A DEPLOYMENT OPTIMIZATION MODEL FOR WIMAX BASE-STATIONS

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A DEPLOYMENT OPTIMIZATION MODEL FOR WIMAX BASE-STATIONS

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ABSTRACT

Telecommunication technologies are growing rapidly due to the highly demanding markets for different telecom services and applications. Wireless solutions are essential in places where cable infrastructure does not exist, like in remote and developing areas. To satisfy the demands of business and residential customers for high quality voice, video and data services, it is required to deploy a reliable broadband wireless network taking into consideration the possible options to maximize the overall profits and customer satisfaction.

This work aims at developing an optimization deployment model for base-stations of fixed wireless access technologies, in particular the Worldwide Interoperability for Microwave Access (WiMAX). The base-stations deployment problem is formulated as a mixed integer linear programming (MILP). The model generates the optimum deployment configurations of the base-stations including the selection of best locations to install the base-stations among a number of candidate sites, number of base-stations to be installed in the selected sites and the optimum transmission power per site. Both technical and economic feasibilities are considered by maximizing the received signal strength, data traffic utilization, number of served nodes and the net annual profit.

A sensitivity analysis is conducted to assess the impact of different parameters on the network performance. The results show that the most critical parameters are the weighting coefficients associated with number of served nodes and annual profit in addition to the maximum net throughput and base-station cost.

A bin packing (BP) algorithm is proposed as a heuristic procedure to solve large size problems within a reasonable computational time. A MATLAB program is developed and the algorithm is applied to the same scenarios solved by the proposed MILP model. The results of the BP model are compared to the optimum solutions in order to benchmark the algorithm performance. The performance of the algorithm is

reasonable since the deviation in objective value varies between 5% and 20% in most of the cases.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

TABLE OF ABBREVIATIONS

ADSL	Asymmetric Digital Subscriber Line
AHP	Analytical Hierarchy Process
BES	Best Effort Service
BP	Bin Packing
CAPEX	Capital Expenditure
CPE	Customer Premise Equipment
CPICH	Common Pilot Channel
DFS	Dynamic Frequency Selection
DL	Downlink
DSL	Digital subscriber line
ertPS	extended real-time Polling Service
ESA	Evolutionary Simulated Annealing
FSL	Free Space Loss
GA	Genetic Algorithm
GS	Greedy Search
GSM	Global Mobile System
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineering
ILP	Integer Linear Programming
IMT	International Mobile Telecommunication
IP	Internet Protocol
ITU	International Telecommunication Union
LOS	Line-of-Sight
LTE	Long-Term Evolution
MILP	Mixed Integer Linear Programming
MIMO	Multiple Input Multiple Output
MIP	mixed integer programming
MS	Mobile Station
nrtPS	non-real-time Polling Service
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditures

PC	Power Control
PDU	Packet Data Unit
PMP	Point to Multi Point
PTP	Point to Point
QAM	Quadrature Amplitude Modulation
QoS	Quality of Services
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
rtPS	real-time Polling Service
SA	Simulated Annealing
SAB	Spatially Adaptive Beamforming
SF	Service Flow
SHO	Soft Handover
SIR	Signal-to-Interference Ratio
SNIR	Signal to Interference plus Noise
TPC	Fast Transmission Power control
TRA	Telecommunication Regulatory Authority
UAE	United Arab Emirates
UGS	Unsolicited Grant Service
UL	Uplink
UMTS	Universal Mobile Telecommunication System
VoIP	Voice over Internet Protocol
W-CDMA	Wideband-Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

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CHAPTER 1

Introduction

Data rate is one of the main factors that drive the development of new communication technologies nowadays. The accelerated demands for high data rate applications, such as live video streaming, form the roadmap for the telecommunication industry to design communication systems with enough capabilities to satisfy all the requirements.

Conducting technical and economic feasibility studies for the deployment of new technology is essential to ensure the success of the investment decision over the long run. Both factors play important role in selecting the appropriate technology considering the trade-off between cost and quality. The technical analysis of the project helps understanding the advantages and limitations of each technology and to select the best one. However, the final decisions of technology selection and network deployment are mainly impacted by the financial analysis. Proper deployment of the wireless network helps the service providers satisfying the customers' demands, saving a lot of money and even achieving high profits. Accurate modeling of the deployment problem, considering all parameters, is really important to achieve optimum network topology, system configurations and maximum possible profits.

Before proceeding with the literature review and the problem modeling, a brief introduction about the wireless environment and broadband technologies is provided in sections 1.1. The problem is described in section 1.2. In section 1.3, one of two candidate technologies is selected to solve the stated problem and to develop the deployment optimization model. The work significance, research methodology and the organization of the remaining report are discussed in sections 1.4, 1.5 and 1.6, respectively.

1.1. Wireless Communication Overview

1.1.1. Components of Wireless Communication System

The main components of the wireless communication system are transmitter, wireless channel, and receiver, as shown in Figure 1. On the transmitter side, the information bits are converted to a modulated electromagnetic signal that is able to travel across the wireless medium. The characteristics of the wireless channel decide the behavior of the transmitted signal. The electromagnetic wave can be attenuated while propagating through the channel due to propagation loss, shadowing, and multipath fading. The waveform of the received signal can be different from the transmitted one, due to multipath delay, the time/frequency selectivity of the channel, in addition to the unwanted noise and interference. At the receiver side, the signal is received and the information bits are recovered through the operations of equalization, demodulation, and channel decoding [1].

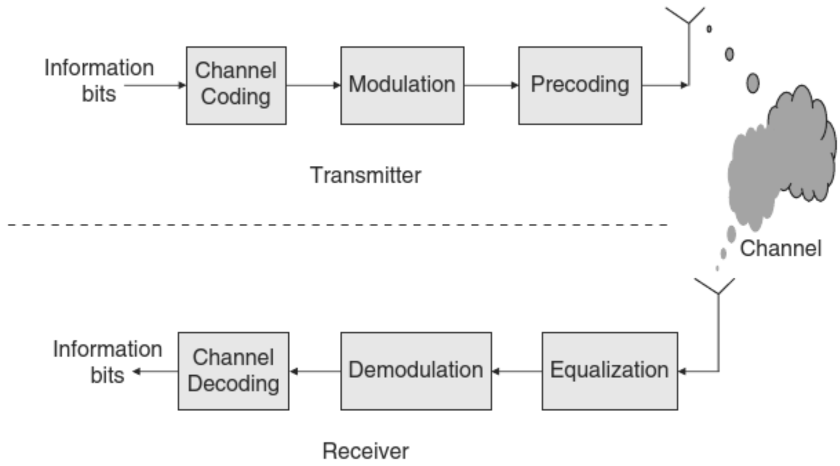

Figure 1: Block diagram of a Wireless Communication System [1]

1.1.2. Wireless Channel and Propagation Conditions

The channel is the medium between the transmitting antenna and the receiving antenna as shown in Figure 2. Many factors affect the wireless signal characteristics while it propagates through the atmosphere from the transmitter to the receiver. Some of these factors are related to the characteristics of atmospheric layers which mainly depend on their meteorological conditions such as temperature, humidity, rain, and pressure of the atmosphere. The channel characteristics are also affected by the distance between the two antennas, path(s) taken by the signal and the environment (buildings and other objects) around the path. The channel model is the model of the medium between the two antennas which is used to obtain the profile of received signal [2].

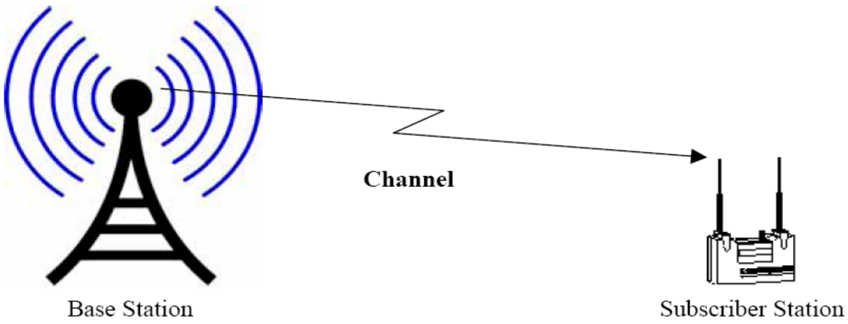

Figure 2: Wireless Channel [2]

The signals propagate through different channels such as free space channel, multipath channel and others. Objects may exist between the transmitting and receiving antennas such as buildings, trees, and mountains. In Line-of-Sight (LOS) situations where there should be a clear path between the two antennas, the transmitted signal energy is reduced during its spread around the transmitting antenna. Also reflected signal from the ground may reduce the net received power based on the phases of the received signals. Furthermore, shadowing phenomenon may occur when the signal intersects with some objects through the path which probably has lognormal distribution. The signal is attenuated due signal absorption, scattering, reflection, and diffraction. The transmitted signal might be lost because of the high attenuation. Reflected signals from different objects take different paths and consequently each could have different amplitude and phase. This phenomenon is known as multipath, as displayed in Figure 3. These multiple signals may increase or decrease the net received power, but sometimes the reflected signal could be totally destructive and cancel the transmitted signal if there is a phase shift of 180° from the main one [2].

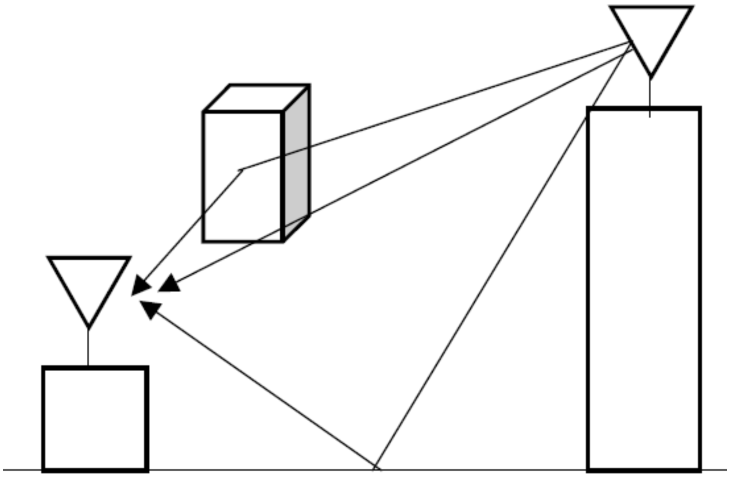

Figure 3: Multipath Propagation [2]

1.1.3. Broadband Wireless Technologies

The market of broadband technologies continues to grow rapidly nowadays. The broadband Information and Communication Technologies (ICTs) drives the economic growth and the recovery after the global recession [3]. In telecommunication sector, broadband refers to transmitting multiplexed information on many different channels within a wide band of frequencies in a given amount of time. Narrowband is simply "not broadband" where the baseband is one-channel band which can carry a voice signal [4]. There are different definitions for the minimum bandwidth and data rate of broadband. According to the Institute of Electrical and Electronics Engineering (IEEE), the broadband refers to frequency channel bandwidth greater than 1MHz and data rates larger than about 1.5Mbps [5].

Worldwide, the number of Internet subscribers in the last two decades is increasing rapidly, reaching around 1.75 billion in 2009 [6], which results in growing demand for higher-speed Internet-access services, and a parallel growth in broadband adoption. Broadband is traditionally provided through wires. Digital subscriber line (DSL) technology delivers broadband over twisted-pair telephone wires, while cable modem delivers it over coaxial cable TV plant. The initial deployment of these technologies was in 1990s, and they are growing considerably to reach more than 400 million subscribers by 2010 [7]. Broadband can also be provided through wireless technologies in fixed and mobile modes.

The rich performance of wireless solutions, which have been considered as the cutting edge of the telecom industry, could potentially accelerate the growth of broadband technologies [7]. The combination between wireless and broadband has been facing a real challenge to be feasible, economically and technically, in delivering cable like performance and high data rates. However, the involvement of other technologies and techniques such as Orthogonal Frequency Division Multiplexing (OFDM), adaptive modulation, Multiple Input Multiple Output (MIMO) technique, and adaptive beamforming, assist in enhancing the reliability of wireless technologies to provide broadband services, improving the coverage and maintaining the service quality while eliminating the cost. WiMAX is an emerging broadband wireless technology that supports both fixed and mobile modes. The technology characteristics are discussed in chapter 3.

1.2. Problem Statement

As part of its international expansion plan, a telecommunication operator intends to enter a new market to provide fixed voice and data services including internet and Voice over IP (VoIP). Many developing countries in the continents of Asia and Africa are good candidates due to their large population and attractive markets. Due to the rugged terrain in the selected country and the high cost of extending fiber cables everywhere, the service provider has to select the proper wireless technology to deploy the new network and the proper network and system configurations.

The challenge is to balance between quality of the services provided, coverage area and the cost of the deployed network. It is required to study carefully the specifications of the selected technology, Capital Expenditures (CAPEX), Operational Expenditures (OPEX) and the expected revenues that affect the final decision. The proposed network deployment model will help deciding on the optimum network topology, the required number of base-stations and the proper transmission power configurations of base-stations, taking into consideration the economic feasibility of the new project.

1.3. Selection of WiMAX Technology for Network Deployment

Fixed WiMAX and Wireless Fidelity (WiFi) are wireless technologies used for deploying fixed access networks to support desired data rates. WiFi is based on IEEE standard 802.11, which is used to provide fixed and nomadic services. It was originally designed to provide data services for small indoor Wireless Local Area Network (WLAN). It has also been developed to provide outdoor coverage within few kilometers. The use of the allocated frequency spectrum for WiFi technology, in the 2.4GHz and 5.8GHz bands which are license-exempt in many countries, makes it a good candidate to provide the outdoor broadband services with the sake of reducing the CAPEX. The fixed WiMAX, which is based on IEEE Standard 802.16d, is an emerging wireless technology which has initially been designed to support fixed Point to Point (PTP) and Point to Multi Point (PMP) communication modes.

It is required to select between outdoor WiFi and WiMAX technologies to build the required fixed wireless network. Roughly speaking; at least double or triple the number of WiMAX base-stations is needed to cover the same area by WiFi base-stations. In addition, the WiFi frequency spectrum is not license exempt everywhere. In some countries, such as the United Arab Emirates (UAE), the use of any band of the frequency spectrum, including both WiFi bands, for outdoor services is not free of charge and the operators must take prior authorization from the Telecommunication Regulatory Authority (TRA) [8].

Consequently, it has been decided to select the WiMAX technology and to consider its specifications in the development of the deployment optimization model.

1.4. Significance of the Work

Due to the technology development such as the growth of “Over Internet Protocol (IP)” technologies (like VoIP) and the increasing demands for high speed data services, telecommunication operators can afford large investments for network infrastructures to satisfy the market requirements. Large bandwidth of the frequency spectrum is needed to provide enough data traffic throughput by the deployed base-stations. However, if more frequency bandwidth is used, the coverage will be reduced. In order to increase coverage and data throughput together, more base-stations need to be deployed. Consequently the CAPEX and OPEX will be increased. From logistic point of view, it is preferred to install multiple base-stations at the same site, if possible; instead of selecting several nearby locations and installing a single base-station at each one of them.

There are many complicated tasks in the network planning problem such as selecting the proper locations for installing the new base-stations, configuring the transmission power from the base-stations, reducing the interference, and maintaining the service quality, while increasing the revenues. Developing quantitative methods for efficient network planning have become essential with the rapid growth of network size and number of users in order to decide on the optimum network architecture and to maximize the overall profits [9].

To the best of our knowledge, no deployment optimization model has been proposed for fixed WiMAX technology considering the actual specifications and field limitations. Important parameters such as different modulation schemes, traffic speed factors, oversubscription capability, number of frequency channels and their bandwidth are considered in this work for the traffic analysis. The LOS and channel availability are taken into account in the coverage calculation and base-station’s transmission power control. A new approach to eliminate the interference problem is proposed at this stage of the network planning as well.

1.5. Research Methodology

The problem of network deployment has a complicated nature due to non-uniform service area in a complex propagation environment, mutual coverage and interference from multiple transmitters, etc. A mathematical model to optimize the deployment of WiMAX base-stations is formulated using Integer Linear Programming. Lingo software is used to solve different scenarios of the problem. Long computational time is expected when enlarging the network size, due to the number of variables and constraints. A sensitivity analysis is performed to investigate the impact of the parameters' variation on the overall objective function. A bin packing greedy algorithm is formulated to solve large scale problems.

1.6. Report Organization

This thesis consists of five chapters followed by appendices. In chapter 1, an introduction highlighting the problem, significance of the work and the research methodology is provided. Previous works in the optimization of the network planning and base-stations' locations are discussed in chapter 2. In chapter 3, an overview of the WiMAX technology and its characteristics is discussed. The proposed deployment model is formulated and explained in chapter 4. Multiple scenarios are tested using LINGO software and computational results are analyzed in chapter 5. In chapter 6, pseudo code of a bin packing greedy algorithm is formulated. MATLAB is used to assess the algorithm performance and the results are compared with the outputs obtained in chapter 5. Chapter 7 gives the final conclusions and recommendations. Finally, the bibliographies followed by the appendices are provided.

CHAPTER 2

LITERATURE REVIEW

The planning of new wireless network can be divided into two phases: the base-stations deployment and the frequency assignment. The large coverage area and accessibility to enough data traffic offered by the installed base-stations should be carefully considered in the deployment phase, in order to satisfy the customers' demands while maintaining the cost within the allocated budget. This problem is considered as a capacitated one due to the limitations of the base-stations' data traffic capacity. The coverage calculation is based on the selection of sites' locations and signal level predictions using suitable propagation models. The power strength should be strong enough to correctly deliver the signal to the receiver while maintaining high signal quality within the area under study.

Several research works have been conducted to develop optimization models for base-station's location problem. Most of the proposed models are related to the different generations of mobile networks. The traditional base-station's location models of the Global Mobile System (GSM) were not appropriate for planning the Universal Mobile Telecommunication System (UMTS), since only signal predictions were considered while the data traffic distribution, the signal quality requirements, and the power control (PC) were not taken into account [9]. More efforts have been exerted for modelling the planning problem of the third generation mobile systems; in particular the UMTS based on the Wideband-Code Division Multiple Access (W-CDMA) technology, due to the increasing system complexity with respect to the second generation technologies.

There are some differences between planning a fixed and a mobile network. Handover is not supported in fixed network, since subscriber stations are not moving between different cells. More restrictions need to be added to the data traffic constraints of the fixed network, to guarantee full utilization of the requested data rate, especially if the services are provided for business subscribers or fixed voice service customers. For example, when a telecom operator provides voice services for mobile and fixed users, the data capacity design might not be the same. The mobile network is usually not designed to provide full capacity to all mobile users under the coverage of a single base-station [10]. Call-blocking rate is a measure of the service quality offered by the mobile network. In case of fixed network, supporting fixed voice services requires sufficient data capacity to be available at the base-station. A dedicated part of the bandwidth should be assigned to each user in order to initiate a voice call. Furthermore, in order to provide data services for fixed business customers, such as high data rate internet access or Virtual Private Network (VPN) between branches of a single organization, a dedicated bandwidth from the base-station's data capacity is required to be assigned to each of those customers in demands.

Furthermore, planning a UMTS or W-CDMA network is different from WiMAX network planning. One of the differences is that the interference calculation of UMTS network depends on the spreading factor where large spreading factor yields to better signal quality but on the expense of the maximum number of customers that can be connected simultaneously. The number of mobile station connected to the same W-CDMA base-station is limited by the accumulated interference level caused by the connected mobile stations at the serving base-station. No such limitation is experienced in case of WiMAX.

Amaldi et al. [9] proposed an un-capacitated integer programming optimization model and algorithms, considering the condition of the Uplink (UL) connection (from mobile unit to base-station), for planning the UMTS network. Two mechanisms for controlling the mobile transmission power were investigated. The first mechanism was based on maintaining the received signal strength above certain threshold; while the other one was based on the Signal-to-Interference Ratio (SIR). A specific power-based Power Control (PC) mechanism for the W-CDMA air interface was used. A target received power level at the base-station was set initially and the thermal noise parameter was not included in the signal quality. The mixed integer programming (MIP) problem was solved using MIP solver, CPLEX 7.0. The quality requirements were determined by measuring the ratio of the wanted received signal by the base-station to the sum of the interfering unwanted signals. The received signal strength depended on the transmitted power levels and the medium attenuation of the radio link. In the SIR-based PC model, no limitation was added to the transmission power of mobile units, except maintaining it below the maximum emission power, and the SIR level of each active connection had to be larger than or equal a threshold value.

Two decision variables were used for the selection of a subset of the candidate sites to install the base-stations and the assignment of the test points to the selected sites. The traffic demand of each point, signal quality threshold in terms of SIR, service coverage and the base-station installation cost were taken into account. The followings were assumed:

a) Each connection from a test point was assigned to a single base-station and no handover was considered. However, splitting the data traffic capacity was allowed in UMTS network in which a test point could get the required data traffic from neighbouring base-stations and not only from the one it was initially assigned to.
b) The test points could adapt their transmission power to achieve adequate received power level at the base-station.
c) Number of available spreading codes was higher than the number of connections assigned to each base-station.
d) Quality of the received signal was related to the bit error rate and depended on the number of connections.

The number of possible connections to a single base-station was limited due to the increased interference level at the base-station. The basic model objectives consisted of two terms that needed to be minimized: the installation cost and the total emission power from the test points to reduce the interference levels.

Two heuristic algorithms, the randomized greedy procedures and tabu search, were developed to reduce the computational time while obtaining acceptable approximate results.

By comparing the results of the proposed models, less number of the selected sites was obtained using the SIR-based PC model. As a result, the offered capacity by the network was efficiently utilized since the system could support more connections per site. The study showed that the reason for less capacity utilization in case of power-based PC mechanism was due to the unnecessary high levels of the power which resulted in increasing the interference level and consequently inadequate use of radio resources.

Another network optimization model was formulated by J. Yang et al. [11] for planning the UMTS radio network. Different from Amaldi et al. [9], the model took into account the link-level performance factors such as, fast transmission power control (TPC), soft handover (SHO) and pilot signal power, in both uplink and downlink directions which were directly affecting the interference calculations of the network. The following parameters and assumptions were considered:

a) Two ways SHO,
b) One Mobile Station (MS) might have two servers during the SHO process but only one could be the best server,
c) Four SHO gains; one in Downlink (DL) direction due to receiving multiple signals by the mobile station from different base-stations, and three gains in the UL.

The selection criterion of the best server depended on which base-station achieved the highest Common Pilot Channel (CPICH) signal at the MS. Three decision variables were used for the selection of base-station location, CPICH power and base-station transmission power taking into consideration two ways SHO situation. The installation costs, coverage and traffic capacity are the three elements of the weighted sum objective function. Only the base-station's location problem was investigated in the experimental section.

Three meta-heuristics; Genetic Algorithm (GA), Simulated Annealing (SA) and Evolutionary Simulated Annealing (ESA), were examined to optimize the network, and the greedy search (GS) algorithm was used to benchmark performance of other models. Several scenarios with different number of searches were tested by each algorithm. An optimum result was adopted after tuning all the parameters many times. It was targeted to compare different results obtained by running each algorithm, instead of measuring the best results in each case separately. Cumulative distributions were drawn for the obtained results, yielding to the conclusion that SA and ESA algorithms had better performance than the GA and GS with a higher probability to achieve optimum or near optimum solutions. In case of large number of searches; the ESA and GA outperformed the SA and GS, respectively. For low number of searches, SA performed better than the ESA, while both GA and GS became comparable.

An integer programming model was developed by Kalvenes et al. [10] to help the network planner selecting sites to install the radio towers, and analyzing the customers' demands and the service quality. The proposed model took into account the candidate towers' locations with their corresponding costs, and the customers' locations and their traffic demands to maximize the revenue. Three decision variables were used; two binary variables for the decision to build a tower in a selected site and an indicator variable to represent if a customer was served, in addition to an integer variable which represented the capacity assignment at the selected site by determining the maximum number of customers that could be assigned to it. Similar to the proposed models by Amaldi et al. and J. Yang et al. [9, 11]; the quality of service constraint was based on the SIR ratio of the session between the customer and the serving site. The model objectives were to maximize the net annual revenue and to eliminate the cost. The cost was assumed to include building and operating a tower and connecting it to the backbone network. Operating cost included the cost of transmission power, marketing, accounting, customer acquisition, retention, and any other contingent cost upon operating a tower. The model was subject to the following constraints:

a) A customer could not be served unless it was covered by at least one of the candidate sites,
b) Service was available for the demand areas with a certain proportion of all customers in the total service area of the operator to ensure minimum service restriction,
c) Signal to interference ratio had to be maintained above a minimum value.

An algorithm with priority branching scheme, optimization-gap tolerance between 1% and 10%, and two sets of global valid inequalities, was used to enhance the computational time. Two propositions were taken into account. Two sets of inequalities were used in the first proposition as follows:

a) The assignment of a customer to a tower required minimum handset emission power which caused interference to other tower locations and minimized the resource consumption. An optimal solution could be obtained by considering that if two towers could serve a customer, it had to be only assigned to a tower location with the largest attenuation factor, which depended on the distance from the site to the demand area, in order to minimize the interference impact on neighboring locations and maximize the profits.
b) The second set of inequalities was related to the quality of service where the interference was considered from the tower location to its served customers and vice versa.

The second proposition is that the W-CDMA base-station's location and service assignment problem is NP-hard. If a single tower location was assumed to serve only one demand area, hence the objective function was converted to one term of the cost associated with the assignment of a demand area to a tower location that needed to be minimized.

Many combinations of the algorithm’s settings were evaluated after implementing over 300 problem instances and utilizing up to 40 towers and 250 service locations. The model was solved using CPLEX software. It was applied on two scenarios with capacity and budget constraints. By considering different branching rules and valid inequalities, it was found that branching on tower locations was beneficial. Both distance-based and the interference-based inequalities worked well for such problem.

The problem of a base-station covering an urban microcell environment was addressed by Anderson et al. [12] using SA technique. The coverage optimization model utilized a simplified propagation model to calculate the signal strength within a hypothetical city grid in order to find the optimum locations where the base-stations could provide the best coverage. LOS and non-LOS conditions were considered, while 25dB attenuation was added in case of non-LOS situation. The base-station randomly moved between different locations, in a Gaussian distribution, without giving any candidate locations, until the cost function was reduced to zero. Four parameters were defined to develop the SA model as follows:

a) Start point or initial temperature which was needed to guarantee high probability of getting outside the local minima.
b) Cooling schedule for lowering the temperature.
c) Equilibrium which was simply defined by permitting certain number of state transitions at each temperature level.
d) Final temperature was defined by either getting the cost function equals to zero or whenever the maximum and minimum costs were the same as the maximum single cost change.

The SA model allowed the transition to a new state if the associated cost was less than the previous one. In some cases, the new state might be accepted even if the cost is higher to avoid getting stuck in local minima.

Two approaches were addressed to determine the overall network performance; the coverage based on the signal level calculations and SIR based network optimization which is considered as the stringent factor affecting the system performance. Two scenarios were tested with one and four transmitters to find out the optimum locations. It was noted that the overall costs were almost the same for some different situations where the starting locations were not identical. It was concluded that the near optimum solutions were not unique. Fast workstations were recommended to be used for larger problems in order to reduce the computational time.

Ting Hu et al. [13] considered the PMP WiMAX network planning as an unsplittable capacitated problem. The genetic algorithm approach was used to solve this optimization problem. Crossover and mutation operations were devised. A capacity constraint was only considered by limiting the number of subscribers that could be connected to a single base-station. Thirty subscribers could be served by one base-station. It was assumed that a subscriber station was served by only one station without data splitting and it might not be connected to the nearest base-station due to load balancing. The traffic demands were represented by units and each subscriber has a single unit of demand. The obtained results showed that as the network size increased, the served subscribers for the same network layout were diverse across different runs. The percentage of the fittest subscribers decreased, due to the increased complexity of the problem.

Ingo Vogelsang, [14], conducted a survey to investigate the possibilities for substitution of fixed network by mobile one or the co-existance with complementarity of both sectors. The number of mobile subscribers have increased dramatically over the last few years compared to fixed network customers. It was concluded that although mobile services have high market penetration due to its mobility, there is still a potential for fixed services due to their high data rates.

CHAPTER 3

WIMAX TECHNOLOGY OVERVIEW

WiMAX is a broadband technology working as a wireless alternative to the cable and DSL. The technology is developed based on IEEE standard 802.16. WiMAX forum is responsible for certifying the compatible devices after testing its interoperability with the standard. The technology has been accepted by the International Mobile Telecommunication (IMT) and the International Telecommunication Union (ITU), but its spectrum allocation is still inconsistent all over the world [15]. WiMAX supports large coverage areas. However, the coverage is also limited by the local regulations of telecommunication authorities in each country and the maximum power of customer device considering the UL connections.

3.1. Fixed and Mobile Versions of IEEE Standard 802.16

WiMAX has different versions of the IEEE standard 802.16: fixed and mobile. Fixed WiMAX (IEEE standard 802.16d) is designed to provide fixed data services for long distances and to backhaul security and surveillance cameras [16]. Mobile WiMAX (IEEE Standards: 802.16e and 802.16m) has been developed in next phases and it is a strong candidate to be the platform for the fourth generation mobile systems against LTE technology. In comparison to the UMTS, the mobility was not supported with the first versions of WiMAX standard, while UMTS is designed as a mobile network from the beginning [17]. Consequently, fixed WiMAX networks are more popular, especially in the Middle East, than mobile WiMAX. Fixed WiMAX does not only tackle the areas without cable infrastructure but even aims at the users of Asymmetric Digital Subscriber Line (ADSL) for broadband data access [18]. Different from ADSL, WiMAX is an IP native network which uses packets instead of circuits. The data traffic can be originally voice, video or data. Voice services over the IP protocol (VoIP) requires more air interface bandwidth than the voice calls over the circuit switched wireless networks such as the GSM. This is due to the fact that IP stack is a general data transmission stack which is not optimized for voice. The increased bandwidth will improve the quality of voice calls over IP networks [19].

Fixed WiMAX technology is expected to have a promising future, especially in developing countries, since it is a feasible broadband solution that can provide latest advanced applications for large coverage area with reasonable prices. The fixed, portable and mobile types of WiMAX PMP mode are shown in Figure 4. The fixed wireless access WiMAX is displayed in Figure 5, where services are only provided for fixed buildings.

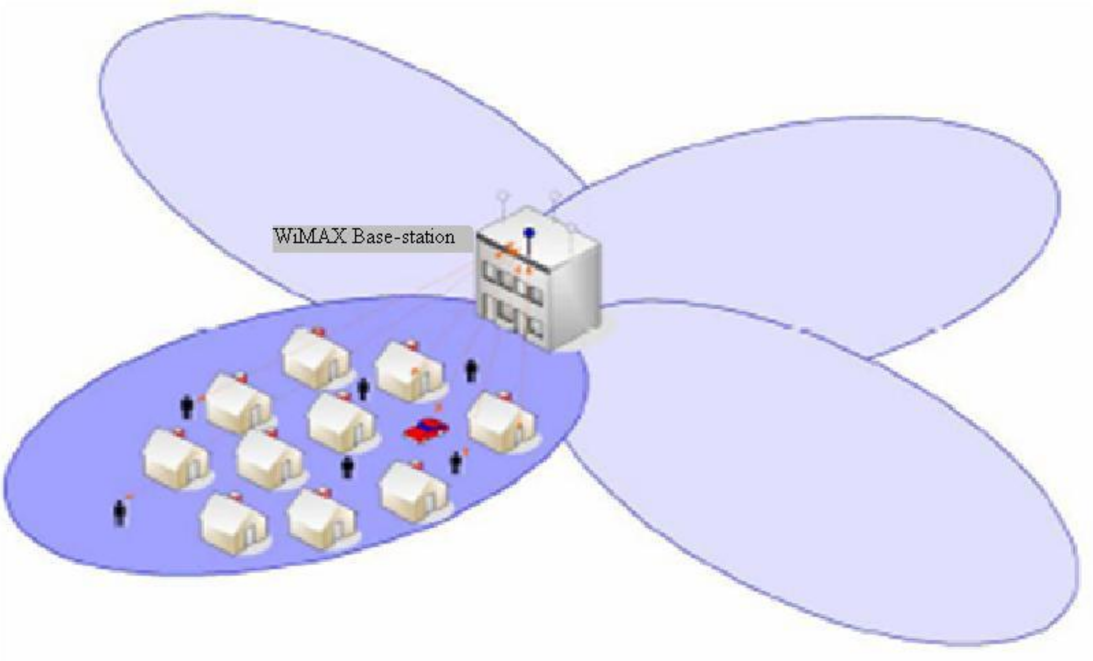

Figure 4: Fixed, portable and mobile types of WiMAX [20]

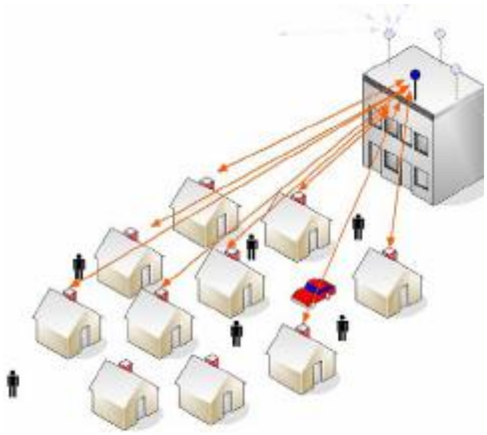

Figure 5: Fixed Wireless Access of WiMAX [20]

3.2. WiMAX Frequency Bands and Data Rates

WiMAX deployment requires a prior authorization from the TRA of the country where it is being deployed, including the definitions of the frequency bands, e.g. 2.3GHz, 2.5GHz, 3.5GHz and 5.8GHz bands, channel bandwidth, power configuration and coverage area. Spectrum license for WiMAX is normally given on a nation-wide basis to allow the operator to reuse the authorized frequency channels within the whole country using just one license. The WiMAX channel bandwidth is ranging from 3.5MHz to 20MHz which makes a base-station possible to provide a throughput up to 72Mbps considering the spectral efficiency of 3.6Mbps/MHz. The co-channel interference, between same frequency channels, and the adjacent channels interference are expected to be less than the conventional WiFi, due to the allowed unlicensed use of WiFi frequency spectrum. By utilizing some techniques such as Spatially Adaptive Beamforming (SAB) and MIMO, the system immunity to the interference from the other base-stations and its coverage are enhanced.

3.3. Coverage and Received Signal Strength Indicator (RSSI) Calculations

The coverage planning of a network plays a very important role in selecting the base stations' locations. It is essential to ensure that a good signal level is received by the Customer Premise Equipment (CPE) before looking for the signal quality or starting the frequency assignment processes and interference calculations. The coverage of the network can be calculated from:

a) The sensitivity of the receiver and the base-station transmission power in the downlink.
b) The maximum possible connection distance in the uplink considering the base-station sensitivity and the CPE transmission power.

For simplicity, a commercial software (e.g. ICS Telecom [20]) can be used to calculate the received power level at each demand node from each candidate site and resultant values will be given as input parameters for the model developed here after.

3.4. Free Space Loss (FSL)

Several propagation models describe the signal behavior. The transmitted power level degrades until it reaches its destination due to several attenuation factors such as distance, diffraction by an obstacle in the path, rain, gas, humidity and other air particles. If the LOS is available, only the meteorological conditions affect the power degradation.

The free space model is used to calculate the FSL or the attenuation factor, A_{fs}, and the base-station transmission power in the proposed optimization model here. However, the results might not be enough all the time to achieve the target received power, since the multipath phenomenon and signal the degradation due to the variations of the atmospheric conditions are not taken into consideration. An additional attenuation level might need to be added to the FSL value depending on the climate of the exact location and surrounding wireless environment. The FSL depends on the distance between the transmitter and receiver in addition to the utilized frequency band as follows: [21]

$$P_r = (P_e . A_e) / (4\pi d^2) \quad (1)$$

where,

P_e is the transmitted power, d is the distance between the transmitted and the receiver, A_e is the effective aperture area of the reception antenna, P_r is the received power (RSSI). The P_r value has to be higher than a threshold level in order to select site (s) as a server of demand node (q). The received signal should also be above the equipment sensitivity with a certain margin to guarantee that the signal could be received and interpreted correctly. The equipment sensitivity plus the margin is normally less than the threshold received power level to achieve high modulation scheme, PRMOD.

The aperture area, A_e, for isotropic antenna which is measured in m^2, is calculated from

$$A_e = \lambda^2 / (4\pi) \quad (2)$$

where,

λ is the wavelength of the transmitted signal in meter, m.

$$\lambda = c \text{ (speed light) } / f \text{ (frequency)} \qquad \text{(Measured in (m))} \quad (3)$$

The free space attenuation (A_{fs}) factor can be calculated by the following equation:

$$\frac{1}{A_{fs}} = \frac{P_r}{P_e} = \frac{A_e}{4\pi d^2} \quad (4)$$

For isotropic antenna:

$$A_{fs} = \left(\frac{4\pi d}{\lambda}\right)^2, \qquad \text{(Measured in Watt, W)} \quad (5)$$

or;

$$A_{fs} = 20 \log_{10}\left(\frac{4\pi d}{\lambda}\right), \qquad \text{(Measured in decibels, dB)} \quad (6)$$

The power level is measured by units of Watt (W) or dBm.

On the other hand, the coverage area can be represented by the field strength, in units of dBu or dBμV/m, regardless the receiver parameters such as antenna gain.

If the transmitting and receiving antennas have gains of G_e and G_r respectively, with respect to the isotropic radiator, where the gain unit is dBi, the free space attenuation will be:

$$\frac{1}{A_{fs}} = \frac{P_r}{P_e} = G_e \, . \, G_r \left(\frac{\lambda}{4\pi \mathrm{d}}\right)^2 \quad (7)$$

$$A_{fs} = \frac{1}{Ge \, . \, Gr}\left(\frac{4\pi \mathrm{d}}{\lambda}\right)^2 \quad (8)$$

Equation (8) can be expressed in decibels (dB) as follows:

$$A_{fs}\,[dB] = -10\log_{10}(G_e) - 10\log_{10}(G_r) + 20\log_{10}\left(\frac{4\pi \mathrm{d}}{\lambda}\right) \quad (9)$$

3.5. Scheduling and Quality of Services

The Service Flow (SF) defines the Quality of Service (QoS) parameters for the Packet Data Unit (PDU) which is communicated over the connection. The QoS is per connection basis and is established at the connection initialization. QoS has several parameters. One of them is the QoS classes or what is also known as scheduling services. There are four scheduling types in the fixed WiMAX technology while there are five in the mobile WiMAX. The four categories of the fixed WiMAX QoS classes are: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), non-real-time Polling Service (nrtPS), extended real-time Polling Service (ertPS) and Best Effort Service (BES). [22, 23] The service flow will be assigned to a connection between the base-station and the CPE based on the traffic type and customer requirements. Voice customers will be given a guaranteed bandwidth, while other data services such as web browsing and data transfer are assigned BES class of services. In BES, the subscriber station uses the contention-based ratio.

The contention ratio (or oversubscription ratio) refers to the ratio of the requested bandwidth by a subscriber to the available data capacity at the base-station. If the available capacity at the base-station is 10Mbps and three 10Mbps subscribers are connected, then the network is operating at a contention ratio of 3:1. The contention ratio of WiMAX products is lower than those of ADSL technology where the ratio reaches around 50:1 and sometimes even 100:1 [24]. This oversubscription approach enables the service provider to deliver more cost effective services with good prices by sharing the available bandwidth among many subscribers. However, it might not be applied to all types of services since different applications require various data rates and might not accept the sharing concept as well. For example, voice services require a dedicated portion of the offered data traffic by each site. Moreover, the requested data traffic by a business customer has to be guaranteed. This approach is commonly used by service providers since not all the customers are always expected to use the entire bandwidth simultaneously. Lower contention ratio is recommended to achieve high service quality and internet speed.

3.6. Capacity Analysis and Modulation Schemes

The key parameter for traffic modeling is to calculate the offered data rates by base-stations which can be utilized by the CPE, with respect to given thresholds of received signal level and Signal to Interference plus Noise (SNIR) ratio. The actual utilization of provided data rate by a base-station depends on the achieved modulation scheme which decides the actual traffic factor (bit rate ratio).

The modulation is determined by the received signal level and the SNIR value. It represents the time required to send the traffic from the base-station located at a site (s) to the demand node (q). There are four modulation schemes used in WiMAX; 64-Quadrature Amplitude Modulation (QAM), 16-QAM, 4-QAM, and Quadrature Phase Shift Keying (QPSK). Higher modulation schemes contain more bits per symbol and so, less time is required to transmit the same amount of data. Therefore, the traffic factor has a lower value. For example; 4 bits per symbol used for 16-QAM modulation, while only 2 bits per symbol is used for 4-QAM. The value of the traffic factor changes from 0.22 to 1, if the modulation varies from 64-QAM to QPSK, respectively.

If a base-station has 1Mbps throughput and a demand node requests guaranteed 1Mbps, the modulation of the connection will decide the capability of this station to serve the node. If the modulation of the connection is not 64-QAM, the node is rejected. If demanded traffic is not guaranteed, then the node can be served with less than 1Mbps data rate.

Adaptive modulation allows the base-station to change its modulation according to the variations in the signal levels. The modulation schemes are dictated by the value of the SNIR and the Received Signal Strength Indicator (RSSI). The adaptive technique will improve the fixed network performance by increasing the average spectral efficiency, by transmitting more bits per symbol in good communication conditions [11]. The system switches to lower modulation scheme in case of hard situations, such as high Bit Error Rate (BER) or bad propagation conditions. The maximum bit rate can be offered if 64-QAM modulation is achieved [25].

3.7. Signal Quality and Interference Calculations

Fixed Wireless Access networks must be properly configured and proper frequencies be assigned to the base-stations precisely in order to eliminate the network interference. The best frequency plan for each base-station located in the selected sites within the network can be obtained automatically using commercial planning tools such as ICS Telecom [20, 25]. The protection ratios from the unwanted frequencies and the SNIR thresholds corresponding to each modulation scheme should be clearly defined by the equipment manufacturer for the UL and DL connections.

SNIR is usually used as the measuring factor of the signal quality [9, 10, 11, 12]. Low SNIR value can be attributed to high levels of the unwanted interfering signals, noise, and low received power level. Two interference types in the DL direction, from the base-station to the CPE, are considered in this work:

1) Intra-site interference from the base-stations installed at the same site.

2) Inter-site interference from the surrounding sites.

In some situations, the interference impact from base-stations located at the same site might be more critical than the one received from other surrounding sites. Accordingly, the maximum number of base-stations that can be installed at one site depends on the number of frequency channels that can be used for the deployment and the possible reuse factor of these channels.

In the proposed deployment model, the interference problem is not handled by calculating the SNIR value at each node due to the followings:

a) The received interference level by unwanted signals from other base-stations installed at the same or surrounding sites depends on several factors. The separation between the frequency carriers of the wanted and unwanted signals and the radiation pattern of the transmitting and receiving antennas are two important factors. The directions of these antennas with respect to each other need to be specified as well. These factors are normally not taken into consideration in the network deployment model in order to simplify the problem.

b) In deployment models, the sites' locations are selected without considering the frequency assignment to each of the selected sites and/or the installed base-stations.

Performing SNIR calculations in deployment models considering Omni antennas, covering 360° horizontally, and only co-channel interference is very pessimistic and even cannot be implemented in reality due to the limited resources of frequency spectrum and its high cost. However, the interference should be eliminated as much as possible to obtain good signal quality and achieve acceptable modulation scheme. The following examples are provided to clarify the interference impact in different situations:

a) A CPE is tuned to receive a carrier frequency F1 with a channel Bandwidth BW around the carrier, which is called the wanted signal. The unwanted interfering signal is assumed to be the first adjacent frequency channel with a carrier of F1+BW. Depending on the design of the interference rejection filter, the received unwanted signal is attenuated by a certain level except if its carrier frequency is F1 as well. The degradation of the received power level of the first adjacent channel is around 30dB. If the unwanted signal is the second adjacent channel with a carrier frequency of F1+2BW, it will be attenuated by around 50dB.

b) The 3dB beam-width of the antenna pattern is known as the main lobe of the antenna pattern. Whenever the unwanted signal is not received within the main lobe, it will suffer from high degradation depending on the exact angle of arrival with respect to the pattern of the receiving directional antenna. If the unwanted signal is shifted from the main lobe of the antenna, it will be received by either its side lobes or the back.

In this work, the received power level is the only factor used to decide on the modulation, the traffic utilization, and the selection of site (s) to serve node (q) if other conditions are satisfied. In some situations, the node may not be assigned to the site with the highest signal due to load balancing and based on number of base-stations and capacity utilization constraints.

3.8. Chanel Availability Prediction

The service availability represents the percentage of time on which the service is available for the subscriber without any outage. The service availability depends on the system reliability. It is usually calculated on annual basis and it should be considered carefully in the design stage to reduce downtime percentages. Some factors contribute to the availability calculation including Radio Frequency (RF) channel availability, hardware (HW) reliability, and unscheduled maintenance time. The hardware reliability could be defined experimentally by the manufacturer. The maintenance should be scheduled to reduce the probabilities for undesired outage. The RF availability is the most difficult factor to be predicted, since it depends on the conditions of the RF environment which keeps varying continuously. To calculate the RF availability, the outage probability due to exceeding the fading limits should be determined. As explained before, the wireless signals normally suffer from high degradation due to several propagation phenomena while propagating through the air. The fading occurrence can result from gas attenuation, rain fall, signal diffraction, and multipath propagation due to reflected and scattered signals that reach the subscriber from different paths. The impact of these conditions differs according to utilized portion of the frequency spectrum. The commonly used frequencies for the fixed WiMAX networks are 3.5GHz and 5.8GHz bands. The effect of signal scattering and gas attenuation can be ignored for this frequency band. The dispersive fading due to multipath and related mechanisms will be considered to calculate the outage and the annual service availability.

Different availability standards can be considered by operators. The higher the availability prediction is, the higher probability of better system performance and less fading is expected. The fading is the long term fluctuations of the propagating signal level. Achieving high service availability is important for the operator to have better customers' satisfaction.

The RF channel availability is only considered here and its value depends on multiple factors including the station location and the propagation conditions. The commercial software, ICS Telecom, is also used to calculate the predicted availability of the channels between the base-stations and the demand nodes based on the ITU recommendation P.530 [26, 27].

One of the important factors which affect the channel availability calculation is the atmospheric refraction. Refractivity plays a vital role in forming most of the clear-air fading mechanisms. Planning of connections with more than few kilometer distances from the base station to the subscriber should take into account the extreme refractive layers in the atmosphere in addition to the beam spreading (commonly referred to as defocusing), antenna decoupling, surface multipath, and atmospheric multipath. The point refractivity gradient, dN1, is the refractivity variation in the lowest atmospheric layers. The dN1 in the lowest 65m of the atmosphere, that needs not to exceed 1% of an average year, has to be determined in the location of deployment. Approximate values are provided for the world by ITU-R recommendation P.453. These values have to be considered in case no other reliable meteorological data is available. [26, 28]

CHAPTER 4

MIXED INTEGER LINEAR PROGRAMMING FORMULATION FOR WIMAX DEPLOYMENT OPTIMIZATION MODEL

A MILP deployment optimization model is formulated. The goal of the proposed model is to assist the telecom operators in deploying new fixed WiMAX network or expanding an existing network. It aims at finding out the optimum network topology and base-stations' configurations that are required to achieve high profits while maintaining good service quality and customers' satisfaction. This is considered as an unsplittable and capacitated problem where the node can be served by at most one server, and the base-station capacity is limited regardless of the value of the contention ratio. The WiMAX network planning problem has multi-objectives nature. The weighted sum strategy is used to convert the multi-objectives problem into scalar one with the following expected outcomes:

a) The best locations from a list of candidate sites to install the base-stations within the area under study.
b) The number of base-stations required to be installed at the selected sites to satisfy the customers' demands considering the allocated budget.
c) The assignment of the nodes to the sites.
d) Transmission power configuration for each site based on the distance to the farthest served customer.

An accurate forecast for the demands considering the developing rate of the area under study is required to obtain good deployment plan. Negotiations between the planning, marketing and higher management teams are necessary to have the forecast and allocate the budget. The telecom industry is being developed on daily basis and the operators can get back what they have invested within few months or even less. It was decided to consider only one year forecast and work on maximizing the overall profits by serving the maximum number of customers and satisfying their demands in addition to efficiently utilize the offered data traffic by the sites.

4.1. New Approach for Handling Interference Problem

The two types of DL interference, from the same and surrounding sites, are considered in this model. The interference problem is not controlled here by calculating the SNIR at each node and maintaining it above a threshold value as explained in section (3.7). The received power level only decides the signal quality and is considered the main criterion to select the sites and assign the demand nodes to them.

The intra-site interference, from the base-stations installed at the same site, is eliminated by adding a constraint on the maximum number of base-stations that can be installed at the same site. The maximum number of base-station depends on the number of the authorized frequency channels for the deployment project and the frequency reuse factor.

The inter-site interference, from the surrounding sites, is controlled by limiting the maximum coverage distance considering the power thresholds in the UL and DL connections. The power configuration at any site has to maintain acceptable signal level within a predefined coverage area and to avoid setting the emission power to maximum. Controlling the stations' transmission power will eliminate the interference levels and improve the SNIR level. The proper transmission power is calculated considering the distance from the site to farthest served node. At the same time, the power should be high enough to keep the received signal level at that node above a threshold value to operate on the required modulation scheme. In this model, it is assumed that the SNIR level is maintained above a threshold value. The interference has to be computed during the frequency assignment process taking into account the outputs of this deployment model. The interference need to be eliminated by properly allocating the frequencies to the base-stations utilizing all frequency reusing techniques.

4.2. Model Assumptions

The following assumptions are considered in the preparation of the deployment model based on the characteristics of WiMAX technology, system specifications and field experience:

a) The calculation of signal to noise plus interference ratio (SNIR) is not considered and the signal quality is only measured by the received signal strength (RSSI).
b) The number of available frequency channels, which can be authorized by the telecommunication regulatory authority for the new deployment, is used to calculate the maximum number of base-stations that can be installed at any

site. A single site can serve a huge number of demand nodes if there is no budget limitation and a large number of base-stations can be installed at the same site. Also a large number of nodes can be assigned to a single base-station if the contention ratio is larger than one, but at the expense of service quality.

c) There should be a clear LOS between the demand node and serving site in order to achieve better stability and availability of the offered services. The site cannot be selected as a server of a demand node if there is a blockage between them. The signal quality of the provided services for either fixed residential houses or business offices has to be maintained by avoiding any degradation due to diffraction at the edge of barriers.

d) More than one base-station can be installed at the same candidate site if the surrounding area is congested and more data traffic is demanded.

e) All base-stations installed at site (s) are given the same transmission power.

f) All base-stations and demand nodes use Omni antennas that send and receive signals in all directions, 360° horizontally. In reality, directional antennas are recommended to be used to eliminate the interference. The antenna type can be decided later based on the outputs of this model.

g) The overall data capacity utilization of all sites in the network should be kept above certain percentage. Maintaining minimum utilization per site is not considered here since a dedicated site might be used to serve a single business customer with a relatively low data rate due to high revenue.

h) It might be required to cover a country, city or smaller region by the deployed network. Regions are divided into smaller areas of different types. Most of the areas are classified as either residential or business areas. All demand nodes located within the same area share common characteristics such as, data traffic demand and annual revenue. An average data traffic demand, in unit of Mbps, is given to each node.

i) Each demand node may include multiple CPEs. It is assumed that the data traffic demand of a CPE in a residential area is 512Kbps including both voice and data services, while it is at a minimum of 2Mbps per CPE in business areas. The price for 1Mbps data traffic is assumed to be 200AED monthly in the residential area, while it is 1,000AED in business one for the same data traffic rate.

j) In order to differentiate between data and voice services, a fixed percentage of the total provided data traffic by all installed base-stations should be dedicated for voice services and should not be multiplied by the oversubscription ratio. Typical values for the areas and their characteristics per demand node are provided in Table 1.

a) The traffic demand and annual revenue are assigned to each demand node according to the characteristics of the area in which it is located.

Table 1: Area Types, Traffic Demands and Annual Revenue per Node

Area	**Area Type**	**Number of CPEs/ Demand Node**	**Traffic Demand / Node [Mbps] (d_q)**	**Annual Revenue / Node [AED] (AR_q)**
L_r	Rural/Suburban Area	2	1	2,400
L_{uR}	Urban-Residential	4	2	4,800
L_{uB}	Urban-Business	1	2	24,000
L_{dR}	Dense Urban-Residential	8	4	9,600
L_{dB}	Dense Urban-Business	3	6	72,000
L_{IR}	Industrial-Residential	6	3	7,200
L_{IB}	Industrial- Business	2	4	48,000
L_v	Vegetation	1	0.5	1,200
L_o	Open Area	0	0	0

4.3. Model Notations

4.3.1. Sets

S: set of candidate sites at which the WiMAX base-stations are to be installed.

S = (s: 1, 2, 3… SS), where SS is the number of the candidate sites

Q: set of demand nodes.

Q = (q: 1, 2, 3… QQ), where QQ is the number of demand nodes

4.3.2. Input Parameters

R: The contention ratio or oversubscription ratio.

K: The maximum net data throughput provided by a single base-station. Its value depends on the utilized frequency channel bandwidth and the achieved modulation scheme. It is measured in Mbps.

B: Allocated budget for the network deployment project (a very high value should be used if there is no budget limitation).

C_s: Cost associated with each candidate site (s).

d_q: Traffic demand [Mbps] requested by a demand node (q). Its value depends on the customer type: residential or business. Since requested traffic demands by business demand nodes should not be shared with other nodes, their demands are multiplied by the contention ratio and results are the demands of the business nodes.

AR_q: Annual revenue in [AED] obtained if a demand node (q) is served.

TF_{sq}: Traffic factor of the connection between site (s) and node (q) that affect the actual utilization of the offered data rate by the site.

DCP: Dedicated Capacity Percentage represents a percentage of the base-station's net throughput which will not be shared among all served demand nodes. A portion of the traffic demand is dedicated to the node based on the DCP value.

NPT: Maximum transmission power from a demand node.

PRBS: Minimum received power level by the base-station.

BSPT: Maximum transmission power from a base-station.

MUP: Minimum utilization percentage of the overall network data traffic. The total traffic utilization should be maintained above this value.

BScost: Cost of each single base-station.

PTmax: Maximum transmitting power from a base-station or site.

PRMOD: Threshold power level required to achieve the minimum accepted modulation scheme.

PRsum: Sum of received power levels from all selected sites to all served nodes.

AVLth: Availability threshold. The calculated availability of any channel between a base-station located as site (s) and demand node (q) should be higher than or equal to the threshold availability.

DLDST: Downlink distance is the maximum acceptable distance between site (s) and demand node (q) in the downlink direction.

ULDST: Uplink distance is the maximum acceptable distance between demand node (q) and site (s) in the uplink direction.

DSTmax: Maximum acceptable distance between site (s) and demand node (q) considering downlink and uplink connections in order for the site to serve the node. DSTmax is the minimum value between DLDST and ULDST. Its calculation depends on the following factors:

a) The used frequency band for the WiMAX deployment (i.e. 3.5GHz band or 5.8GHz band). The higher the frequency, the lesser the distance covered.
b) The minimum accepted modulation scheme. A threshold value of the received power corresponding to the selected scheme has to be maintained. The higher is the modulation scheme, the larger required power threshold and less the distance that can be covered.
c) The maximum transmission power by a demand node, which is less than the transmission power from a base-station, and the minimum received power by the base-station in the uplink connection from node to site.

Ge_{sq} and Gr_{sq}: Gains of the transmitting antenna of a base-station and the receiving antenna of a demand node, respectively, in the downlink connection.

Ge_{qs} and Gr_{qs}: Gains of the transmitting antenna of a demand node and the receiving antenna of a base-station, respectively, in the uplink connection.

$DLPR_{sq}$: Power received by demand node (q) from site (s) in the downlink direction.

$ULPR_{qs}$: Power received by site (s) from demand node (q) in the uplink direction.

$DST\_Far\_Node_s$: Distance from site (s) to the farthest served node.

DST_{sq}: A binary indicator for the distance between site (s) and a demand node (q).

$$DST_{sq} = \begin{cases} 1 & if\ DST_{sq}\ \leq DSTmax \\ 0 & if\ DST_{sq}\ > DSTmax \end{cases}$$

LOS_{sq}: Line-of Sight existence or path clearance between site (s) and demand node (q).

$$LOS_{sq} = \begin{cases} 1 & if\ there\ is\ line-of-sight\ between\ site\ (s)\ and\ node\ (q) \\ 0 & if\ line-of-sight\ \ cannot\ be\ obtained \end{cases}$$

AVL_{sq}: A binary indicator for the availability of the channel between site (s) and demand node (q) based on the electromagnetic wave propagation conditions in the area under study.

$$AVL_{sq} = \begin{cases} 1 & if\ Channel\ availability\ is\ \geq \text{AVLth} \\ 0 & if\ Channel\ availability\ is\ < \text{AVLth} \end{cases}$$

4.3.3. Decision Variables

4.3.3.1. Binary Variables

The selection of site (s) to install the base-stations is denoted by a binary value, X_s, where;

$$X_s = \begin{cases} 1 & if\ site\ (s)\ is\ selected \\ 0 & else \end{cases}$$

The selection of site (s) to serve a demand node (q) is defined by a binary variable Y_{sq}:

$$Y_{sq} = \begin{cases} 1 & if\ site\ (s)\ is\ the\ server\ of\ node\ (q) \\ 0 & else \end{cases}$$

Site (s) can serve demand node (q) if the following conditions are satisfied:

a) Site (s) is selected.
b) There is LOS between the site (s) and node (q).
c) The distance between the site and the demand node is less than the maximum acceptable distance (DSTmax).
d) The received power by a demand node is larger than or equals the threshold power (PRMOD) to achieve the minimum modulation. The modulation at the node (q) has to be maintained above 16QAM, in order to have better service quality and traffic

utilization. Since the interference calculations are not considered, the modulation will be decided based on the received power only.

e) The calculated annual availability of the channel between site (s) and demand node (q) should be higher than a threshold value.

f) There is enough capacity at site (s) to serve the node (q).

4.3.3.2. Integer Variables

NBS_s: Number of base-stations installed at site (s). The followings should be taken into account when calculating NBS_s:

a) The overall cost should be within the allocated budget.

b) Maximum number of base-stations that can be installed at site (s) according to the available number of frequency channels and the frequency reuse factor.

4.3.3.3. Continuous Variables

PT_s: The transmission power by site (s) based on the distance to the farthest served demand node.

4.3.4. Problem Outputs

Eserved: Number of selected demand nodes to be served.

TAP: Total annual profit of the whole deployed network.

APS_s: Site annual profit obtained from serving number of demand nodes by site(s).

TUT: Overall traffic utilization of the network after assigning the selected nodes to the sites.

UT_s: Utilization of data traffic offered by site (s).

4.4. Mathematical Model Constraints

At least one of the candidate sites should be selected:

$$\sum_{s \in S} X_s \geq 1 , \qquad s \in S \tag{10}$$

A candidate site (s) cannot be a server of demand node (q) unless the site (s) is selected:

$$Y_{sq} - X_s \leq 0 , \qquad s \in S, q \in Q \tag{11}$$

A site (s) is selected if it serves at least one of the surrounding demand nodes:

$$X_s - \sum_{q \in Q} Y_{sq} \leq 0 , \qquad s \in S, q \in Q \tag{12}$$

A demand node (q) can be served by only one site.

$$\sum_{s\in S} Y_{sq} \leq 1 , \qquad s \in S, q \in Q \tag{13}$$

As discussed before, a demand node (q) might not be served by any site due to the limitations of budget, available number of channels, low profits, signal level and limited base-station capacity. The number of served demand nodes (E_{served}) is to be maximized and is calculated by:

$$E_{served} = \sum_{s\in S} \sum_{q\in Q} Y_{sq} , \qquad s \in S, q \in Q \tag{14}$$

4.4.1. Budget Constraint

The associated cost with each candidate sites (C_s), includes several components such as costs of equipment, installation, spectrum fees (paid to the telecommunication regulatory authority), site rental, tower construction (if new tower is constructed for WiMAX base-stations), operational and maintenance costs. The total cost of all selected sites should be less than the dedicated budget for the whole deployment project.

In this model, it is assumed that only the capital cost of the installed base-stations is considered while other components are ignored due to the followings:

a) The company has its own staff and they have to do the installation and maintenance as part of their daily work.
b) Sites are owned by the operator and the tower already exists and used by the mobile network.
c) The spectrum is authorized on a nation-wide basis regardless of the deployment design. The spectrum fees will not be deducted from the allocated budget for the deployment project.

The total cost of the deployed network should be less than the allocated budget.

$$\sum_{s\in S} BScost \, . \, NBS_s \leq B , \qquad s \in S \tag{15}$$

where,

BScost is the cost of single base-station and NBS_s is the number of base-stations installed at site (s).

4.4.2. Received Power Constraint

A demand node (q) is served by site (s) if the received power at the node (PR_{sq}) is larger than or equals the threshold received power to achieve the minimum accepted modulation (PRMOD):

$$PRMOD - PR_{sq} \leq Inf.(1 - Y_{sq}) , \qquad s \in S, q \in Q \qquad (16)$$

where,

Inf is any very large value.

The site (s) with the highest received power at demand node (q) is selected to be the server of the node if other conditions of the traffic utilization and annual profit are satisfied.

4.4.3. LOS Constraint

The demand node (q) can be served by site (s) if there is a clear line-of-sight between them:

$$Y_{sq} - LOS_{sq} \leq 0 , \qquad s \in S, q \in Q \qquad (17)$$

4.4.4. Availability Constraint

The service availability at a demand node (q) from site (s) is not only affected by the equipment reliability, but also by the propagation conditions in-between. Different availability standards can be considered. The node can be served by the site if the connection availability is larger than or equals a threshold value:

$$Y_{sq} - AVL_{sq} \leq 0 , \qquad s \in S, q \in Q \qquad (18)$$

4.4.5. Maximum Distance Constraint

The maximum distance that can be served by site (s) at which the threshold modulation power level can be received by demand node (q) in the downlink direction, is calculated as follows:

$$DLDST = \sqrt{\frac{BSPT . \mathrm{Ge_{sq}} . \mathrm{Gr_{sq}}}{\mathrm{PRMOD}}} * \left(\frac{\lambda}{4\pi}\right) , \qquad s \in S, q \in Q \qquad (19)$$

where,

BSPT is the maximum transmission power from a base-station, and PRMOD is the threshold received power to achieve the minimum acceptable modulation. $\mathrm{Ge_{sq}}$ and $\mathrm{Gr_{sq}}$ are the base-station transmitting antenna gain and the CPE receiving antenna gain, respectively.

The maximum distance that can be covered by a site (s) should satisfy the condition of receiving an acceptable power level at the base-station located at site (s) from the demand node in the uplink connection. The threshold received level at the base-station which should be set equally to all base-stations in the network. Hence the maximum distance from demand node (q) to site (s) is controlled by the maximum transmission power from the demand node (according to the CPE specifications) in order to receive acceptable power level at the base-station.

$$ULDST = \sqrt{\frac{NPT\ .\ \mathrm{Ge_{qs}}\ .\ \mathrm{Gr_{qs}}}{\mathrm{PRBS}}} * \left(\frac{\lambda}{4\pi}\right), \qquad s \in S,\ q \in Q \qquad (20)$$

where,

PRBS is the minimum acceptable received power by a base-station in the uplink connection, and NPT is the maximum transmission power from a demand node. $\mathrm{Ge_{qs}}$ and $\mathrm{Gr_{qs}}$ are the CPE transmitting antenna gain and the base-station receiving antenna gain, respectively.

DSTmax, which is the maximum distance in which site (s) can be selected to serve node (q), is the minimum value between DLDST and ULDST.

The demand node (q) can be served by site (s) if the distance between the server site (s) and a served demand node (q) is less than DSTmax.

$$Y_{sq} - DST_{sq} \leq 0\ , \qquad s \in S,\ q \in Q \qquad (21)$$

4.4.6. Number of base-stations Constraint

The required number of base-stations to be installed at site (s) in order to satisfy all the demands can be calculated by dividing the sum of the traffic demands from all served nodes, by the offered traffic capacity of a single base-station. The traffic factor parameter (TF_{sq}) is considered per connection from site (s) to node (q). The traffic demand calculation has to consider traffic factor that depends on the achieved modulation in order to calculate the actual utilized traffic from the site by each node. This is called "*Utilized Traffic by nodes served by site(s)*". The number of installed base-stations should have an integer value and any fractions have to be rounded up in order to satisfy the demand. The value of (0.22) in the denominator of the right hand side of the equation represents the minimum traffic factor value that corresponds to a connection achieving the best modulation.

$$NBS_s \geq \left(\frac{Utilized\ Traffic\ by\ nodes\ served\ by\ site(s)}{((0.22)\ .\ BS\ Capacity)}\right), \quad s \in S, \quad \text{or} \qquad (22)$$

Let $\quad BS\ Capacity = K.R.(1 - DCP) + K.DCP$, then (23)

$$NBS_s \geq \left(\frac{\sum_{q \in Q} Y_{sq} \cdot d_q . TF_{sq}}{(\,(0.22).(K.R.(1 - DCP) + K.DCP)\,)}\right), \qquad s \in S,\ q \in Q \qquad (24)$$

where,

K is the maximum net throughput of the base-station, R is the contention ratio, and DCP is the dedicated capacity percentage.

The last equation will prevent the site utilization to be above 100%, since the total traffic demand per site divided by total data capacity of the installed base-stations, should be less than or equal one.

The maximum number of base-stations that can be installed per site (s) can be calculated based on the number of available frequency channels that will be used for the network deployment. It is assumed that the maximum number of base-stations that can be installed at site (s) equals the number of available frequency channels multiplied by frequency reuse factor. The selected channels should satisfy acceptable separation between each two channels.

$$NBS_S \leq (Number\ of\ Available\ Channels *\ Reuse\ Factor * X_s) \qquad (25)$$

where;

Reuse factor can be 1, 2 or maximum 3, considering antenna azimuth of 60°. Six 60° sector base-stations can cover all the directions around the station. If a reuse factor of 2 is selected, the same frequency can be used only twice for two base-stations at the same site.

4.4.7. Base-Station Transmission Power and Related Constraints

The model has to find out the best power configuration that will achieve the required signal levels at all served demand nodes by site (s) including the farthest one. Proper PT_s value needs to be configured to satisfy the requirements of all demand nodes which are served by site (s) while eliminating the interference impact on other sites by using less transmitting power if possible.

The received power levels at all served demand nodes should be maintained above the CPE reception sensitivity with a certain margin to achieve the minimum modulation scheme, PRMOD. It is also required to find out the distance to the farthest served demand node, DST_Far_Node_s. The proposed procedure is as follows:

a) Initially, the received power levels from all sites to all demand nodes are calculated using the maximum base-station transmission power.

b) After assigning the demand nodes to the sites, the model should calculate the distance between each site (s) and the farthest served demand node (q), $\mathrm{DST\_Far\_Node}_s$.

c) The minimum received power by a demand node to achieve the minimum acceptable modulation scheme in the downlink direction should be defined from the system specifications.

d) The proper value of PT_s is calculated for each selected site (s) based on the distance of demand node from its server site (s) and the received power level from the site which is supposed to provide high modulation schemes as requested.

For simplicity, proper PT_s value can be calculated for each selected site (s) using the free space model discussed in section (3.4) using the obtained values of PRMOD and $\mathrm{DST\_Far\_Node}_s$. Other propagation models which include multipath effect and other propagation losses can be used instead to obtain more accurate results.

$$PT_s = \frac{\mathrm{PRMOD}}{\mathrm{Ge}_{sq} \,.\, \mathrm{Gr}_{sq}} * \left(\frac{4\pi \,.\, \mathrm{DST\_Far\_Node}_s}{\lambda}\right)^2 \qquad (26)$$

where,

$\mathrm{DST\_Far\_Node}_s$ is the distance from site (s) to the farthest served node (q).

$$\mathrm{DST\_Far\_Node}_s \geq DST_{sq} \,.\, Y_{sq} \qquad (27)$$

The transmission power from a base-station located at site (s) is limited to the maximum power that can be transmitted by the equipment (PT_{max}) as per the manufacturer specifications.

$$PT_s \leq PT_{max} \cdot X_s \qquad (28)$$

4.5. Model Objectives

The multiobjective function consists of four components that need to be maximized which are: the total number of served demand nodes, the received power levels at the demand nodes, the overall traffic utilization of the installed base-stations and the total annual profit of the deployed network. This model aims at improving two main objectives; the net profit and the customer satisfaction, which are directly or indirectly affected by the four components of the multiobjective function.

The following table summarizes the components of the multiobjective function and their relationships with the net profit and customer satisfaction:

Table 2: Direct and Indirect Relationship of Four Objectives to Overall Profit and Customer Satisfaction

Main Targets	Objectives	Relationship Type	Parameter Weight
Overall Profit	Annual Profit	Direct	β1
	Data Traffic Utilization	Indirect (Due to less number of BSs to install)	β2
Customer Satisfaction	E_{served}	Direct	β3
	Received Signal Strength	Indirect (By improved signal quality and services)	β4

The overall objective is to maximize the total summation value of the four components. It is clear that each component is measured with different units. In order to sum all together, each factor has to be normalized and weighting coefficients to be assigned to each component in order to represent the importance level for the network owner. It is also required to find out the minimum and maximum values that can be obtained for each component to get the corresponding normalized value. The sum of these weights should equal 1. It is assumed that the four components are equally important for the operators since all together lead to increasing the income and net profits either at present or future. Consequently, the weighting coefficients are equivalent as well. However, if an operator prefers to use different coefficients for the four components, the Analytical Hierarchy Process (AHP) technique can be used to find out the proper values of these factors according to the importance of each objective component with respect to that particular operator.

The four components of the multiobjective function to be maximized are formulated as follows:

1) The total annual profit of the deployed network:

The annual profit (APS_s) generated by site (s) is obtained from:

$$\mathrm{APS_s} = \left(\sum_{q \in Q} Y_{sq} .\ AR_q \right) - \ C_s \tag{29}$$

where,

AR_q is the annual revenue generated by serving a demand node (q).

The overall profit (TAP) to be maximized is calculated from:

$$\text{TAP} = \sum_{s \in S} \text{APS}_s = \sum_{s \in S} \sum_{q \in Q} Y_{sq} .\ AR_q \ - \ \sum_{s \in S} C_s \tag{30}$$

Moreover, the minimum profit is zero and the maximum profit is given by:

$$\text{maximum Profit} = \sum_{q \in Q} AR_q \tag{31}$$

2) The overall traffic utilization of the deployed network:

One of the model objectives is to maximize the overall traffic utilization of the network. The summation of traffic demands from a subset of nodes which are assigned to a site (s) should be less than the total offered data traffic capacity by all base-stations installed at that site. The actual utilized traffic by a demand node (q) from site (s) depends not only on the requested traffic demands, but also on the achieved modulation, traffic factor, and contention ratio. Since the business customers need dedicated bandwidth, their traffic demands have to be multiplied by the contention ratio, if the ratio value is more than one, to avoid sharing their bandwidth with any other customers.

The maximum number of demand nodes that can be served by site (s) is limited to the maximum data offered by each site which depends on the number of installed base-stations at that site. The utilization of data traffic offered by site (s) can be calculated by:

$$UT_s = \frac{Utilized\ Traffic\ by\ Nodes\ served\ by\ Site(s)}{Offered\ Traffic\ by\ Site\ (s)} \tag{32}$$

where;

$$Utilized\ Traffic\ by\ Nodes\ served\ by\ Site(s) = \sum_{q \in Q} (Y_{sq}\ .\ d_q\ .\ TF_{sq}) \tag{33}$$

$$Offered\ Traffic\ by\ Site\ (s) = \ (0.22).(BS\ Capacity).(NBS_s) \tag{34}$$

$$UT_s = \frac{\sum_{q \in Q} (Y_{sq}\ .\ d_q\ .TF_{sq})}{(0.22)\ .\ (K.R.(1-DCP)+ K.DCP)\ .\ (NBS_s\ )} \tag{35}$$

The overall traffic utilization of the whole network (TUT) is the one to be maximized while maintaining its value below 100%. It can be calculated by:

$$TUT = \frac{\sum_{s \in S} \sum_{q \in Q} (Y_{sq}\ .\ d_q\ .TF_{sq})}{(0.22)\ .\ (K.R.(1-DCP)+ K.DCP)\ .\ (\sum_{s \in S} NBS_s)}, \qquad \text{with} \tag{36}$$

minimum Utilization = 0, and maximum Utilization = 100% = 1.

3) The total number of served demand nodes:

$$E_{\text{served}} = \sum_{s \in S} \sum_{q \in Q} Y_{sq} \, , \quad \text{with} \tag{37}$$

minimum E_{served} = 0, and maximum E_{served} = QQ.

4) The received power level at the demand node (q):

The received power level at the demand node (q) needs to be maximized by assigning it to site (s) that achieves the highest signal level at the node if all other constraints are satisfied. Instead of considering the received signal per connection, the sum of all received power levels at all served nodes from all selected sites, PRsum, is maximized in the multiobjective function.

$$\text{PRsum} = \sum_{s \in S} \sum_{q \in Q} Y_{sq} \, . \, PR_{sq} \, , \quad \text{with} \tag{38}$$

minimum sum of received power = 0W, and

$$\text{maximum sum of received power} = \sum_{s \in S} \sum_{q \in Q} PR_{sq} \tag{39}$$

The multiobjective function including the four components and their weighting coefficients is given by.

Maximize Z =

$$\left\{ \beta 1 \, . \left(\frac{\text{TAP} - 0}{Maximum\ Profit - 0} \right) + \beta 2 \, . \left(\frac{TUT - 0}{1 - 0} \right) + \beta 3 \, . \left(\frac{E_{\text{served}} - 0}{\text{QQ} - 0} \right) + \beta 4 \, . \left(\frac{\text{PRsum} - 0}{\text{Max PRsum} - 0} \right) \right\} \tag{40}$$

where;

β1 - β4: are the associated weighing factors for each of the objective function's components.

The final equation can be written as:

Maximize Z

$$= \left\{ \beta 1 \, . \left(\frac{\sum_{s \in S} \sum_{q \in Q} Y_{sq} . \ AR_q \ - \ \sum_{s \in S} C_s}{\sum_{q \in Q} AR_q} \right) + \beta 2 \, . \left(\frac{\sum_{s \in S} \sum_{q \in Q} (Y_{sq} \, . \, d_q \, . \, TF_{sq})}{(0.22) \, . \, (K.R.(1 - DCP) + K.DCP) \, . \, (\sum_{s \in S} NBS_s)} \right) + \beta 3 \, . \left(\frac{\sum_{s \in S} \sum_{q \in Q} Y_{sq}}{\text{QQ}} \right) + \beta 4 \, . \left(\frac{\sum_{s \in S} \sum_{q \in Q} Y_{sq} \, . \, PR_{sq}}{\sum_{s \in S} \sum_{q \in Q} PR_{sq}} \right) \right\} \tag{41}$$

It is clear that all objective function's components at all constraints are linear except the utilization component, which makes the problem non-concave. Therefore, this component was removed from the objective function and added as a constraint to the problem stating that the overall utilization should be maintained above a certain threshold. Different threshold value will be tried until the maximum value the modified objective function is obtained.

Given that the overall network utilization of the data traffic should larger than certain percentage (MUP), the new constraint can be written as:

$$\sum_{s\in S}\sum_{q\in Q}(Y_{sq}\,.\,d_q\,.\,TF_{sq}) \geq (MUP).\Big(\,(0.22).\big(K.R.(1-DCP)+K.DCP\big)\,.\,(\textstyle\sum_{s\in S} NBS_s)\big)\Big) \quad (42)$$

where;

MUP is minimum utilization percentage of the overall data traffic of the network.

Moreover, the site utilization is maintained below than 100% by using equation (25). Consequently the overall utilization of the network will be less than 100%:

Finally, the deployment optimization problem for fixed WiMAX network is presented below in compact form as a mixed integer linear programming (MILP):

$$\text{Maximize Z} = \left\{\beta 1\,.\left(\frac{\sum_{s\in S}\sum_{q\in Q} Y_{sq}.\ AR_q - \sum_{s\in S} C_s}{\sum_{q\in Q} AR_q}\right) + \beta 2\,.\left(\frac{\sum_{s\in S}\sum_{q\in Q}(Y_{sq}\,.\,d_q\,.\,TF_{sq})}{(0.22)\,.\,(K.R.(1-DCP)+K.DCP)\,.\,(\sum_{s\in S} NBS_s)}\right) + \beta 3\,.\left(\frac{\sum_{s\in S}\sum_{q\in Q} Y_{sq}}{\text{QQ}}\right) + \beta 4\,.\left(\frac{\sum_{s\in S}\sum_{q\in Q} Y_{sq}\,.\,PR_{sq}}{\sum_{s\in S}\sum_{q\in Q} PR_{sq}}\right)\right\} \quad (43)$$

Subject to;

$$\sum_{s\in S} X_s \geq 1\,, \quad s\in S \quad (44)$$

$$Y_{sq} - X_s \leq 0\,, \quad s\in S, q\in Q \quad (45)$$

$$X_s - \sum_{q\in Q} Y_{sq} \leq 0\,, \quad s\in S, q\in Q \quad (46)$$

$$\sum_{s\in S} Y_{sq} \leq 1\,, \quad s\in S, q\in Q \quad (47)$$

$$\sum_{s\in S} BScost\,.NBS_s \leq B\,, \quad s\in S \quad (48)$$

$$PRMOD - PR_{sq} \leq Inf * (1 - Y_{sq})\,, \quad s\in S, q\in Q \quad (49)$$

$$Y_{sq} - LOS_{sq} \leq 0\,, \quad s\in S, q\in Q \quad (50)$$

$$Y_{sq} - AVL_{sq} \leq 0\,, \quad s\in S, q\in Q \quad (51)$$

$$Y_{sq} - DST_{sq} \leq 0\,, \quad s\in S, q\in Q \quad (52)$$

$$NBS_s \geq \left(\frac{\sum_{q\in Q} Y_{sq}\,.\,d_q.TF_{sq}}{(\,(0.22).(K.R.(1-DCP)+K.DCP)\,)}\right), \quad s\in S, q\in Q \quad (53)$$

$$NBS_s \leq (Number\ of\ Available\ Channels * Reuse\ Factor * X_s), \quad s\in S \quad (54)$$

$$\text{DST\_Far\_Node}_s \geq DST_{sq} . Y_{sq} , \qquad s \in S, q \in Q \tag{55}$$

$$\sum_{s\in S} \sum_{q\in Q} (Y_{sq} . d_q . TF_{sq}) \geq (MUP).(0.22).\big(K.R.(1 - DCP) + K.DCP) . (\sum_{s\in S} NBS_s)\big), s \in S, q \in Q \tag{56}$$

$$\frac{\text{PRMOD}}{\text{Ge}_{sq} * \text{Gr}_{sq}} * (\frac{4*\pi*\text{DST\_Far\_Node}_s}{\lambda})^2 \leq PT_{max} \cdot X_s , \qquad s \in S, q \in Q \tag{57}$$

The above MILP model has (SS + (SS x QQ)) binary variables, SS integer variables, SS continuous variables, and (14 x SS x QQ) constraints. The following table below shows how the size of the developed MILP grows as the number of candidate sites and demand nodes increase.

Table 3: MILP model size with respect to the number of candidate sites and demand nodes

Scenario	SS	QQ	Variables			Constraints
			Binary	Integer	Continuous	
1	3	20	63	3	3	840
2	4	50	204	4	4	2800
3	4	70	284	4	4	3920
4	4	80	324	4	4	4480
5	5	100	505	5	5	7000
6	6	150	906	6	6	12600
7	6	200	1206	6	6	16800
8	6	250	1506	6	6	21000

CHAPTER 5

COMPUTATIONAL RESULTS AND ANALYSIS

The proposed MILP model is investigated on multiple scenarios with increasing network size and problem is solved using LINGO 8.0 software. The LINGO program is provided in Appendix A. A square service area located within two cities of UAE is considered for the network deployment. Different numbers of candidate sites and demand nodes are tested. The list of demand nodes and their characteristics including, the types of areas where they are located, coordinates of the locations' longitude and latitude, the data traffic demands and the annual revenue by each node, are given in Appendix B. There are seven business nodes; adr1, adr2, adr3, adr151, adr152, adr153, and adr154 which should be given higher priority due to their high revenues. A sensitivity analysis is conducted to find out the most critical parameters that need special attention from the network planner. A tornado diagram is plotted to rank different parameters based on their impact on the objective value.

5.1. Network Layout

A network layout is generated within around 625Km^2 area, 25Km X 25Km, in the emirates of Sharjah and Dubai as shown in Figure 6.

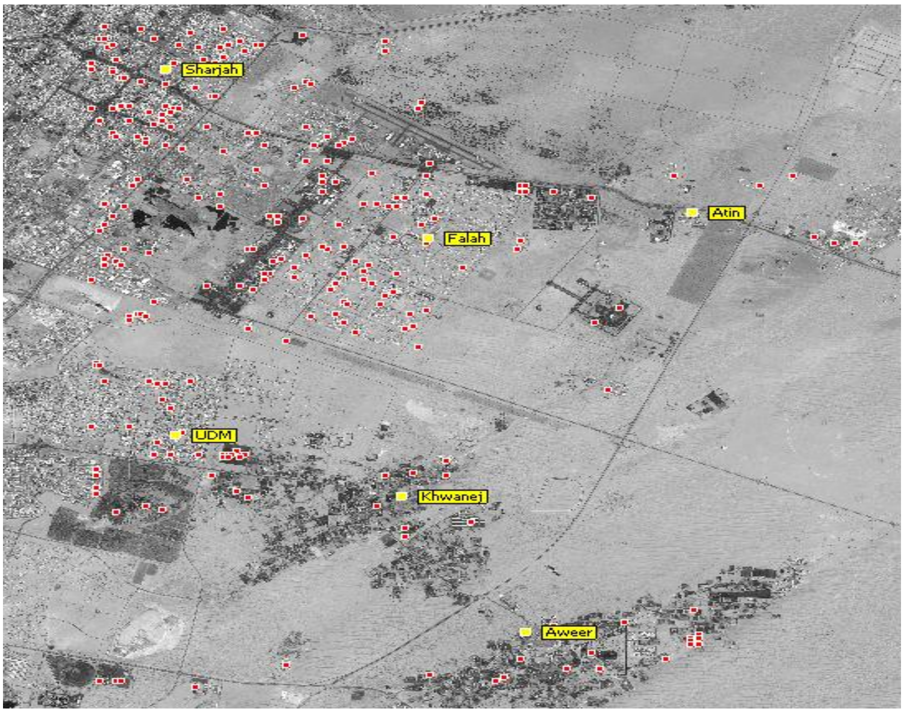

Figure 6: Network Layout

The sites and demands nodes are displayed as yellow and red square boxes, respectively.

5.2. Site Configurations and Input Model Parameters

The initial configurations of the sites are provided in Table 4. The transmission power and antenna gain are given in units of dBm and dBi, respectively. The received signal strength is calculated considering the maximum transmission power from the base-station.

Table 4: Sites' Configurations of Six Sites Scenarios

Site Number	Site Name	Longitude [DEC]	Latitude [DEC]	BS Ant. Height [m]	Frequency [GHz]	Channel bandwidth [KHz]	DL Net Data Throughput [Mbps]	Transmission power (dBm)	Antenna Gain (dBi)	Antenna Pattern	Azimuth (°)	Tilt (°)	Polarization
Site 1	Atin	55.35	25.18	35	3.5	3500	10	27	14	Omni	0	0	V
Site 2	Aweer	55.32	25.11	35	3.5	3500	10	27	14	Omni	0	0	V
Site 3	Falah	55.31	25.18	35	3.5	3500	10	27	14	Omni	0	0	V
Site 4	Khwanej	55.30	25.13	35	3.5	3500	10	27	14	Omni	0	0	V
Site 5	Sharjah	55.27	25.20	35	3.5	3500	10	27	14	Omni	0	0	V
Site 6	Oud Matina	55.27	25.14	35	3.5	3500	10	27	14	Omni	0	0	V

As explained before, the received power level at each demand node, channel availability and traffic factor for connections between all sites and nodes, in addition to the connection distance and LOS between each site and node, are calculated using commercial software, ICS Telecom, and high resolution maps for the area under study. All these values are provided in Appendix B. Table 5 gives values for the threshold power levels to achieve different modulation schemes and the resulted net data throughput in the downlink and traffic factor.

Table 5: Received power thresholds, net throughput and traffic factor of different modulation schemes

Modulation	Received Power (≥) [dBm]	DL Net Data Throughput for 3.5MHz Channel BW [Mbps]	Traffic Factor
BPSK	-91	1.7	1
QAM-4	-88	3.4	0.66
QAM-16	-81	7	0.33
QAM-64	-75	10	0.22

The model parameters have to be set carefully based on the available budget and frequency spectrum resources. It is assumed that only three frequency channels are authorized to be deployed in the network and the frequencies are not reused within the same site in order to eliminate the intra-site interference. Accordingly, maximum of three base-stations can be installed at any site. The allocated budget for the project is assumed to be 300,000AED and the cost of a single base-station is 25,000AED. The weighting coefficients associated with the objective function components are assumed to be equal, as discussed in section 4.5. Although the utilization component is removed from the objective function and added as a constraint, the overall data capacity utilization of the network is still considered in the calculation of the objective value in order to accurately assess the model performance. The utilization associated coefficient is assumed to be 0.25 in all the scenarios.

The maximum coverage distance, DSTmax, is determined from the minimum value between the DLDST and ULDST parameters. The minimum modulation scheme that needs to be maintained within the coverage area is assumed to be 16-QAM. As given in Table 5, the threshold received power level that corresponds to the 16-QAM modulation is larger than or equals -81dBm.

The transmitting and receiving antenna gains of the base-stations installed at any site, Ge_{sq} and Gr_{qs}, respectively, are equal with 14dBi gain value. On the other hand, the transmitting and receiving antennas of the CPE installed at any demand node, Ge_{qs} and Gr_{sq}, have equal gain of 17dBi. The values of BSPT and NPT are assumed to be 27dBm and 18dBm, respectively, while PRMOD and PRBS are -81dBm and -75dBm, respectively.

Accordingly, the values of DLDST and ULDST are 60.7Km and 10.8Km, respectively. A 10Km radius is considered as the maximum coverage distance of any site.

The default values of the input parameters and weighting coefficients are summarized in Table 6.

Table 6: Default Values of Input Parameters

Input Parameter	Value	Input Parameter	Value	Weighting Coefficient	Value
Contention Ratio	1	Max Distance [m]	10,000	Beta 1	0.25
Bs Cost [AED]	25,000	Number of Frequency Channels	3	Beta 2	0.25
Budget [AED]	300,000	Frequency Reuse Factor	1	Beta 3	0.25
PRMOD [dBm]	-81	Minimum Overall Utilization	50%	Beta 4	0.25
DCP	0.2	Threshold Availability	99.99		
BS Max Net Throughput (K) [Mbps]	10				

5.3. Analysis of Eight Scenarios with Different Network Sizes

Eight scenarios with different numbers of candidate sites and demand nodes are tested. The network size varies from 3 candidate sites with 20 nodes up to 6 candidate sites with 250 demand nodes. In each scenario, the demand nodes are selected in order from Table 22 in Appendix B, i.e. the 50 nodes scenario considers the first 50 nodes in the table. Tables 25 and 26 in Appendix B, present the assignment of the selected nodes to the serving sites in each scenario. The search area is found to be enlarged and the computational time increases exponentially by adding more sites and nodes. In some cases, the time also increases with changing the input parameters such as contention ratio.

5.3.1. Scenario 1 – 3 Candidate Sites with 20 Demand Nodes

The first 20 nodes of Table 22 are considered in scenario 1. The model outputs including the objective value, annual profit, capacity utilization and site transmission power are given in Table 7. The global optimum solution could be obtained after 1 second. All the 20 nodes are served with only 4 base-stations installed at only two sites: 1 and 2. The objective value is around 0.79 and the highest annual profit that can be achieved is 53,000AED. The data capacity utilization of all base-stations is 100%. The first three business nodes; adr1, adr2 and adr3, are selected first since they have higher priority than other residential nodes due to their high revenues.

Table 7: Scenario 1 results (3 Candidate Sites with 20 Demand Nodes)

Computation Time [Second]	1		
Objective Value	0.785038975		
Total Number of Served Nodes	20		
Total Number of BSs	4		
Total Annual Profit [AED]	53600		
Overall Utilization	1		
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah
	1	1	0
Number of Base-Stations/ Site	3	1	0
Number of Nodes/ Site	15	5	0
Site Utilization	1.000	1.000	0
Site Transmission Power [W]	0.035	0.015	0
Site Transmission Power [dBm]	15.389	11.836	0

5.3.2. Scenario 2 – 4 Candidate Sites with 50 Demand Nodes

Similar to scenario 1, all the demand nodes in scenario 2 are served by installing 10 base-stations in four candidate sites as given in Table 8. The objective value and the annual profit are less, since the additional 30 nodes, from adr21 to adr50, are all residential with low revenues when compared to the cost of the newly installed base-stations.

Table 8: Scenario 2 results (4 candidate sites and 50 demand nodes)

Computation Time [Second]	1			
Objective Value	0.6907651			
Total Number of Served Nodes	50			
Total Number of BSs	10			
Total Annual Profit [AED]	47600			
Overall Utilization	1			
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina
	1	1	1	1
Number of Base-Stations/ Site	2	3	3	2
Number of Nodes/ Site	10	15	15	10
Site Utilization	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.045	0.010	0.042	0.009
Site Transmission Power [dBm]	16.486	9.868	16.238	9.629

5.3.3. Scenario 3 – 4 Candidate Sites with 70 Demand Nodes

In scenario 3, 65 out of 70 nodes are served with 11 base-stations installed at 4 candidate sites. The business nodes, adr1, adr2 and adr3, are first selected to be served due to their high revenues. The nodes adr17, adr19 and adr23 are not served although one more base-station can be installed at site 4, because some of the constraints are not satisfied by this site, whereas sites 1, 2 and 3 are fully utilized and no more base-stations can be installed at any of them, as provided in Table 9. Furthermore, the nodes adr33 and adr42 are not selected since they are not economically feasible and serving them will reduce the objective value.

Table 9: Scenario 3 results (4 candidate sites and 70 demand nodes)

Computation Time [Second]	1			
Objective Value	0.7197832			
Total Number of Served Nodes	65			
Total Number of BSs	11			
Total Annual Profit [AED]	46600			
Overall Utilization	1			
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina
	1	1	1	1
Number of Base-Stations/ Site	3	3	3	2
Number of Nodes/ Site	16	15	24	10
Site Utilization	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.047	0.013	0.015	0.009
Site Transmission Power [dBm]	16.750	11.076	11.836	9.629

5.3.4. Scenario 4 – 4 Candidate Sites with 80 Demand Nodes

In this scenario, 10 demand nodes are not served for the same reasons mentioned in scenario 2. The sites 1, 2 and 3 have already three base-stations installed with 100% utilization, and site 4 does not satisfy the model constraints for 8 nodes.

Table 10: Scenario 4 results (4 candidate sites and 80 demand nodes)

Computation Time [Second]	1			
Objective Value	0.7093513			
Total Number of Served Nodes	70			
Total Number of BSs	11			
Total Annual Profit [AED]	46600			
Overall Utilization	1			
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina
	1	1	1	1
Number of Base-Stations/ Site	3	3	3	2
Number of Nodes/ Site	16	15	29	10
Site Utilization	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.047	0.013	0.003	0.009
Site Transmission Power [dBm]	16.750	11.076	5.055	9.629

5.3.5. Scenario 5 – 5 Candidate Sites with 100 Demand Nodes

The results of 100 nodes scenario are shown in Table 11. It is observed that the total annual profit is less than the profit from scenarios 1, 2, 3 and 4, since one more base-station is added to serve the additional residential nodes which have relatively low revenues in comparison to the base-station cost. Furthermore, maximum 12 base-stations can be deployed due to the budget constraint. The offered data capacity of the sites is utilized and no more nodes can be served.

Table 11: Scenario 5 results (5 candidate sites and 100 demand nodes)

Computation Time [Second]	1				
Objective Value	0.6746527				
Total Number of Served Nodes	85				
Total Number of BSs	12				
Total Annual Profit [AED]	45600				
Overall Utilization	1				
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina	Site 5: Khawaneej
	1	1	1	1	1
Number of Base-Stations/ Site	2	3	2	3	2
Number of Nodes/ Site	12	24	10	29	10
Site Utilization	1.000	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.047	0.046	0.038	0.002	0.009
Site Transmission Power [dBm]	16.750	16.613	15.757	3.568	9.629

5.3.6. Scenario 6 – 6 Candidate Sites with 150 Demand Nodes

In scenario 6, only five sites are selected to serve 109 demand nodes. It is clear that the computational time increases exponentially with adding one more site and additional 20 nodes with respect to the previous scenario. Only 12 base-stations are installed due to the budget constraints. If the allocated budget and the maximum number of base-stations increase, most of the nodes can be served. Also the contention ratio is assumed to be 1. The objective value, number of served nodes and the annual profit can be also improved by using larger contention ratio but on the expense of service quality due to the bandwidth sharing. Long computational time, exceeding one week, is experienced when larger values of the ratio, number of base-stations and budget are used. For example, when the budget and the maximum number of base-stations per site are increased to 1 million and 4 base-stations, respectively, the LINGO program kept running for more than one week without finding the global optimum solution.

Table 12: Scenario 6 results (6 candidate sites and 150 demand nodes)

Computation Time [Second]	82					
Objective Value	0.660702025					
Total Number of Served Nodes	109					
Total Number of BSs	12					
Total Annual Profit [AED]	45600					
Overall Utilization	1					
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina	Site 5: Kha-waneej	Site 6: Aweer
	1	0	1	1	1	1
Number of Base-Stations/ Site	1	0	3	2	3	3
Number of Nodes/ Site	8	0	29	19	29	24
Site Utilization	1.000	0	1.000	1.000	1.000	1.000
Site Transmission Power [Watt]	0.047	0	0.046	0.044	0.002	0.018
Site Transmission Power [dBm]	16.750	0	16.613	16.475	2.840	12.443

5.3.7. Scenario 7 – 6 Candidate Sites with 200 Demand Nodes

Table 13 gives the results of running the LINGO program for 6 sites with 200 nodes scenario. Four business nodes, adr151, adr152, adr153 and adr154, in addition to another 46 residential nodes are added to the 150 nodes in scenario 6. The offered data capacity of the whole network is restricted to the limited number of base-stations to be installed at all sites because of the budget limitation. The total number of served demand nodes is less than the served nodes number of scenario 6 by 13 nodes. This is due to the limitations of budget and network capacity while giving higher priority to serve the new business nodes. Each of these new business nodes requests 4Mbps traffic demands. Accordingly, 17 residential nodes are discarded in this scenario with respect to previous one to be able to serve the new business nodes. The total annual profit is higher than the obtained profits in scenario 6 due to the high revenues of the new business nodes.

Table 13: Scenario 7 results (6 candidate sites and 200 demand nodes)

Computation Time [Second]	11
Objective Value	0.6177199
Total Number of Served Nodes	96
Total Number of BSs	12
Total Annual Profit [AED]	199200

Overall Utilization	1					
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina	Site 5: Kha-waneej	Site 6: Aweer
	1	1	1	1	1	1
Number of Base-Stations/ Site	1	1	3	2	3	2
Number of Nodes/ Site	8	6	19	18	26	19
Site Utilization	1.000	1.000	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.047	0.053	0.051	0.040	0.001	0.018
Site Transmission Power [dBm]	16.750	17.263	17.113	15.985	1.218	12.443

5.3.8. Scenario 8 – 6 Candidate Sites with 250 Demand Nodes

In scenario 8, only 128 nodes are served due to the budget limitation. The total annual profit is the same as in scenario 7, but the objective value is higher due to the larger number of served nodes. Although the network limitation of budget and capacity are the same as in scenario 7, more nodes are served by selecting many nodes with small demands, 0.5Mbps, from the additional 50 residential nodes instead of serving other few residential nodes with larger traffic demands, since the net profit in both cases is the same.

Table 14: Scenario 8 results (6 candidate sites and 250 demand nodes)

Computation Time [Second]	34					
Objective Value	0.620816125					
Total Number of Served Nodes	128					
Total Number of BSs	12					
Total Annual Profit [AED]	199200					
Overall Utilization	1					
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina	Site 5: Kha-waneej	Site 6: Aweer
	1	1	1	1	1	1
Number of Base-Stations/ Site	2	1	3	1	3	2
Number of Nodes/ Site	23	17	20	13	29	26
Site Utilization	1.000	1.000	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.048	0.053	0.051	0.051	0.027	0.005
Site Transmission Power [dBm]	16.842	17.263	17.113	17.097	14.364	6.619

A total of 6 candidate sites and 250 nodes are analyzed in scenario 9 as well. The value of frequency reuse factor is changed from 1 to 2, while keeping the number of authorized frequency channels equals 3. Accordingly, the maximum number of base-stations per site becomes 6. The allocated budget is raised to 1 million as well. The obtained results after running the program for 65 second are presented in Table 15. The number of served nodes increased from 128 to 233 nodes. Although the objective value is larger than value in case of scenario 8, the annual net profit is found to be less. The profit decreased because the additional served nodes are residential with relatively low revenues.

Table 15: Scenario 9 results (6 candidate sites and 250 demand nodes with 1Million budget and maximum 6 base-stations per site)

Computation Time [Second]	65					
Objective Value	0.73857617					
Total Number of Served Nodes	233					
Total Number of BSs	33					
Total Annual Profit [AED]	178200					
Overall Utilization	1					
Sites Selection	Site 1: Atin	Site 2: Falah	Site 3: Sharjah	Site 4: Oud Matina	Site 5: Kha-waneej	Site 6: Aweer
	1	1	1	1	1	1
Number of Base-Stations/ Site	6	3	6	6	6	6
Number of Nodes/ Site	35	22	36	39	55	46
Site Utilization	1.000	1.000	1.000	1.000	1.000	1.000
Site Transmission Power [W]	0.052	0.053	0.035	0.051	0.027	0.020
Site Transmission Power [dBm]	17.156	17.263	15.389	17.097	14.364	12.993

A summary of all the scenarios with their main outputs is presented in Table 16. It is clear that the model maximizes the overall utilization of the capacity in all the scenarios in order to serve the maximum number of nodes with the minimum number of base-station. Accordingly the net profit of the first year is above 45000AED in all the scenarios and the total objective value is maximized.

Table 16: Scenarios Comparison

Scenario #	Number of Sites	Number of Nodes	Computa-tion Time [Second]	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total An-nual Profit [AED]	Overall Utilization
1	3	20	1	0.7850	20	4	53600	1
2	4	50	1	0.6908	50	10	47600	1

3	4	70	1	0.7198	65	11	46600	1
4	4	80	1	0.7157	70	11	46600	1
5	5	100	1	0.6747	85	12	45600	1
6	6	150	84	0.6607	109	12	45600	1
7	6	200	11	0.6177	96	12	199200	1
8	6	250	34	0.6208	128	12	199200	1
9	6	250	65	0.7386	233	33	178200	1

5.4. Sensitivity Analysis

The 4 candidate sites and 70 demand nodes scenario is selected to conduct the sensitivity analysis considering the default values of input parameters given in table 5. Forty five scenarios are tested by changing the value of one parameter at a time. Most of the model parameters are tested to study their impact on the objective value such as the base-station net data throughput, base-station cost, budget, contention ratio, maximum number of base-stations per site, minimum overall utilization, DCP, AVLth and DSTth, in addition to the three weighting coefficients; β1, β3 and β4, which are associated with the number of served nodes, annual net profit and the sum of received signals' strength, respectively. β2, which is the coefficient of the overall capacity utilization, is not considered in the sensitivity analysis since it has no impact on the model's outputs after removing the utilization parameter from the objective function. However, it is used in calculation of the final objective value in each scenario.

A tornado diagram is plotted in Figure 7 to show the most critical parameters. The weighting coefficients associated with the total annual profit and total number of served nodes, β1 and β3, are the most sensitive factors that have big impact on the overall objective value. Their values should be set carefully between 0 and 1 to obtain the optimum results. The base-station's cost and net throughput showed the highest impact on the objective value among the remaining input parameters when their values changed from 20,000AED to 50,000AED and from 5Mbps to 40Mbps, respectively. Some of the parameters, such as DCP and minimum overall utilization, seem to have no impact on the objective value when the default the contention ratio is 1. This result is expected since the base-station capacity is always 10Mbps if the contention ratio is 1 regardless of the DCP value. Also the overall utilization of the default scenario is 100%; hence changing the minimum utilization has no impact on the objective value. The obtained results from each scenario are given in Table 17.

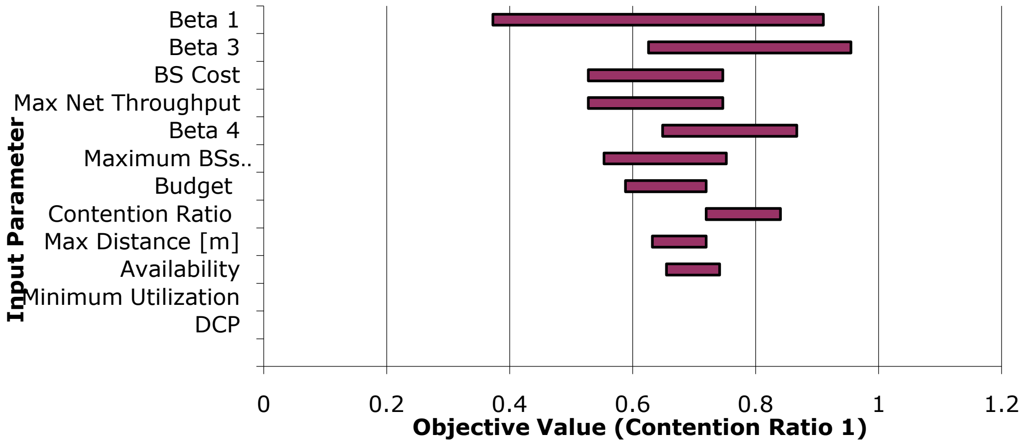

Figure 7: Tornado diagram for the 4 sites and 70 nodes sensitivity analysis (default contention ratio 1)

Table 17: Sensitivity analysis of 4 Sites and 70 nodes scenario (default contention ratio 1)

Scenario #	Parameter	Parameter Value	Computation Time	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total Annual Profit [AED]	Overall Utilization
Sc1	Availability	99%	1	0.74155	70	12	45600	1
Sc2		99.90%	1	0.74155	70	12	45600	1
Sc3		99,99%	1	0.71978	65	11	46600	1
Sc4		99.999%	1	0.65516	45	7	50600	1
Sc5	Beta 1	0 (B2=0.25 & B3=0.375 & B4=0.375)	1	0.91053	67	12	31200	0.95
Sc6		0.33 -> 0.25 (B2=0.25 & B3=0.25 & B4=0.25)	1	0.71978	65	11	46600	1
Sc7		0.375 (B2=0.25 & B3=0.1872 & B4=0.1875)	1	0.63118	65	11	46600	1
Sc8		0.75 (B2=0.25 & B3=0 & B4=0)	1	0.37283	5	1	56600	1
Sc9	Beta 3	0 (B1=0.375 & B2=0.25 & B4=0.375)	1	0.62616	55	9	48600	1
Sc10		0.33 -> 0.25 (B1=0.25 & B2=0.25 & B4=0.25)	1	0.71978	65	11	46600	1
Sc11		0.375 (B1=0.1872 & B2=0.25 & B4=0.1875	1	0.77041	67	12	31200	0.95
Sc12		0.75 (B1=0 & B2=0.25 & B4=0)	1	0.95536	67	12	31200	0.95
Sc13	Beta 4	0 (B1=0.375 & B2=0.25 & B3=0.375)	1	0.64878	65	11	46600	1
Sc14		0.33 -> 0.25 (B1=0.25 & B2=0.25 & B3=0.25)	1	0.71978	65	11	46600	1
Sc15		0.375 (B1=0.1872 & B2=0.25 & B3=0.1875	1	0.76240	65	11	46600	1
Sc16		0.75 (B1=0 & B2=0.25 & B3=0)	1	0.86722	58	11	13000	0.872727273
Sc17	Maximum Number of BSs Per Site (Number of Frequency Channels X Frequency Reuse Factor)	1 (1 X 1)	1	0.55365	28	4	53600	1
Sc18		3 (3 X 1)	1	0.71978	65	11	46600	1
Sc19		6 (2 X 3)	1	0.75239	70	12	45600	1
Sc20		8 (4 X 2)	1	0.75239	70	12	45600	1

Scenario #	Parameter	Parameter Value	Computa-tion Time	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total An-nual Profit [AED]	Overall Utilization
Sc21	Max Net Through-put	5	1	0.50813	35	10	-72400	1
Sc22		10	1	0.71978	65	11	46600	1
Sc23		20	1	0.85982	70	6	195600	1
Sc24		40	1	0.83346	70	4	245600	0.75
Sc25	BS Cost	20,000	1	0.74701	67	12	91200	0.95
Sc26		25,000	1	0.71978	65	11	46600	1
Sc27		35,000	1	0.61754	50	8	-30400	1
Sc28		50,000	1	0.52796	40	6	-98400	1
Sc29	Budget	100,000	1	0.58870	30	4	53600	1
Sc30		200,000	1	0.67483	50	8	49600	1
Sc31		300,000	1	0.71978	65	11	46600	1
Sc32		500,000	1	0.71978	65	11	46600	1
Sc33	Contention Ratio	1	1	0.71978	65	11	46600	1
Sc34		2	1	0.84051	70	7	170600	1
Sc35		4	1477	0.83076	70	5	220600	0.811764706
Sc36		10	1	0.84031	70	3	270600	0.707317073
Sc37	DCP	10%	1	0.71978	65	11	46600	1
Sc38		20%	1	0.71978	65	11	46600	1
Sc39		30%	1	0.71978	65	11	46600	1
Sc40		40%	1	0.71978	65	11	46600	1

Scenario #	Parameter	Parameter Value	Computa-tion Time	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total An-nual Profit [AED]	Overall Utilization
Sc41	Max Distance [m]	4000	1	0.63239	39	6	51600	1
Sc42		6000	1	0.67483	50	8	49600	1
Sc43		10000	1	0.71978	65	11	46600	1
Sc44		16000	1	0.71978	65	11	46600	1
Sc45	Minimum Overall Utilization	10%	1	0.71978	65	11	46600	1
Sc46		50%	1	0.71978	65	11	46600	1
Sc47		80%	1	0.71978	65	11	46600	1
Sc48		99%	1	0.71978	65	11	46600	1

The 45 scenarios are repeated considering default contention ratio value of 2. The sensitivity of different parameters changed as shown in Figure 8.

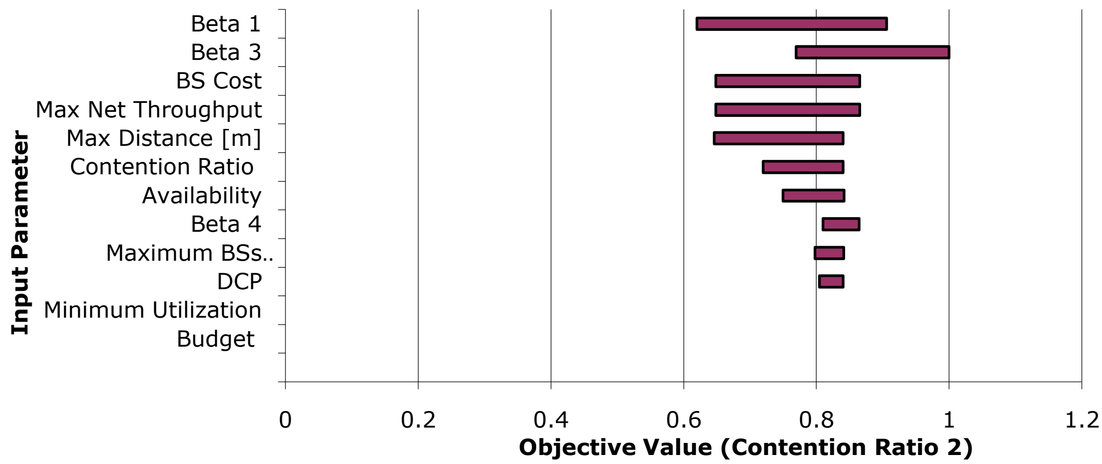

Figure 8: Tornado diagram for the 4 sites and 70 nodes sensitivity analysis (default contention ratio 2)

The overall data rate is doubled in case of increasing the contention ratio value to 2. The first four factors, β1, β3, base-station cost and base-station net throughput are the most sensitive factors. β1 and β3 coefficients are still the most critical factors. Different from previous sensitivity analysis when contention ratio is 1, the fifth and sixth most critical parameters are the maximum distance and contention ratio. Also the DCP value has low impact on the objective value. The scenarios of 5Mbps base-station net throughput and 4 contention ratio, take long computational time since the search area is enlarged. The outputs of each scenario are provided in Table 18, as well.

Table 18: Sensitivity analysis of 4 Sites and 70 nodes scenario (default contention ratio 2)

Scenario #	Parameter	Parameter Value	Computation Time	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total Annual Profit [AED]	Overall Utilization
Sc1	Availability	99%	1	0.84174	70	7	170600	1.00
Sc2		99.90%	1	0.84174	70	7	170600	1.00
Sc3		99,99%	1	0.84051	70	7	170600	1.00
Sc4		99.999%	1	0.74970	62	7	132200	0.87
Sc5	Beta 1	0 (B2=0.25 & B3=0.375 & B4=0.375)	1	0.90590	70	9	120600	0.78
Sc6		0.33 -> 0.25 (B2=0.25 & B3=0.25 & B4=0.25)	1	0.84051	70	7	170600	1.00
Sc7		0.5 -> 0.375 (B2=0.25 & B3=0.1872 & B4=0.1875)	1	0.78991	70	7	170600	1.00
Sc8		1 -> 0.75 (B2=0.25 & B3=0 & B4=0)	1	0.62023	70	7	170600	1.00
Sc9	Beta 3	0 (B1=0.375 & B2=0.25 & B4=0.375)	1	0.76971	70	7	170600	1.00
Sc10		0.33 -> 0.25 (B1=0.25 & B2=0.25 & B4=0.25)	1	0.84051	70	7	170600	1.00
Sc11		0.5 -> 0.375 (B1=0.1872 & B2=0.25 & B4=0.1875	1	0.88485	70	7	170600	1.00
Sc12		1 -> 0.75 (B1=0 & B2=0.25 & B4=0)	1	1	70	10	95600	0.70
Sc13	Beta 4	0 (B1=0.375 & B2=0.25 & B3=0.375)	1	0.81011	70	7	170600	1.00
Sc14		0.33 -> 0.25 (B1=0.25 & B2=0.25 & B3=0.25)	1	0.84051	70	7	170600	1.00
Sc15		0.5 -> 0.375 (B1=0.1872 & B2=0.25 & B3=0.1875	1	0.86465	70	7	170600	1.00
Sc16		1 -> 0.75 (B1=0 & B2=0.25 & B3=0)	1	0.84791	70	10	95600	0.70
Sc17	Maximum Number of BSs Per Site (Number of Frequency Channels X Frequency Reuse Factor)	1 (1 X 1)	1	0.79771	42	4	111200	0.97
Sc18		3 (3 X 1)	1	0.84051	70	7	170600	1.00
Sc19		6 (2 X 3)	1	0.84150	70	7	170600	1.00
Sc20		8 (4 X 2)	1	0.84150	70	7	170600	1.00

Scenario #	Parameter	Parameter Value	Computa-tion Time	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total Annual Profit [AED]	Overall Utilization
Sc21	Max Net Throughput	5	7838	0.65691	59	12	-4800	0.97
Sc22		10	1	0.84051	70	7	170600	1.00
Sc23		20	1	0.86463	70	4	245600	0.88
Sc24		40	1	0.80961	70	3	270600	0.58
Sc25	BS Cost	20,000	1	0.86557	70	7	205600	1.00
Sc26		25,000	1	0.84051	70	7	170600	1.00
Sc27		35,000	1	0.79038	70	7	100600	1.00
Sc28		50,000	1	0.64823	70	12	32400	0.58
Sc29	Budget	100,000	1	0.84051	43	4	116000	1.00
Sc30		200,000	1	0.84051	70	7	170600	1.00
Sc31		300,000	1	0.84051	70	7	170600	1.00
Sc32		500,000	1	0.84051	70	7	170600	1.00
Sc33	Contention Ratio	1	1	0.71978	65	11	46600	1.00
Sc34		2	1	0.84051	70	7	170600	1.00
Sc35		4	1477	0.83076	70	5	220600	0.81
Sc36		10	1	0.84031	70	3	270600	0.71
Sc37	DCP	10%	116	0.82760	70	7	170600	0.95
Sc38		20%	1	0.84051	70	7	170600	1.00
Sc39		30%	4	0.80449	70	8	145600	0.93
Sc40		40%	1	0.81627	70	8	145600	0.98
Sc41	Max Distance [m]	4000	1	0.64622	48	6	94800	0.78
Sc42		6000	1	0.81648	68	7	161000	0.97
Sc43		10000	1	0.84051	70	7	170600	1.00
Sc44		16000	1	0.84051	70	7	170600	1.00

Scenario #	Parameter	Parameter Value	Computa-tion Time	Objective Value	Total Number of Served Nodes	Total Number of BSs	Total Annual Profit [AED]	Overall Utilization
Sc45	Minimum Over-all Utilization	10%	1	0.84051	70	7	170600	1.00
Sc46		50%	1	0.84051	70	7	170600	1.00
Sc47		80%	1	0.84051	70	7	170600	1.00
Sc48		99%	1	0.84051	70	7	170600	1.00

CHAPTER 6

BIN PACKING (BP) GREEDY HEURISTIC PROCEDURE FOR WIMAX NETWORK DEPLOYMENT OPTIMIZATION

A bin packing greedy algorithm is proposed for the WiMAX network deployment. This is a heuristic algorithm to solve large scale optimization problem within very short computational time in comparison with the developed MILP model. The algorithm is called bin packing since a site is considered as a bin which is packed with demand nodes until its data capacity is full. Similar to the packing process of number of bins, the demand nodes are assigned to the first site if all the conditions are satisfied. The nodes should be first numbered in descending order of the revenues. In case of a tie (nodes with the same revenue), the nodes are numbered in ascending order of the data traffic demand. Once the data traffic capacity of the site is totally utilized, considering the maximum possible number of base-station per site, the algorithm starts adding the remaining nodes to the next site and so on.

6.1. Pseudo Code of the Bin Packing Greedy Algorithm

Based on the above, the pseudo code of the bin packing greedy algorithm can be written as follows:

0 - Initialization

- Input all problem parameters.
- Renumber the nodes in descending order of the annual revenues.
- Renumber the nodes with same revenues in ascending order of data traffic demands.
- Set the initial values of site traffic utilization and base-station number to zero.
- Calculate the capacity of any single base-station installed at any site using Equation (25).
- Compute the maximum possible number of base-stations that can be installed at any single site of the network, NBSmax, using the following equation:

$$\text{NBSmax} = \text{Number of Available Channels} * \text{Reuse Factor}$$

1 For each demand node (q = 1,2,3,…,QQ) do the following:

1.1 Find the site, s(q), which achieves the maximum received power at node q. s(q) = Argmax {PR_{sq}(sq)}, where Argmax is the site's number giving the maximum received power to node q.

1.2 Compute current utilized data capacity, UT_s(s(q)) from site s(q) after including node q.

1.3 Do the following:

1.3.1 If the site s(q) satisfies the following five conditions with respect to the current node, q:

– (PR_{sq}(s(q)) >= PRMOD) & (LOS_{sq}(s(q)) >= 1)
– (AVL_{sq}(s(q)) >= AVLth)
– (DST_{sq}(s(q)) <= DSTmax)
– (UT_s(s(q)) <= Maximum capacity offered by maximum number of base-stations per site), then

Calculate the number of base-station, NBS_s(s(q)), needed to satisfy the current utilized capacity.

1.3.2 If NBS_s(s(q)) > NBSmax

Then the site s cannot serve node q, i.e. Y_{sq}(s(q)) = 0, and go to step (1.4).

If NBS_s(s(q)) < NBSmax, then go to step (1.5).

1.4 Find among the remaining sites, the one satisfying all the conditions in step (1.3) to serve node q and then go to step (1.5).

If no such site is found, then node q cannot be served at all; i.e. Ysq = 0, and go to the next node (increment q by 1).

1.5 Calculate the current overall cost of all base-stations installed at all sites,

If the current overall cost > Budget, then the node q cannot be served at all and stop the program.

Else, go to the next node (increment q by 1).

2 Compute all problem outputs such as NBSs, PTs, X, and Y.

6.2. Performance Assessment of the Heuristic bin packing Algorithm

The performance of the heuristic BP algorithm is assessed by comparing its results to the optimum outputs obtained by the MILP model. All the scenarios explained in chapter 5 are solved again using MATLAB.

Table 19 presents the deviation of the BP objective value results, from the optimum values. The error is calculated by subtracting the objective values obtained by the BP algorithm from the optimum ones, then dividing the difference by the optimum objective value. The errors of the BP algorithm results are found to vary from 5% to 20% for around 83% of the scenarios.

Table 19: BP results compared to optimum objective values

	0-5%	5% - 10%	10% - 20%	20% - 30%	>30%
Number of Scenarios	7	34	40	5	4
Percentage	0.075268817	0.3978495	0.4301075	0.0537634	0.0430108

Table 20 compare the computational time required by the MILP model and the BP heuristic algorithm. It is clear that the running time of MILP programs increases exponentially while enlarging the network size and when changing the values of some parameters. However, such variations do not affect the computational time of the BP algorithm and solutions with reasonable quality can be obtained. BP algorithm can be used to solve large scale problems within short computational time.

Table 20: Comparison of the computational Times

	Computation Time [Second]	
	MILP	BP
Average	119.6	1
Minimum	1	1
Maximum	7838	1

The comparison of objective values obtained by the MILP and BP algorithm is presented in Table 21.

Table 21: Comparison of MILP and BP objective values

Scenario	Parameter	Parameter Value	Computation Time	MILP Optimum Objective Value	BP Objective Value	Difference
Sc1	6 Sites and 250 Nodes	250 Node	34	0.6208	0.440229174	0.2908864
Sc2	6 Sites and 200 Nodes	200 Node	11	0.6177	0.52540854	0.1494389
Sc3	6 Sites and 150 Nodes	150 Node	84	0.6607	0.641818342	0.0285812
Sc4	5 Sites and 100 Nodes	100 Node	1	0.6747	0.615789691	0.0872493
Sc5	4 Sites and 80 Nodes	80 Node	1	0.7157	0.63039001	0.1191715
Sc6	4 Sites and 70 Nodes	70 Node	1	0.7198	0.650210739	0.0966575
Sc7	4 Sites and 50 Nodes	50 Node	1	0.6908	0.609140464	0.1181655
Sc8	3 Sites and 20 Nodes	20 Node	1	0.7850	0.701039833	0.107
Sc9	Availability (R =1)	99%	1	0.74155375	0.653503954	0.1187369
Sc10		99.90%	1	0.74155375	0.653503954	0.1187369
Sc11		99,99%	1	0.7197832	0.650210739	0.0966575
Sc12		99.999%	1	0.655155025	0.58657469	0.104678
Sc13	Beta 1 (R =1)	0 (B2=0.25 & B3=0.375 & B4=0.375)	1	0.910528025	0.851115259	0.0652509
Sc14		0.33 -> 0.25 (B2=0.25 & B3=0.25 & B4=0.25)	1	0.71978	0.650210739	0.0966575
Sc15		0.5 -> 0.375 (B2=0.25 & B3=0.1872 & B4=0.1875)	1	0.6311785	0.556235502	0.118735
Sc16		1 -> 0.75 (B2=0.25 & B3=0 & B4=0)	1	0.372829825	0.261355745	0.2989945
Sc17	Beta 3 (R =1)	0 (B1=0.375 & B2=0.25 & B4=0.375)	1	0.626161375	0.554358066	0.1146722
Sc18		0.33 -> 0.25 (B1=0.25 & B2=0.25 & B4=0.25)	1	0.71978	0.650210739	0.0966575
Sc19		0.5 -> 0.375 (B1=0.1872 & B2=0.25 & B4=0.1875	1	0.770405375	0.704614098	0.0853983
Sc20		1 -> 0.75 (B1=0 & B2=0.25 & B4=0)	1	0.955357175	0.85487013	0.1051827
Sc21	Beta 4 (R =1)	0 (B1=0.375 & B2=0.25 & B3=0.375)	1	0.648778525	0.558112937	0.1397481
Sc22		0.33 -> 0.25 (B1=0.25 & B2=0.25 & B3=0.25)	1	0.71978	0.650210739	0.0966575
Sc23		0.5 -> 0.375 (B1=0.1872 & B2=0.25 & B3=0.1875	1	0.76240345	0.702736662	0.0782614
Sc24		1 -> 0.75 (B1=0 & B2=0.25 & B3=0)	1	0.867216743	0.847360387	0.0228966

Scenario	Parameter	Parameter Value	Computation Time	MILP Optimum Objective Value	BP Objective Value	Difference
Sc25	Maximum Number of BSs Per Site (R =1)	1 (1 X 1)	1	0.553650775	0.403354178	0.2714646
Sc26		3 (3 X 1)	1	0.7197832	0.650210739	0.0966575
Sc27		6 (2 X 3)	1	0.752393575	0.716481012	0.0477311
Sc28		8 (4 X 2)	1	0.752393575	0.716481012	0.0477311
Sc29	BS Net Throughput (R =1)	5	1	0.508126975	0.348411783	0.3143214
Sc30		10	1	0.7197832	0.650210739	0.0966575
Sc31		20	1	0.909815475	0.761950292	0.1625222
Sc32		40	1	0.83345805	0.778161229	0.0663463
Sc33	BS Cost (R =1)	20,000	1	0.747011	0.68959876	0.0768559
Sc34		25,000	1	0.7197832	0.650210739	0.0966575
Sc35		35,000	1	0.617543125	0.576585604	0.0663233
Sc36		50,000	1	0.5279572	0.48523192	0.0809257
Sc37	Budget (R =1)	100,000	1	0.5887048	0.553455402	0.0598762
Sc38		200,000	1	0.6748348	0.633877271	0.0606927
Sc39		300,000	1	0.7197832	0.650210739	0.0966575
Sc40		500,000	1	0.7197832	0.650210739	0.0966575
Sc41	Contention Ratio	1	1	0.7197832	0.403354178	0.4396171
Sc42		2	1	0.840507025	0.748641238	0.1092981
Sc43		4	1477	0.830760476	0.779375231	0.0618533
Sc44		10	1	0.840307468	0.73425879	0.1262022
Sc45	DCP (R =1)	10%	1	0.7197832	0.650210739	0.0966575
Sc46		20%	1	0.7197832	0.650210739	0.0966575
Sc47		30%	1	0.7197832	0.650210739	0.0966575
Sc48		40%	1	0.7197832	0.650210739	0.0966575

Scenario	Parameter	Parameter Value	Computation Time	MILP Optimum Objective Value	BP Objective Value	Difference
Sc49	Max Distance [m] (R =1)	4000	1	0.632393875	0.542998697	0.14136
Sc50		6000	1	0.6748348	0.595513478	0.1175418
Sc51		10000	1	0.7197832	0.650210739	0.0966575
Sc52		16000	1	0.7197832	0.650210739	0.0966575
Sc53	Availability (R =2)	99%	1	0.84174025	0.748691789	0.110543
Sc54		99.90%	1	0.84174025	0.748691789	0.110543
Sc55		99,99%	1	0.840507025	0.748641238	0.1092981
Sc56		99.999%	1	0.749695943	0.661197083	0.1180463
Sc57	Beta 1 (R =2)	0 (B2=0.25 & B3=0.375 & B4=0.375)	1	0.905900294	0.90327718	0.0028956
Sc58		0.5 -> 0.375 (B2=0.25 & B3=0.1872 & B4=0.1875)	1	0.789910225	0.679720187	0.1394969
Sc59		1 -> 0.75 (B2=0.25 & B3=0 & B4=0)	1	0.620225725	0.456163194	0.2645207
Sc60	Beta 3 (R =2)	0 (B1=0.375 & B2=0.25 & B4=0.375)	1	0.769707625	0.659136555	0.1436533
Sc61		0.5 -> 0.375 (B1=0.1872 & B2=0.25 & B4=0.1875	1	0.88485385	0.8017905	0.0938724
Sc62		1 -> 0.75 (B1=0 & B2=0.25 & B4=0)	1	1	0.944444444	0.0555556
Sc63	Beta 4 (R =2)	0 (B1=0.375 & B2=0.25 & B3=0.375)	1	0.810112825	0.700303819	0.1355478
Sc64		0.5 -> 0.375 (B1=0.1872 & B2=0.25 & B3=0.1875	1	0.86465125	0.781206868	0.0965064
Sc65		1 -> 0.75 (B1=0 & B2=0.25 & B3=0)	1	0.87911775	0.862109916	0.0193465
Sc66	Maximum Number of BSs Per Site (R =2)	1 (1 X 1)	1	0.797713481	0.504927055	0.3670321
Sc67		3 (3 X 1)	1	0.840507025	0.748641238	0.1092981
Sc68		6 (2 X 3)	1	0.841504825	0.713643	0.1519443
Sc69		8 (4 X 2)	1	0.841504825	0.713643	0.1519443
Sc70	BS Net Throughput (R =2)	5	7838	0.656912981	0.610501682	0.0706506
Sc71		10	1	0.840507025	0.748641238	0.1092981
Sc72		20	1	0.864629525	0.756090917	0.1255319
Sc73		40	1	0.809613933	0.755439875	0.0669134

Scenario	Parameter	Parameter Value	Computation Time	MILP Optimum Objective Value	BP Objective Value	Difference
Sc74	BS Cost (R =2)	20,000	1	0.865572175	0.7808678	0.0978594
Sc75		25,000	1	0.840507025	0.748641238	0.1092981
Sc76		35,000	1	0.7903768	0.698183674	0.1166445
Sc77		50,000	1	0.648226908	0.595876723	0.080759
Sc78	Budget (R =2)	100,000	1	0.840507025	0.655586198	0.220011
Sc79		200,000	1	0.840507025	0.755475341	0.1011671
Sc80		300,000	1	0.840507025	0.748641238	0.1092981
Sc81		500,000	1	0.840507025	0.748641238	0.1092981
Sc82	Contention Ratio	1	1	0.840507025	0.403354178	0.5201061
Sc83		2	1	0.840507025	0.748641238	0.1092981
Sc84		4	1477	0.830760476	0.779375231	0.0618533
Sc85		10	1	0.840307468	0.73425879	0.1262022
Sc86	DCP (R =2)	10%	116	0.827601505	0.739318876	0.1066729
Sc87		20%	1	0.840507025	0.748641238	0.1092981
Sc88		30%	4	0.804492622	0.749186934	0.068746
Sc89		40%	1	0.816269325	0.759851845	0.0691163
Sc90	Max Distance [m] (R =2)	4000	1	0.646217444	0.646217425	2.962E-08
Sc91		6000	1	0.816477017	0.707844566	0.1330502
Sc92		10000	1	0.840507025	0.748641238	0.1092981
Sc93		16000	1	0.840507025	0.748641238	0.1092981

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

A network deployment problem of fixed WiMAX technology was addressed and formulated as a Mixed Integer Linear Program. The model took into consideration the signal strength and channel availability calculations, signal quality, traffic analysis, transmission power control in downlink connections and the economic feasibility of the deployment project. It considered the LOS situation, where the path had to be clear between the end points of the connection. The site data capacity varied according to the number of base-stations installed at the site and the maximum net data throughput.

A new approach to eliminate the downlink interference was proposed. Limitations on the maximum number of base-stations to be installed per site and maximum coverage distance were added. The site transmission power was controlled by maintaining the signal quality within the coverage area above certain threshold. The model aimed at maximizing the total number of served nodes, annual profit and the received power by the serving site. The node was assigned to the site from which the maximum signal strength was received, except in some case due to load balancing. The traffic utilization of the network capacity was maintained above certain percentages to reduce the cost of new base-station installation, maximize the net profits and serving the largest number of demand nodes with the limited resources.

Multiple scenarios with different network sizes were tested to measure the performance of the proposed model. When the network size was enlarged by adding more demand nodes for the same number of sites and not changing the default values of the input parameters, a lot of nodes were discarded. However, the number of served nodes increased from 128 to 233 nodes in case of the 6 candidate sites and 250 nodes scenario, when the budget and the maximum number of base-stations per site changed from 300000AED and 3 base-stations per site to 1million AED and 6 base-stations per site, respectively. Less number of base-stations and higher profits could be achieved by increasing the contention ratio, but at the expense of the service quality.

A sensitivity analysis was performed and different network configurations were investigated. It was found that the weighting coefficients associated with the total annual profit and total number of served nodes, were the most sensitive factors that need to be set carefully. The base-station cost and net throughput were the most critical among all input parameters except the weighting coefficients.

The proposed MILP model was solved using LINGO software to search for the global optimum solutions. Long computational time was experienced when increasing the network size. Efficient processing workstations and other heuristic techniques can be incorporated to reduce the computational time.

A heuristic bin packing greedy algorithm was developed and found to produce good quality solutions in a very short computational time. The results of the MILP model and BP algorithm were compared to benchmark the performance of the heuristic algorithm. The difference of the BP results from the optimum solutions varied between 5% and 20% for more than 80% of the scenarios.

7.2. Recommendations

The BP algorithm is recommended to be used to solve large scale problems. However, advanced computers with high processing capabilities and advanced modelling software such as CPLEX [32] can be used to obtain the optimum solutions from the MILP model.

The trade-off between the service quality improvement and net profit maximization should be studied with care. Contention ratio has to be carefully decided to compromise between the cost and quality. Using high values of the contention ratio reduces the required number of base-stations and the associated cost. However, the customers will receive lower data rates than the demands due to the bandwidth sharing. If low ratio is considered to improve the service quality and increase the delivered data rates to customers, more money should be spent to install enough base-stations in order to satisfy the customers' demands.

Commercial software was used to calculate the received signal strength and other input parameters, whereas the base-station transmission power was calculated using the simple free space propagation model. In reality, other complicated propagation models incorporate different types of propagation losses, which can be used to accurately predict the attenuation factor of the wireless channel.

The equipment cost was only considered during the profit calculation. Other costs of operation, maintenance and frequency spectrum can be considered to properly calculate the net profit of the project.

This deployment model is recommended to be integrated with a frequency assignment model considering the actual locations of the sites and nodes and their directions with respect to each other in order to enhance the model performance through precise calculation of the interference and find out the best design to eliminate it.

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APPENDIX A: LINGO PROGRAM

```
MODEL:
        ! WiMAX Deployment Model;
Data:
        Number_of_Sites = 6 ;
        Number_of_Nodes = 250;
        Frequency_Channels_Number = 2;
        Frequency_Reuse_Factor = 3;
        Beta1 = 0.33;
        Beta2 = 0.25;
        Beta3 = 0.33;
        Beta4 = 0.33;
        DCP = 0.2;
        Inf=999999999;
        Cont_Ratio = 1;
        BS_Net_Throughput = 10;
        Budget = 3000000;
        BS_Cost = 25000;
        Mod_Rx_Power_Thresh = 0.00000794;
ENDDATA
SETS:
! ********* Sets' Members *********;
        Sites /1..Number_of_Sites/: X, Site_Cost, Number_BS_Per_Site, Site_Profit ;
        Nodes/1..Number_of_Nodes/:Node_Traffic_Demand,Node_Annual_Revenue;
        Site_Node_Link(Sites, Nodes): Y, Distance, LOS, DL_RSSI, Availability,
Traffic_Factor;
ENDSETS
Data:
        Node_Traffic_Demand, Node_Annual_Revenue, Distance, LOS, Traf-
fic_Factor, DL_RSSI, Availability  =
        @OLE( 'C:\Documents and Settings\Administrator\Desktop\Thesis Scena-
rios\Scenario 2 - First by First - 15 April 2011\6 Sites - 250 Nodes\Input Parameters
for Model 250 Nodes - 16 April - Final.XLSX');
```

```
@OLE( 'C:\Documents and Settings\Administrator\Desktop\Thesis Scenarios\Scenario 2 - First by First - 15 April 2011\6 Sites - 250 Nodes\Input Parameters for Model 250 Nodes - 16 April - Final.XLSX') = X, Y, Number_BS_Per_Site, Site_Profit;
EndData
! ******** Constraints *********;
	@for(Sites(s): @for(Site_Node_Link(s,q): @Bin(X(s))));
	@for(Site_Node_Link(s,q): @Bin(Y(s,q)));
	@for(Sites(s): @GIN(Number_BS_Per_Site(s)));
	@for(Sites(s): @free (Site_Profit(s)));
	@sum(Sites(s): X(s)) >= 1 ;
	@for(Site_Node_Link(s,q): Y(s,q) <= (LOS(s,q)));!
	@for(Site_Node_Link(s,q): Y(s,q) <= (Availability(s,q)));
	@for(Site_Node_Link(s,q): (Mod_Rx_Power_Thresh - DL_RSSI(s,q)) <= (Inf*(1-Y(s,q)))) ;
	@for(Site_Node_Link(s,q): Y(s,q) <= (Distance(s,q)));
	@for(Nodes(q):@sum(Sites(s): Y(s,q)) <= 1);
	BS_Data_Rate = (Cont_Ratio * BS_Capacity * (1-DCP)) + (BS_Capacity * DCP);
	@for(Sites(s): Number_BS_Per_Site(s) >= ( (@sum(Nodes(q): (Y(s,q)*Node_Traffic_Demand(q)*Traffic_Factor(s,q))) / (0.22*BS_Data_Rate)) ) );
	Max_Number_BS_Site = Frequency_Channels_Number * Frequency_Reuse_Factor;
	@for(Sites(s): Number_BS_Per_Site(s)<= (Max_Number_BS_Site * X(s)));
	@for(Sites(s): Site_Cost(s)= BS_Cost * Number_BS_Per_Site(s));
	@sum(Sites(s): Site_Cost(s)) <= Budget;
	@for(Sites(s): Site_Profit(s)= (@sum(Nodes(q): Y(s,q) * Node_Annual_Revenue(q)) - Site_Cost(s)));
	@sum(Site_Node_Link(s,q):Y(s,q)*Node_Traffic_Demand(q)*Traffic_Factor(s,q)) - (0.5*(0.22 * BS_Data_Rate *@sum(Sites(s): Number_BS_Per_Site(s))))>= 0;
	@for(Sites(s):@for(Site_Node_Link(s,q): (Y(s,q) - X(s)) <= 0)); !Site (s) can
	@for(Sites(s): X(s) - @sum(Site_Node_Link(s,q): Y(s,q)) <= 0);
!!! Multiobjective Function;
```

```
Max = ( (Beta1*(@sum(Sites(s): Site_Profit(s))/@sum (Nodes(q): Node_Annual_Revenue(q))))+(Beta3*(@sum(Site_Node_Link(s,q): Y(s,q))/Number_of_Nodes))+(Beta4*(@sum(Site_Node_Link(s,q): Y(s,q) * DL_RSSI(s,q))/@sum (Site_Node_Link(s,q): DL_RSSI(s,q)))) );
END
```

APPENDIX B: DEMAND NODES DETAILS AND SERVED NODES

Table 21 gives the details of each demand node including, the area type where it is located, the antenna height, the location coordinates in terms of longitude and latitude, the data traffic demand and the annual revenue. The received power, availability and traffic factor calculations, in addition to the distance and LOS existence of all the connections between the sites and nodes, are provided in Tables 22 and 23.

Table 22: Demand Nodes Characteristics

Demand Node	Area Type	Antenna Height [m]	Longitude	Latitude	Data Traffic Demand	Annual Revenue/ Node
adr1	Urban-Business	60	55.45138	25.35554	2	24000
adr2	Urban-Business	60	55.49356	25.31986	2	24000
adr3	Urban-Business	60	55.50453	25.31636	2	24000
adr4	Urban	60	55.49262	25.31534	2	4800
adr5	Urban	60	55.49264	25.31353	2	4800
adr6	Urban	60	55.49562	25.31356	2	4800
adr7	Urban	60	55.4629	25.30871	2	4800
adr8	Urban	60	55.51058	25.3092	2	4800
adr9	Urban	60	55.50563	25.30734	2	4800
adr10	Urban	60	55.44506	25.30582	2	4800
adr11	Urban	60	55.4679	25.30606	2	4800
adr12	Urban	60	55.50862	25.30647	2	4800
adr13	Urban	60	55.44212	25.30308	2	4800
adr14	Urban	60	55.48781	25.30265	2	4800
adr15	Urban	60	55.44017	25.30035	2	4800
adr16	Urban	60	55.49677	25.30093	2	4800
adr17	Urban	60	55.4392	25.29853	2	4800
adr18	Urban	60	55.49784	25.29463	2	4800
adr19	Urban	60	55.44522	25.29318	2	4800
adr20	Urban	60	55.47501	25.29349	2	4800
adr21	Urban	60	55.47601	25.2935	2	4800
adr22	Urban	60	55.49388	25.29368	2	4800
adr23	Urban	60	55.44127	25.29133	2	4800
adr24	Urban	60	55.48894	25.29183	2	4800
adr25	Urban	60	55.48299	25.29086	2	4800
adr26	Urban	60	55.48102	25.28994	2	4800
adr27	Urban	60	55.50289	25.28745	2	4800
adr28	Urban	60	55.48007	25.28632	2	4800
adr29	Urban	60	55.4791	25.2845	2	4800
adr30	Urban	60	55.50293	25.28474	2	4800
adr31	Urban	60	55.49599	25.28377	2	4800
adr32	Urban	60	55.50493	25.28386	2	4800
adr33	Urban	60	55.46522	25.28255	2	4800
adr34	Urban	60	55.47316	25.28263	2	4800
adr35	Urban	60	55.47615	25.28176	2	4800

Demand Node	Area Type	Antenna Height [m]	Longitude	Latitude	Data Traffic Demand	Annual Revenue/ Node
adr36	Urban	60	55.49804	25.27838	2	4800
adr37	Urban	60	55.49904	25.27748	2	4800
adr38	Urban	60	55.44844	25.27425	2	4800
adr39	Urban	60	55.44944	25.27426	2	4800
adr40	Urban	60	55.44647	25.27333	2	4800
adr41	Urban	60	55.45044	25.27337	2	4800
adr42	Urban	60	55.49016	25.27378	2	4800
adr43	Urban	60	55.44648	25.27242	2	4800
adr44	Urban	60	55.55868	25.27266	2	4800
adr45	Urban	60	55.47531	25.27002	2	4800
adr46	Urban	60	55.51608	25.26501	2	4800
adr47	Urban	60	55.4391	25.22811	2	4800
adr48	Urban	60	55.43913	25.2263	2	4800
adr49	Urban	60	55.43917	25.22269	2	4800
adr50	Urban	60	55.4392	25.22088	2	4800
adr51	Rural / Surburban	30	55.43941	25.35903	1	2400
adr52	Rural / Surburban	30	55.46824	25.35843	1	2400
adr53	Rural / Surburban	30	55.4603	25.35744	1	2400
adr54	Rural / Surburban	30	55.43847	25.3554	1	2400
adr55	Rural / Surburban	30	55.43946	25.35541	1	2400
adr56	Rural / Surburban	30	55.47226	25.35486	1	2400
adr57	Rural / Surburban	30	55.50703	25.35521	1	2400
adr58	Rural / Surburban	30	55.45737	25.3538	1	2400
adr59	Rural / Surburban	30	55.46929	25.35392	1	2400
adr60	Rural / Surburban	30	55.47624	25.35399	1	2400
adr61	Rural / Surburban	30	55.47724	25.354	1	2400
adr62	Rural / Surburban	30	55.46234	25.35294	1	2400
adr63	Rural / Surburban	30	55.46731	25.353	1	2400
adr64	Rural / Surburban	30	55.50706	25.3525	1	2400
adr65	Rural / Surburban	30	55.46834	25.3503	1	2400
adr66	Rural / Surburban	30	55.44252	25.34912	1	2400
adr67	Rural / Surburban	30	55.46338	25.34934	1	2400
adr68	Rural / Surburban	30	55.43657	25.34816	1	2400
adr69	Rural / Surburban	30	55.45644	25.34837	1	2400
adr70	Rural / Surburban	30	55.46637	25.34847	1	2400
adr71	Rural / Surburban	30	55.44156	25.34641	1	2400
adr72	Rural / Surburban	30	55.44157	25.34551	1	2400
adr73	Rural / Surburban	30	55.44358	25.34372	1	2400
adr74	Rural / Surburban	30	55.44458	25.34373	1	2400
adr75	Rural / Surburban	30	55.44856	25.34287	1	2400
adr76	Rural / Surburban	30	55.4615	25.3412	1	2400
adr77	Rural / Surburban	30	55.46551	25.33853	1	2400
adr78	Rural / Surburban	30	55.4665	25.33854	1	2400
adr79	Rural / Surburban	30	55.44369	25.33559	1	2400
adr80	Rural / Surburban	30	55.44567	25.33562	1	2400
adr81	Rural / Surburban	30	55.45461	25.33571	1	2400
adr82	Rural / Surburban	30	55.43675	25.33462	1	2400
adr83	Rural / Surburban	30	55.44171	25.33467	1	2400
adr84	Rural / Surburban	30	55.45661	25.33483	1	2400

Demand Node	Area Type	Antenna Height [m]	Longitude	Latitude	Data Traffic Demand	Annual Revenue/ Node
adr85	Rural / Surburban	30	55.45761	25.33484	1	2400
adr86	Rural / Surburban	30	55.45066	25.33386	1	2400
adr87	Rural / Surburban	30	55.45563	25.33391	1	2400
adr88	Rural / Surburban	30	55.45366	25.33299	1	2400
adr89	Rural / Surburban	30	55.44573	25.3311	1	2400
adr90	Rural / Surburban	30	55.45368	25.33119	1	2400
adr91	Rural / Surburban	30	55.4517	25.33026	1	2400
adr92	Rural / Surburban	30	55.45569	25.3294	1	2400
adr93	Rural / Surburban	30	55.44181	25.32745	1	2400
adr94	Rural / Surburban	30	55.44281	25.32656	1	2400
adr95	Rural / Surburban	30	55.44778	25.32661	1	2400
adr96	Rural / Surburban	30	55.44977	25.32573	1	2400
adr97	Rural / Surburban	30	55.45476	25.32398	1	2400
adr98	Rural / Surburban	30	55.57704	25.31618	1	2400
adr99	Rural / Surburban	30	55.59793	25.31367	1	2400
adr100	Rural / Surburban	30	55.51751	25.31017	1	2400
adr101	Rural / Surburban	30	55.51256	25.30922	1	2400
adr102	Rural / Surburban	30	55.50265	25.30731	1	2400
adr103	Rural / Surburban	30	55.51061	25.30649	1	2400
adr104	Rural / Surburban	30	55.51959	25.30297	1	2400
adr105	Rural / Surburban	30	55.51663	25.30114	1	2400
adr106	Rural / Surburban	30	55.50973	25.29746	1	2400
adr107	Rural / Surburban	30	55.61102	25.29844	1	2400
adr108	Rural / Surburban	30	55.54052	25.29686	1	2400
adr109	Rural / Surburban	30	55.53956	25.29414	1	2400
adr110	Rural / Surburban	30	55.50088	25.29014	1	2400
adr111	Rural / Surburban	30	55.50387	25.28927	1	2400
adr112	Rural / Surburban	30	55.486	25.28818	1	2400
adr113	Rural / Surburban	30	55.52672	25.2886	1	2400
adr114	Rural / Surburban	30	55.47908	25.28631	1	2400
adr115	Rural / Surburban	30	55.49794	25.2865	1	2400
adr116	Rural / Surburban	30	55.51085	25.28663	1	2400
adr117	Rural / Surburban	30	55.48604	25.28548	1	2400
adr118	Rural / Surburban	30	55.49502	25.28196	1	2400
adr119	Rural / Surburban	30	55.50992	25.28121	1	2400
adr120	Rural / Surburban	30	55.50795	25.28028	1	2400
adr121	Rural / Surburban	30	55.50699	25.27756	1	2400
adr122	Rural / Surburban	30	55.51793	25.27587	1	2400
adr123	Rural / Surburban	30	55.4961	25.27474	1	2400
adr124	Rural / Surburban	30	55.51397	25.27493	1	2400
adr125	Rural / Surburban	30	55.49812	25.27206	1	2400
adr126	Rural / Surburban	30	55.51501	25.27132	1	2400
adr127	Rural / Surburban	30	55.51303	25.2704	1	2400
adr128	Rural / Surburban	30	55.50113	25.26938	1	2400
adr129	Rural / Surburban	30	55.4387	25.2597	1	2400
adr130	Rural / Surburban	30	55.43871	25.2588	1	2400
adr131	Rural / Surburban	30	55.43971	25.25881	1	2400
adr132	Rural / Surburban	30	55.44076	25.25431	1	2400
adr133	Rural / Surburban	30	55.45168	25.25442	1	2400

Demand Node	Area Type	Antenna Height [m]	Longitude	Latitude	Data Traffic Demand	Annual Revenue/ Node
adr134	Rural / Surburban	30	55.4616	25.25453	1	2400
adr135	Rural / Surburban	30	55.45367	25.25354	1	2400
adr136	Rural / Surburban	30	55.45566	25.25356	1	2400
adr137	Rural / Surburban	30	55.5619	25.25283	1	2400
adr138	Rural / Surburban	30	55.45472	25.24904	1	2400
adr139	Rural / Surburban	30	55.45674	25.24635	1	2400
adr140	Rural / Surburban	30	55.43795	25.24073	1	2400
adr141	Rural / Surburban	30	55.44688	25.24083	1	2400
adr142	Rural / Surburban	30	55.45981	25.23916	1	2400
adr143	Rural / Surburban	30	55.45389	25.23639	1	2400
adr144	Rural / Surburban	30	55.45294	25.23277	1	2400
adr145	Rural / Surburban	30	55.45691	25.23281	1	2400
adr146	Rural / Surburban	30	55.46386	25.23288	1	2400
adr147	Rural / Surburban	30	55.52343	25.23168	1	2400
adr148	Rural / Surburban	30	55.54982	25.18319	1	2400
adr149	Rural / Surburban	30	55.44486	25.16587	1	2400
adr150	Rural / Surburban	30	55.44585	25.16588	1	2400
adr151	Industrial-Business	20	55.44837	25.35822	4	48000
adr152	Industrial-Business	20	55.44049	25.35272	4	48000
adr153	Industrial-Business	20	55.47328	25.35216	4	48000
adr154	Industrial-Business	20	55.4883	25.34328	4	48000
adr155	Industrial	20	55.4893	25.34239	3	7200
adr156	Industrial	20	55.48534	25.34145	3	7200
adr157	Industrial	20	55.46463	25.32949	3	7200
adr158	Industrial	20	55.48847	25.32974	3	7200
adr159	Industrial	20	55.47458	25.32779	3	7200
adr160	Industrial	20	55.47657	25.32781	3	7200
adr161	Industrial	20	55.49347	25.32708	3	7200
adr162	Industrial	20	55.49944	25.32624	3	7200
adr163	Industrial	20	55.49746	25.32532	3	7200
adr164	Industrial	20	55.4786	25.32422	3	7200
adr165	Industrial	20	55.49648	25.32441	3	7200
adr166	Industrial	20	55.45875	25.32311	3	7200
adr167	Industrial	20	55.46869	25.32231	3	7200
adr168	Industrial	20	55.48859	25.31981	3	7200
adr169	Industrial	20	55.47671	25.31698	3	7200
adr170	Industrial	20	55.51745	25.31559	3	7200
adr171	Industrial	20	55.60585	25.31645	3	7200
adr172	Industrial	20	55.44794	25.31397	3	7200
adr173	Industrial	20	55.45986	25.3141	3	7200
adr174	Industrial	20	55.44697	25.31216	3	7200
adr175	Industrial	20	55.47875	25.31249	3	7200
adr176	Industrial	20	55.49267	25.31083	3	7200
adr177	Industrial	20	55.46786	25.30967	3	7200
adr178	Industrial	20	55.44009	25.30667	3	7200
adr179	Industrial	20	55.51769	25.29573	3	7200
adr180	Industrial	20	55.61601	25.29668	3	7200
adr181	Industrial	20	55.62097	25.29673	3	7200
adr182	Industrial	20	55.49287	25.29458	3	7200

Demand Node	Area Type	Antenna Height [m]	Longitude	Latitude	Data Traffic Demand	Annual Revenue/ Node
adr183	Industrial	20	55.45119	25.29234	3	7200
adr184	Industrial	20	55.44029	25.29042	3	7200
adr185	Industrial	20	55.44328	25.28954	3	7200
adr186	Industrial	20	55.44032	25.28861	3	7200
adr187	Industrial	20	55.44429	25.28865	3	7200
adr188	Industrial	20	55.43739	25.28407	3	7200
adr189	Industrial	20	55.45237	25.2779	3	7200
adr190	Industrial	20	55.48429	25.2665	3	7200
adr191	Industrial	20	55.51554	25.22799	3	7200
adr192	Industrial	20	55.46692	25.22659	3	7200
adr193	Industrial	20	55.52349	25.22717	3	7200
adr194	Industrial	20	55.5296	25.21369	3	7200
adr195	Industrial	20	55.48547	25.17081	3	7200
adr196	Industrial	20	55.56088	25.17065	3	7200
adr197	Industrial	20	55.52022	25.16845	3	7200
adr198	Industrial	20	55.53809	25.16772	3	7200
adr199	Industrial	20	55.44089	25.16583	3	7200
adr200	Industrial	20	55.46373	25.16426	3	7200
adr201	Vegetation	10	55.48714	25.35681	0.5	1200
adr202	Vegetation	10	55.44147	25.35363	0.5	1200
adr203	Vegetation	10	55.43659	25.34636	0.5	1200
adr204	Vegetation	10	55.45453	25.34203	0.5	1200
adr205	Vegetation	10	55.51619	25.33725	0.5	1200
adr206	Vegetation	10	55.51522	25.33543	0.5	1200
adr207	Vegetation	10	55.43878	25.33103	0.5	1200
adr208	Vegetation	10	55.44979	25.32483	0.5	1200
adr209	Vegetation	10	55.49052	25.32434	0.5	1200
adr210	Vegetation	10	55.5184	25.31921	0.5	1200
adr211	Vegetation	10	55.54032	25.31311	0.5	1200
adr212	Vegetation	10	55.54132	25.31312	0.5	1200
adr213	Vegetation	10	55.54035	25.3113	0.5	1200
adr214	Vegetation	10	55.54134	25.31131	0.5	1200
adr215	Vegetation	10	55.54829	25.31138	0.5	1200
adr216	Vegetation	10	55.55725	25.30966	0.5	1200
adr217	Vegetation	10	55.47986	25.30347	0.5	1200
adr218	Vegetation	10	55.48184	25.30349	0.5	1200
adr219	Vegetation	10	55.48186	25.30168	0.5	1200
adr220	Vegetation	10	55.56459	25.27723	0.5	1200
adr221	Vegetation	10	55.47278	25.23388	0.5	1200
adr222	Vegetation	10	55.46981	25.23294	0.5	1200
adr223	Vegetation	10	55.47081	25.23295	0.5	1200
adr224	Vegetation	10	55.4718	25.23296	0.5	1200
adr225	Vegetation	10	55.47478	25.23299	0.5	1200
adr226	Vegetation	10	55.46983	25.23204	0.5	1200
adr227	Vegetation	10	55.47082	25.23205	0.5	1200
adr228	Vegetation	10	55.47379	25.23208	0.5	1200
adr229	Vegetation	10	55.5086	25.22702	0.5	1200
adr230	Vegetation	10	55.47293	25.22214	0.5	1200
adr231	Vegetation	10	55.47593	25.22036	0.5	1200

Demand Node	Area Type	Antenna Height [m]	Longitude	Latitude	Data Traffic Demand	Annual Revenue/ Node
adr232	Vegetation	10	55.45115	25.2174	0.5	1200
adr233	Vegetation	10	55.50673	25.21797	0.5	1200
adr234	Vegetation	10	55.45513	25.21654	0.5	1200
adr235	Vegetation	10	55.44423	25.21552	0.5	1200
adr236	Vegetation	10	55.51375	25.21172	0.5	1200
adr237	Vegetation	10	55.51378	25.20901	0.5	1200
adr238	Vegetation	10	55.5835	25.18803	0.5	1200
adr239	Vegetation	10	55.56667	25.18425	0.5	1200
adr240	Vegetation	10	55.58457	25.18081	0.5	1200
adr241	Vegetation	10	55.5826	25.17989	0.5	1200
adr242	Vegetation	10	55.58458	25.17991	0.5	1200
adr243	Vegetation	10	55.58261	25.17899	0.5	1200
adr244	Vegetation	10	55.58262	25.17809	0.5	1200
adr245	Vegetation	10	55.5846	25.17811	0.5	1200
adr246	Vegetation	10	55.55884	25.17515	0.5	1200
adr247	Vegetation	10	55.542	25.17318	0.5	1200
adr248	Vegetation	10	55.57672	25.17352	0.5	1200
adr249	Vegetation	10	55.55294	25.17058	0.5	1200
adr250	Vegetation	10	55.53612	25.1668	0.5	1200

Table 23: Received power level and availability calculations for all connections between sites and nodes

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr1	-74.5	-78	-70.8	-75.6	-52.3	-73.7	99.7876	99.2088	99.987	99.6732	100	98.9804
adr2	-70.5	-75.6	-62.4	-72.3	-65.8	-71.1	99.9925	99.6506	100	99.9433	99.9999	99.7679
adr3	-69.4	-75.2	-59.4	-71.9	-67.6	-71.2	99.9973	99.6129	100	99.9692	99.9996	99.8088
adr4	-70.6	-75.3	-61.7	-72	-66.2	-70.6	99.9933	99.6368	100	99.964	99.9998	99.848
adr5	-70.5	-75.2	-61.4	-71.8	-66.4	-70.5	99.9934	99.6574	100	99.9675	99.9998	99.8629
adr6	-70.2	-75.1	-60.7	-71.8	-66.8	-70.6	99.9933	99.7499	100	99.9529	99.9997	99.8038
adr7	-73	-75.6	-66.6	-72.2	-64.6	-69.2	99.9291	99.7824	99.9994	99.9476	99.9999	99.8698
adr8	-68.6	-74.6	-55.1	-71.2	-68.9	-70.9	99.9987	99.711	100	99.9845	99.999	99.867
adr9	-69.1	-74.6	-56	-71.1	-68.5	-70.4	99.9975	99.7554	100	99.9798	99.9991	99.8644
adr10	-74.2	-76	-68.9	-72.7	-65.2	-69	99.8672	99.7094	99.9974	99.9161	99.9998	99.8551
adr11	-72.6	-75.3	-65.7	-71.8	-65.4	-69	99.94	99.822	99.9997	99.962	99.9998	99.8994
adr12	-68.8	-74.5	-54.4	-71	-68.9	-70.5	99.9986	99.7865	100	99.9889	99.9991	99.9033
adr13	-74.4	-75.9	-69.2	-72.7	-65.9	-68.7	99.8342	99.7345	99.9964	99.9303	99.9997	99.9017
adr14	-70.9	-74.6	-61.4	-70.9	-67.4	-69.1	99.9873	99.8396	100	99.9616	99.9994	99.8906
adr15	-74.5	-75.9	-69.4	-72.6	-66.5	-68.4	99.8547	99.7047	99.9966	99.9072	99.9997	99.893
adr16	-70.1	-74.3	-58.4	-70.5	-68.4	-69.4	99.9945	99.8256	100	99.982	99.9991	99.9156
adr17	-74.6	-75.8	-69.5	-72.5	-66.8	-68.2	99.8242	99.7431	99.9958	99.9315	99.9995	99.9163
adr18	-70.1	-73.9	-57.9	-69.8	-69.1	-68.7	99.9951	99.8467	100	99.9904	99.9985	99.9493
adr19	-74.2	-75.4	-68.8	-71.8	-67.5	-67.3	99.8397	99.8174	99.997	99.9611	99.999	99.9624
adr20	-72.1	-74.4	-64.3	-70.4	-67.8	-67.4	99.9678	99.8771	99.9999	99.9744	99.999	99.9391
adr21	-72	-74.4	-64.1	-70.3	-67.9	-67.4	99.9711	99.8739	99.9999	99.9716	99.9991	99.9466
adr22	-70.5	-73.9	-59.5	-69.8	-69	-68.4	99.9935	99.8442	100	99.9905	99.9987	99.9594
adr23	-74.5	-75.4	-69.3	-71.9	-67.9	-67.1	99.8417	99.7905	99.9965	99.9476	99.9989	99.9474
adr24	-71	-73.9	-61.1	-69.7	-68.8	-67.8	99.988	99.8909	100	99.9831	99.9984	99.9526
adr25	-71.5	-74	-62.7	-69.8	-68.6	-67.4	99.9827	99.8839	100	99.9821	99.9987	99.9643
adr26	-71.7	-74	-63.2	-69.8	-68.6	-67.1	99.9823	99.8708	100	99.9861	99.9988	99.9747

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr27	-69.7	-73.3	-57.2	-68.8	-70.2	-68.3	99.9965	99.8755	100	99.9956	99.997	99.9656
adr28	-71.8	-73.8	-63.6	-69.4	-69.1	-66.5	99.9796	99.8918	100	99.9875	99.9983	99.9809
adr29	-71.9	-73.7	-63.9	-69.3	-69.2	-66.2	99.9799	99.8847	100	99.991	99.9982	99.9874
adr30	-69.8	-73.1	-57.9	-68.5	-70.5	-68	99.9967	99.8525	100	99.9972	99.9968	99.9758
adr31	-70.5	-73.2	-60.2	-68.5	-70.2	-67.3	99.9903	99.9381	100	99.9886	99.9957	99.9563
adr32	-69.6	-73	-57.6	-68.3	-70.7	-68.1	99.9968	99.8866	100	99.9971	99.996	99.9716
adr33	-73	-74.1	-66.4	-69.8	-69.1	-65.3	99.9672	99.7834	99.9998	99.9922	99.9987	99.9958
adr34	-72.4	-73.8	-65.1	-69.4	-69.3	-65.6	99.9679	99.8974	99.9999	99.9862	99.9979	99.9886
adr35	-327	-73.7	-64.7	-69.1	-69.5	-65.6	0	99.9326	99.9999	99.9917	99.9965	99.9822
adr36	-70.5	-72.7	-60.8	-67.7	-70.8	-66.9	99.9937	99.9171	100	99.9978	99.9953	99.9858
adr37	-70.4	-72.6	-60.9	-67.6	-70.9	-66.9	99.9932	99.9378	100	99.9973	99.9943	99.9824
adr38	-329	-74.3	-68.9	-70.3	-70.1	-63.7	0	99.9173	99.9958	99.9893	99.9923	99.9977
adr39	-329	-74.3	-68.8	-70.2	-70.1	-63.6	0	99.9042	99.9971	99.9851	99.9945	99.9956
adr40	-329	-74.4	-69.2	-70.3	-70.2	-63.6	0	99.8993	99.9963	99.9836	99.994	99.9957
adr41	-74.1	-74.2	-68.7	-70	-70.2	-63.4	99.9173	99.8397	99.9984	99.9866	99.9967	99.9983
adr42	-71.3	-72.6	-318	-67.4	-70.9	-65.4	99.9888	99.9216	0	99.9982	99.995	99.9946
adr43	-329	-74.3	-69.2	-70.3	-70.3	-63.4	0	99.8942	99.9966	99.9809	99.9942	99.9942
adr44	-64.1	-71.6	-65.2	-68.8	-74.5	-72	100	99.9833	99.9999	99.9986	99.9669	99.8332
adr45	-72.6	-72.9	-65.9	-67.8	-70.8	-63.2	99.9805	99.9139	99.9999	99.9987	99.9965	99.9994
adr46	-69.5	-71.1	-62.5	-65.2	-72.8	-67.6	99.9978	99.9746	100	99.9998	99.9863	99.9861
adr47	-75.9	-72.7	-327	-68.8	-74.4	-58.5	99.8294	99.924	0	99.9974	99.9575	100
adr48	-75.9	-72.7	-72.4	-68.8	-74.6	-58.9	99.8404	99.9452	99.9871	99.9979	99.958	100
adr49	-76	-72.5	-72.6	-68.8	-74.8	-59.8	99.8068	99.9266	99.983	99.9973	99.9438	100
adr50	-76.1	-72.5	-72.7	-68.8	-75	-60.2	99.7493	99.9286	99.9771	99.9955	99.9242	99.9999
adr51	-75.2	-78.4	-71.8	-76	-58.2	-74	99.8579	99.4805	99.9793	99.842	100	99.394
adr52	-73.6	-77.8	-69.9	-75.4	-57.5	-73.9	99.9533	99.6258	99.9948	99.8954	100	99.4518
adr53	-74	-77.9	-70.3	-75.5	-54.5	-73.8	99.941	99.6175	99.9935	99.8943	100	99.4981
adr54	-75.2	-78.2	-71.7	-75.8	-57.4	-73.7	99.8718	99.5353	99.9835	99.8655	100	99.5013

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr55	-75.1	-78.2	-71.6	-75.8	-57	-73.7	99.8792	99.5464	99.9848	99.8699	100	99.5128
adr56	-73.2	-77.6	-69.3	-75.1	-58	-73.6	99.9612	99.6618	99.9962	99.9088	100	99.5013
adr57	-70.8	-77.2	-67.6	-74.9	-66.6	-77.7	99.9904	99.7075	99.9983	99.9136	99.9995	97.7371
adr58	-329	-77.8	-70.3	-75.3	-50.6	-74.5	0	99.6588	99.9948	99.9109	100	99.473
adr59	-73.4	-77.6	-69.4	-75.1	-56.5	-73.6	99.9569	99.661	99.9959	99.9094	100	99.5253
adr60	-72.9	-77.5	-69	-75	-59.3	-84.4	99.9699	99.6899	99.9973	99.9185	100	0
adr61	-72.9	-77.5	-68.9	-75	-59.7	-76.3	99.9702	99.6881	99.9973	99.9175	100	98.9386
adr62	-329	-333	-69.8	-75.2	-52.4	-73.5	0	0	99.9955	99.9128	100	99.5844
adr63	-73.5	-77.6	-69.5	-75.1	-55.3	-73.5	99.9542	99.6629	99.9957	99.9107	100	99.5461
adr64	-70.7	-77.1	-67.2	-74.7	-66.5	-74	99.9902	99.7163	99.9984	99.9171	99.9994	99.2565
adr65	-328	-77.5	-69.2	-74.9	-55.2	-73.3	0	99.6801	99.9962	99.9173	100	99.5776
adr66	-74.8	-77.9	-71	-75.4	-53.8	-73.2	99.892	99.6063	99.9885	99.8939	100	99.6121
adr67	-73.6	-77.5	-69.4	-75	-51.5	-73.2	99.9513	99.6862	99.996	99.9206	100	99.624
adr68	-75.1	-78	-71.4	-75.5	-57.1	-73.2	99.882	99.6083	99.9873	99.8952	100	99.6425
adr69	-74	-77.6	-69.9	-75.1	-41	-73.9	99.9433	99.6882	99.9954	99.9225	100	99.5887
adr70	-73.4	-77.4	-69.1	-74.9	-53.6	-73.1	99.9551	99.694	99.9965	99.923	100	99.6208
adr71	-74.8	-77.8	-70.9	-75.3	-54.2	-73	99.8951	99.632	99.9896	99.904	100	99.6617
adr72	-74.8	-77.8	-70.9	-75.2	-54.2	-73	99.8934	99.6349	99.9896	99.9052	100	99.6688
adr73	-74.7	-77.7	-70.6	-75.1	-53.1	-72.8	99.8973	99.6492	99.9904	99.9105	100	99.6856
adr74	-74.6	-77.7	-70.5	-75.1	-52.3	-72.8	99.9009	99.6534	99.9909	99.912	100	99.6871
adr75	-74.4	-77.5	-70.1	-74.9	-49.1	-72.7	99.913	99.6723	99.9926	99.9185	100	99.6984
adr76	-73.5	-77.2	-68.9	-74.5	-51.2	-72.5	99.9527	99.7393	99.9971	99.9402	100	99.7393
adr77	-73.2	-77	-68.3	-74.2	-55	-72.3	99.958	99.7583	99.9978	99.9462	100	99.7536
adr78	-73.1	-77	-68.2	-74.2	-55.4	-72.3	99.9584	99.7571	99.9978	99.9457	100	99.7466
adr79	-74.5	-77.3	-70.1	-74.6	-56.2	-72.1	99.9093	99.7186	99.9934	99.9355	100	99.7948
adr80	-74.4	-77.3	-70	-74.6	-55.4	-72.1	99.9184	99.7299	99.9944	99.9391	100	99.8017
adr81	-329	-77.1	-69.1	-74.3	-53.5	-72	0	99.763	99.997	99.949	100	99.8118
adr82	-74.9	-77.5	-70.7	-74.8	-58.9	-72.1	99.89	99.7061	99.9911	99.9315	100	99.8024

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr83	-74.6	-77.3	-70.3	-74.6	-57.2	-72.1	99.8971	99.7091	99.992	99.9325	100	99.7921
adr84	-73.7	-77	-68.9	-74.2	-54.3	-72	99.9466	99.768	99.9972	99.9505	100	99.8128
adr85	-73.6	-77	-68.8	-74.2	-54.4	-72	99.9472	99.7674	99.9972	99.9503	100	99.8084
adr86	-74.1	-77.1	-69.4	-74.3	-55.2	-71.9	99.9362	99.7625	99.9964	99.9493	100	99.8278
adr87	-73.8	-77	-68.9	-74.2	-54.9	-71.9	99.9449	99.7709	99.9971	99.9516	100	99.8217
adr88	-73.9	-77	-69	-74.2	-55.5	-71.8	99.9389	99.7672	99.9967	99.9507	100	99.8258
adr89	-74.3	-77.1	-69.7	-74.3	-57.6	-71.7	99.9172	99.7532	99.9948	99.9469	100	99.8375
adr90	-73.8	-76.9	-68.9	-74.1	-56.5	-71.6	99.9381	99.7753	99.9968	99.9533	100	99.8386
adr91	-73.9	-76.9	-69.1	-74.1	-57.1	-71.6	99.9334	99.7749	99.9965	99.9534	100	99.8459
adr92	-73.7	-76.8	-68.6	-73.9	-57.5	-71.5	99.936	99.7783	99.9967	99.9543	100	99.8384
adr93	-74.5	-77	-69.9	-74.2	-59.8	-71.4	99.9165	99.7762	99.9951	99.9542	100	99.8763
adr94	-74.5	-77	-69.8	-74.1	-59.9	-71.3	99.9244	99.7907	99.9959	99.9584	100	99.8887
adr95	-74.1	-76.9	-69.3	-74	-59.2	-71.2	99.9218	99.7812	99.9957	99.9557	100	99.8698
adr96	-74	-76.8	-69	-73.8	-59.4	-71.1	99.9145	99.7749	99.9951	99.9538	100	99.8588
adr97	-73.7	-76.6	-68.4	-73.6	-59.9	-70.9	99.9464	99.8226	99.9979	99.9674	100	99.8981
adr98	-53.7	-75.1	-67.3	-73.3	-74.2	-74.7	100	99.8726	99.9984	99.9331	99.8834	97.9377
adr99	-56.7	-75.3	-69.6	-73.9	-75.5	-75.6	100	99.8321	99.9943	99.8668	99.802	97.4023
adr100	-67.7	-74.6	-54.3	-71.3	-69.5	-71.3	99.9969	99.9246	100	99.987	99.9836	99.7366
adr101	-68.3	-74.6	-54.5	-71.2	-69.1	-71	99.9975	99.9373	100	99.991	99.9952	99.8484
adr102	-69.5	-74.6	-57.2	-326	-68.2	-70.3	99.9949	99.9376	100	0	99.9975	99.9029
adr103	-68.5	-74.5	-53.5	-70.9	-69.1	-70.6	99.9956	99.9351	100	99.9907	99.9906	99.8376
adr104	-67.4	-74.1	-47.1	-70.6	-70.2	-93.9	99.9972	99.9445	100	99.9917	99.9791	0
adr105	-67.8	-74	-44.4	-70.4	-70.1	-82.6	99.997	99.9504	100	99.9934	99.9805	0
adr106	-68.7	-73.9	-50.5	-70	-69.8	-69.8	99.9958	99.9584	100	99.9956	99.9888	99.9117
adr107	-61	-74.7	-70.8	-73.8	-76.5	-75.8	100	99.8862	99.9873	99.8876	99.6352	97.0643
adr108	-64	-73.5	-58.2	-70.4	-72.2	-71.8	99.9996	99.9521	100	99.9892	99.9668	99.3681
adr109	-64.4	-73.3	-58	-70.1	-72.3	-71.6	99.9996	99.9552	100	99.99	99.9696	99.5238
adr110	-69.8	-73.5	-57.3	-69.2	-69.8	-68.4	99.981	99.9593	100	99.9963	99.9887	99.9317

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr111	-69.5	-73.4	-56.2	-69.1	-70.1	-68.6	99.9916	99.948	100	99.9934	99.994	99.927
adr112	-71.3	-73.8	-62.1	-69.4	-69.1	-67.2	99.9864	99.9684	100	99.9979	99.9968	99.9896
adr113	-66.8	-73	-53.5	-69.1	-71.7	-70.3	99.9975	99.9726	100	99.9968	99.9593	99.8195
adr114	-71.9	-73.9	-63.8	-69.5	-69	-66.5	99.9785	99.9658	99.9999	99.9977	99.9969	99.9933
adr115	-325	-73.3	-59.1	-68.8	-70	-67.8	0	99.9735	100	99.9983	99.9913	99.9793
adr116	-68.9	-73.1	-54.6	-68.7	-70.8	-68.9	99.994	99.9741	100	99.998	99.9699	99.9401
adr117	-326	-73.6	-62.4	-69.1	-69.4	-66.8	0	99.9731	100	99.9984	99.9965	99.9926
adr118	-70.6	-73.1	-316	-68.3	-70.3	-67	99.9947	99.9846	0	99.9993	99.9963	99.9941
adr119	-69.2	-72.6	-57.5	-67.9	-71.2	-68.3	99.9938	99.9813	100	99.9989	99.9701	99.9632
adr120	-69.4	-72.6	-58.2	-67.8	-71.2	-68	99.9927	99.9817	100	99.999	99.9707	99.9691
adr121	-69.6	-72.4	-59.4	-67.4	-71.3	-67.7	99.9891	99.9827	100	99.9991	99.9528	99.9699
adr122	-68.6	-72	-59	-67.1	-84.6	-68.6	99.9961	99.988	100	99.9994	99.5277	99.9576
adr123	-70.8	-72.5	-62	-67.3	-71.1	-66.2	99.9863	99.9846	99.9999	99.9994	99.9812	99.9927
adr124	-69.1	-72	-59.5	-67	-71.9	-68.1	99.9907	99.9859	100	99.9993	99.9485	99.9528
adr125	-70.7	-72.2	-62.3	-66.8	-71.4	-66.1	99.9786	99.9848	99.9999	99.9995	99.9513	99.9891
adr126	-69.2	-71.7	-60.7	-66.4	-72.3	-67.9	99.9873	99.9881	100	99.9995	99.9489	99.9492
adr127	-69.4	-71.7	-61.1	-66.2	-72.2	-67.7	99.9896	99.9894	99.9999	99.9996	99.9311	99.9675
adr128	-70.6	-71.9	-62.5	-66.2	-71.8	-66.2	99.982	99.9881	99.9998	99.9997	99.9473	99.9895
adr129	-75.1	-74.1	-70.6	-70.1	-71.8	-61.3	99.8574	99.9639	99.9898	99.9969	99.9847	99.9999
adr130	-75.1	-74	-70.6	-70	-71.9	-61.1	99.8601	99.9655	99.99	99.9971	99.9844	99.9999
adr131	-75.1	-74	-70.5	-70	-71.8	-60.9	99.8687	99.9672	99.991	99.9974	99.9852	99.9999
adr132	-75.1	-73.7	-70.7	-69.6	-72.3	-59.5	99.818	99.9674	99.9832	99.9973	99.9694	100
adr133	-74.5	-73.2	-325	-68.5	-72.2	-57.1	99.8079	99.9729	0	99.9983	99.9407	100
adr134	-73.9	-72.6	-324	-67.5	-72.2	-56.6	99.8845	99.9824	0	99.9993	99.9553	100
adr135	-74.4	-73	-325	-68.2	-72.3	-56.3	99.8809	99.9802	0	99.999	99.9696	100
adr136	-74.3	-72.9	-325	-68	-72.3	-56.1	99.8682	99.9799	0	99.999	99.9602	100
adr137	-67.2	-69.6	-67.8	-67.1	-75.6	-71.8	99.999	99.9941	99.999	99.995	99.8519	99.7054
adr138	-74.5	-72.7	-325	-67.8	-72.7	-53.4	99.8455	99.9819	0	99.9991	99.9445	100

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr139	-74.5	-72.4	-325	-67.4	-72.9	-50.7	99.7897	99.9825	0	99.9992	99.8875	100
adr140	-75.6	-73.3	-327	-69.3	-73.5	-57.9	99.8228	99.9799	0	99.9984	99.9584	100
adr141	-75.1	-72.8	-326	-68.3	-73.4	-53.2	99.7605	99.9807	0	99.9987	99.9072	100
adr142	-74.5	-71.9	-70.3	-66.5	-73.5	-34.4	99.6867	99.9864	99.9851	99.9994	99.901	100
adr143	-74.9	-72.1	-326	-67.2	-73.7	-46	99.7403	99.9865	0	99.9993	99.8402	100
adr144	-75.1	-72	-71.2	-67.2	-74	-49.9	99.7433	99.9881	99.9512	99.9994	99.8433	100
adr145	-74.9	-71.7	-70.9	-66.6	-74	-47.4	99.7711	99.9902	99.9576	99.9996	99.8435	100
adr146	-74.5	-71.2	-70.5	-65.5	-74	-49.2	99.7641	99.9922	99.9741	99.9998	99.812	100
adr147	-71.5	-66.8	-68.7	-55.6	-75.3	-67.7	99.9628	99.9995	99.9967	100	99.8106	99.9382
adr148	-74.3	-48.6	-73.7	-66.3	-78.3	-74.8	99.9318	100	99.9618	99.9994	99.4872	99.5371
adr149	-77.7	-71.4	-75.7	-70.6	-78.1	-69.6	98.4091	99.9899	99.6004	99.9899	98.7921	99.8564
adr150	-77.7	-71.3	-75.7	-70.5	-78.1	-69.6	98.5114	99.9908	99.583	99.9908	98.7318	99.8698
adr151	-330	-78.2	-71.2	-75.8	-55	-74.6	0	99.5875	99.9904	99.8845	100	99.4489
adr152	-75	-78.1	-71.4	-75.7	-55.8	-73.5	99.9007	99.6048	99.9891	99.8929	100	99.627
adr153	-73.1	-77.5	-69	-75	-57.9	-73.5	99.9707	99.7133	99.9977	99.9278	100	99.6263
adr154	-327	-332	-66.8	-74.2	-62.6	-77.8	0	0	99.9995	99.9562	100	98.4835
adr155	-327	-332	-66.6	-74.1	-62.9	-77.3	0	0	99.9996	99.9583	100	98.7698
adr156	-327	-332	-66.8	-74.1	-61.9	-79.2	0	0	99.9995	99.9579	100	96.7102
adr157	-73.1	-76.6	-67.6	-73.7	-58.6	-71.5	99.9649	99.8209	99.9988	99.9659	100	99.8726
adr158	-71.2	-76.2	-64.8	-73.2	-63.7	-75.2	99.9917	99.8753	99.9999	99.9779	100	99.617
adr159	-72.3	-76.3	-66.3	-73.3	-61.2	-71.4	99.979	99.8503	99.9996	99.9732	100	99.8779
adr160	-72.2	-76.3	-66	-73.3	-61.6	-74.9	99.9817	99.8561	99.9997	99.9745	100	99.6605
adr161	-70.7	-331	-63.7	-72.9	-65	-73.8	99.9927	0	99.9999	99.9788	99.9999	99.7303
adr162	-70.1	-75.8	-62.8	-72.8	-66	-87.1	99.9953	99.8914	100	99.981	99.9998	0
adr163	-70.3	-75.8	-62.9	-72.7	-65.8	-91.1	99.9955	99.9009	100	99.9836	99.9998	0
adr164	-71.9	-76.1	-65.4	-73	-62.7	-71.1	99.9771	99.8526	99.9996	99.9737	100	99.8712
adr165	-70.4	-75.8	-62.8	-72.7	-65.7	-87.6	99.9943	99.8939	100	99.9821	99.9998	0
adr166	-73.4	-76.4	-67.9	-73.4	-60.3	-70.8	99.9616	99.8488	99.9989	99.9741	100	99.9222

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr167	-72.7	-76.2	-66.6	-73	-61.6	-70.8	99.9788	99.8793	99.9996	99.981	100	99.9297
adr168	-71	-75.6	-63.2	-72.4	-65.1	-74.7	99.9917	99.9053	100	99.9858	99.9999	99.7323
adr169	-72	-75.7	-64.9	-72.4	-63.9	-70.4	99.9856	99.906	99.9999	99.9869	100	99.9438
adr170	-67.8	-75	-57.4	-71.8	-69.1	-71.7	99.9986	99.9256	100	99.9874	99.9961	99.8116
adr171	-60	-75.6	-70.5	-74.4	-75.9	-76.1	100	99.8196	99.9871	99.8565	99.6947	96.8884
adr172	-74	-76.3	-68.7	-73.1	-63.2	-89.4	99.9495	99.874	99.9983	99.9806	100	0
adr173	-73.2	-76	-67.2	-72.7	-63.1	-69.9	99.9698	99.8955	99.9994	99.9853	100	99.9629
adr174	-74.1	-76.2	-68.8	-73	-63.7	-69.7	99.9422	99.8717	99.998	99.9802	100	99.964
adr175	-71.8	-75.4	-64.2	-72	-65	-75	99.9872	99.9211	99.9999	99.99	99.9999	99.7844
adr176	-70.5	-75	-60.9	-71.5	-66.8	-90.7	99.9916	99.9251	100	99.9902	99.9993	0
adr177	-72.6	-75.5	-65.9	-72.1	-64.6	-69.4	99.9764	99.9139	99.9997	99.9891	99.9999	99.9692
adr178	-74.5	-76.2	-69.4	-73	-65.3	-80.6	99.9293	99.8807	99.9972	99.9822	99.9999	93.2422
adr179	-67.8	-73.6	-38.4	-69.8	-70.6	-70.2	99.9979	99.9655	100	99.9963	99.9836	99.9105
adr180	-62.4	-74.8	-71.2	-73.9	-76.7	-76	99.9998	99.8969	99.978	99.8987	99.485	97.0173
adr181	-63.5	-74.9	-327	-74.2	-77	-90.4	99.9996	99.8958	0	99.8963	99.3147	0
adr182	-70.5	-74	-59.7	-69.9	-68.8	-68.4	99.9924	99.9642	100	99.9972	99.9978	99.9802
adr183	-73.8	-75.1	-68.1	-71.4	-67.5	-70.3	99.953	99.9385	99.9989	99.9938	99.9995	99.9867
adr184	-74.6	-75.4	-69.4	-71.9	-68.1	-67	99.9152	99.9198	99.9965	99.9904	99.9991	99.994
adr185	-74.4	-75.3	-69.1	-71.7	-68.1	-66.8	99.9301	99.9305	99.9976	99.9923	99.9992	99.9954
adr186	-74.6	-75.3	-69.4	-71.8	-68.3	-66.8	99.9248	99.9296	99.9971	99.992	99.9991	99.9956
adr187	-74.3	-75.2	-69	-71.6	-68.2	-66.6	99.9325	99.934	99.9977	99.9929	99.9991	99.9959
adr188	-74.8	-75.2	-69.8	-71.7	-69	-66.2	99.9134	99.934	99.9962	99.9927	99.9985	99.9971
adr189	-329	-74.4	-68.3	-70.3	-69.6	-64.3	0	99.9647	99.9987	99.9974	99.9979	99.9993
adr190	-72	-72.3	-320	-66.7	-71.4	-63.5	99.9628	99.9854	0	99.9996	99.9693	99.999
adr191	-72.1	-66.7	-69.1	-50	-75.3	-66.7	99.9072	99.9996	99.9934	100	99.7482	99.9809
adr192	-74.6	-70.6	-70.9	-64.7	-74.5	-55	99.7923	99.9953	99.9532	99.9999	99.7746	100
adr193	-71.8	-66.1	-69.2	-53.7	-75.5	-67.8	99.9662	99.9996	99.9962	100	99.8161	99.9345
adr194	-72.6	-63	-70.8	-56.9	-76.4	-69	99.9486	100	99.9894	100	99.6995	99.8846

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr195	-76.4	-66.8	-74.6	-67.2	-78	-69.4	99.4412	99.9994	99.8648	99.9981	99.2318	99.825
adr196	-75	-58.1	-74.7	-68.7	-79	-74.8	99.8994	100	99.9284	99.9973	99.2627	99.3048
adr197	-75.7	-60	-74.5	-66.7	-78.4	-76.3	99.8035	100	99.926	99.9989	99.3777	99.2148
adr198	-75.4	-55.4	-74.6	-67.5	-78.7	-73.6	99.8495	100	99.9259	99.9985	99.3149	99.6018
adr199	-77.9	-71.8	-75.8	-70.9	-78.1	-69.7	98.7864	99.9896	99.3363	99.991	98.5741	99.9249
adr200	-77.3	-69.7	-75.4	-69.4	-78.2	-69.7	98.7928	99.9971	99.6478	99.9957	98.682	99.8971
adr201	-72.3	-333	-324	-330	-62.8	-88.9	99.9895	0	0	0	100	0
adr202	-75	-78.1	-326	-75.7	-55.6	-86.1	99.9319	99.6731	0	99.9168	100	0
adr203	-75.1	-333	-71.3	-330	-57	-80.5	99.9288	0	99.9939	0	100	92.1908
adr204	-329	-77.4	-69.6	-74.7	-45.9	-75	0	99.7854	99.998	99.9544	100	99.6045
adr205	-68.9	-331	-64.3	-73.6	-83.7	-91.3	99.9988	0	100	99.9765	99.9756	0
adr206	-68.9	-331	-319	-329	-90.2	-92.6	99.9988	0	0	0	99.4027	0
adr207	-330	-77.3	-70.3	-74.5	-59.3	-80.1	0	99.8036	99.9966	99.961	100	94.8197
adr208	-74	-76.7	-69	-73.8	-59.7	-71.1	99.9586	99.8485	99.9985	99.9737	100	99.9205
adr209	-70.9	-331	-63.7	-328	-64.8	-87.2	99.9951	0	100	0	100	0
adr210	-323	-330	-314	-327	-69	-93.6	0	0	0	0	99.9988	0
adr211	-64	-74.7	-60.3	-71.9	-71.5	-72.7	99.9999	99.9496	100	99.9901	99.9897	99.6869
adr212	-63.8	-330	-60.5	-71.9	-71.5	-72.8	100	0	100	99.9906	99.9902	99.6982
adr213	-64	-330	-59.9	-327	-71.5	-72.6	100	0	100	0	99.9909	99.7363
adr214	-63.8	-330	-60.2	-71.8	-71.6	-81