results show that the proposed positioning methods achieve accuracy far better than Cell-ID and trilateration approaches for the tested network environments especially for rural area. The 67 % positioning error for rural area is 1045 m and 1386 m with basic Cell-ID and trilateration techniques while proposed fingerprinting based technique reports 67% positioning error as 221m.

With indoor positioning this thesis reports 50% positioning error as 20.5m and 8.7m for the selected two buildings. Also it was possible to accurately differentiate between floors in these multi storey buildings. Results achieved for Building 2 is reasonable when compared with the results reported in a similar study by Veljo Otsason *et al.* (2005).

*To all my teachers,
for their support, encouragement and guidance*



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

*To my parents,
for their love, understanding and encouragement*

Acknowledgement

This research would not have been possible without the extremely valuable support and continuous guidance of my supervisor Professor Dileeka Dias. Thank you very much for encouraging me to be successful in this research. I would also like to express my gratitude to the Research Coordinator Dr. Ajith Pasqual and all the staff members of Department of Electronic and Telecommunication Engineering, University of Moratuwa for their comments and advice.

I am grateful to Dialog Telekom Ltd for their sponsorship of this research and providing access to their GSM network. I would also like to thank Head of Computer Science and Engineering Department, Mrs. Vishaka Nanayakkara, Head of Electrical Engineering department, Professor H.Y.R. Perera and Head of Textile and Clothing Engineering Department, Dr. E.A.S.K. Fernando for allowing me to perform terminal measurements at their respective departments.

I am especially grateful to all the researchers and authors for the useful and effective ideas I gained from their works published in the references.



University of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations

www.lib.mrt.ac.lk

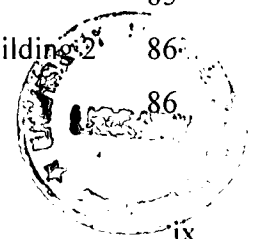
I am grateful for the General Administration Division of University of Moratuwa for providing a vehicle for measurement trials and Mr. Dayananda Amarasinghe and my colleagues Pushpika Wijesinghe and Lakshitha Wijesinghe for assisting me to carryout the terminal measurements. Also I would like to thank my colleagues Upeka De Silva and Kalhari Liyanagama for working with me on the initial experiments during my final year project of the B.Sc. Engineering course that finally led to this M.Sc thesis. I would also like to thank the staff of Dialog-UoM Mobile Communications Research Laboratory, and the non academic staff members of Department of Electronic and Telecommunications Engineering, for their support on this research.

Finally heartfelt appreciation and gratitude is deserved by all my teachers, lecturers, friends and family who brought me into this status.

List of Figures

Figure	Page
4.1 RSS variation over time	25
4.2 RSS variation along a road	25
4.3 Sliding window approach of creating fingerprints	27
4.4 RSS variation over time in indoor environment	28
4.5 Summary of positioning methodologies used	29
4.6 Performance comparison with number of measurements for outdoor positioning	30
4.7 An example illustrating the signal level differences between the two database fingerprints and the observation	36
4.8 RSS of two different cells measured simultaneously at one location	38
4.9 RSS of the same cell measured at two different locations	38
4.10 Screen shots of the fingerprint database and tables- outdoor positioning	45
4.10 Screen shots of the fingerprint database and tables-Indoor positioning	46
5.1 Measurement Equipment	47
5.2 Indoor Measurement setup	48
5.3 Selected Urban area with all the hearable BS locations	49
5.4 Selected Suburban area with all the hearable BS locations	49
5.5 Environmental difference in the two buildings	51
5.6 layout of the floors- Building 1	52
5.7 Layout of the ground floor – Building 2	53
5.8 Layout of the 1 st floor – Building 2	54
6.1 Summary of positioning methods- outdoor positioning	56
6.2 Error CDF comparison of <i>DCM-NN</i> – Urban	57
6.3 Error CDF comparison of cost function-III and cost function-0 for Urban area	58
6.4 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> methods – Urban	59
6.5 RMS error Variation with <i>k</i> – Urban	60
6.6 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Urban	60
6.7 Error CDF comparison of <i>DCM-NN3</i> with different methods – Urban	61
6.8 Error CDF comparison of <i>DCM-NN</i> – Suburban	62

6.9 Error CDF comparison of cost function-III and cost function-0 for Suburban area	63
6.10 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> methods	
– Suburban	64
6.11 RMS error Variation with <i>k</i> - Suburban	65
6.12 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Suburban	66
6.13 Error CDF comparison of <i>DCM-WkNN</i> with different methods – Suburban	67
6.14 Error CDF comparison of <i>DCM-NN</i> – Rural	68
6.15 Error CDF comparison of cost function-III and cost function-0 for Rural area	69
6.16 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> methods–Rural	70
6.17 RMS error Variation with <i>k</i> – Rural	71
6.18 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Rural	72
6.19 Error CDF comparison of <i>DCM-WkNN</i> with different methods – Rural	72
6.20 Summary of positioning methods- Indoor positioning	74
6.21 Error CDF comparison of results obtained with different number of measurements – Building 1	75
6.22 Error CDF comparison of <i>DCM-NN</i> – Building 1	76
6.23 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> methods	
– Building 1	78
6.24 Variation of the percentage of success floor classification with <i>k</i> – Building 1	78
6.25 RMS error Variation with <i>k</i> – Building 1	79
6.26 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Building 1	79
6.27 Error CDF comparison of Histogram methods –Building 1	81
6.28 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-Hist-WkNN-Clust</i> methods	
–Building 1	82
6.29 Error CDF comparison of results obtained with different number of measurements	
– Building 2	83
6.30 Error CDF comparison of <i>DCM-NN</i> – Building 2	84
6.31 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> methods	
– Building 2	85
6.32 Variation of the percentage of success floor classification with <i>k</i> – Building 2	86
6.33 RMS error Variation with <i>k</i> – Building 2	86



6.34 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Building 2	87
6.35 Error CDF comparison of Histogram methods –Building 2	88
6.36 Error CDF comparison of <i>DCM-WkNN</i> and <i>DCM-Hist-WkNN</i> methods –Building 2	89



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Tables

Table	Page
3.1 Frequency bands allocated for GSM	19
4.1 Sample view of the Histogram database	40
4.2 Observation vector S	41
4.3 Fingerprint database with histograms	41
5.1 Summary of Outdoor data collection	50
5.2 Number of fingerprints collected - Building 1	52
5.3 Number of fingerprints collected- Building 2	54
6.1 Results summary of <i>DCM-NN</i> – Urban	57
6.2 Results summary of cost function-III and cost function-0 for Urban area	58
6.3 Best scenarios for WkNN estimation- Urban	59
6.4 Results summary of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> –Urban	59
6.5 Results summary of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods –Urban	61
6.6 Results comparison of <i>DCM-NN3</i> with different methods – Urban	62
6.7 Results summary of <i>DCM-NN</i> – Suburban	62
6.8 Results summary of cost function-III and cost function-0 for Suburban area	63
6.9 Best scenarios for WkNN estimation- Suburban	63
6.10 Results summary of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> –Suburban	64
6.11 Results summary of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Suburban	66
6.12 Results comparison of <i>DCM-NN3</i> with different methods – Suburban	67
6.13 Results summary of <i>DCM-NN</i> – Rural	68
6.14 Results summary of cost function-III and cost function-0 for Rural area	69
6.15 Best scenarios for WkNN estimation- Rural	69
6.16 Results summary of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> – Rural	70
6.17 Results summary of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods – Rural	71
6.18 Results comparison of <i>DCM-NN3</i> with different methods – Rural	73
6.19 Percentage of successful floor classification for different number of measurements- Building 1	75
6.20 Results summary of <i>DCM-NN</i> – Building 1	76

6.21 Best scenarios for WkNN estimation- Building 1	77
6.22 Results summary of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> –Building 1	77
6.23 Results summary of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods –Building 1	80
6.24 Results summary of Histogram methods –Building 1	80
6.25 Results summary of <i>DCM-WkNN</i> and <i>DCM-Hist-WkNN-Clust</i> methods –Building 1	81
6.26 Percentage of successful floor classification for different number of measurements- Building 2	82
6.27 Results summary of <i>DCM-NN</i> – Building 1	83
6.28 Best scenarios for WkNN estimation- Building 1	84
6.29 Results summary of <i>DCM-WkNN</i> and <i>DCM-WkNN-Clust</i> –Building 1	85
6.30 Results summary of <i>DCM-WkNN</i> and <i>DCM-NN3</i> methods –Building 1	87
6.31 Results summary of Histogram methods –Building 1	88
6.32 Results summary of <i>DCM-WkNN</i> and <i>DCM-Hist-WkNN-Clust</i> methods –Building 1	89
6.33 Best results obtained for outdoor positioning	90
6.34 Best results obtained for indoor positioning	91
7.1 Best technologies identified for each outdoor trial	93
7.2 Best technologies identified for each indoor trial	94

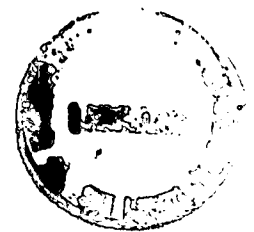


List of Principal Symbols

2G	-	2nd generation
3G	-	3rd generation
3GPP	-	3rd Generation Partnership Project
AOA	-	Angle Of Arrival
BCCH	-	Broadcast Control CHannel
BS	-	Base Station
BTS	-	Base Transceiver Station
CDF	-	Cumulative Distribution Function
CDMA	-	Code Division Multiple Access
Cell ID	-	Cell Identification
DC	-	Database Correlation
E-911	-	Enhanced 911
E-OTD	-	Enhanced Observed Time Difference
FCC	-	Federal Communications Commission
FDMA	-	Frequency Division Multiple Access
GPS	-	Global Positioning System
GSM	-	Global System for Mobile Communications
LBS	-	Location Based Services
LOS	-	Line Of Site
LMU	-	Location Measurement Unit
MATLAB	-	MATrix LABoratory
MLE	-	Maximum Likelihood Estimation
MS	-	Mobile Station
NLOS	-	Non Line of Sight
NMR	-	Network Measurement Report
OTD	-	Observed Time Difference
p.d.f	-	Probability Distribution Function
PCS	-	Personal Communications Services
RMS	-	Root Mean Square
RSS	-	Received Signal Strength



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk



RSSI	-	Received Signal Strength Indicator
RTD	-	Round Trip Delay
SIM	-	Subscriber Identity Module.
SMS	-	Short Message Service
TA	-	Timing Advance
TDOA	-	Time Difference of Arrival
TOA	-	Time of Arrival
TDMA	-	Time Division Multiple Access
WGS-84	-	World Geodetic System 1984
WLAN	-	Wireless Local Area Network
UMTS	-	Universal Mobile Telecommunications Systems



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk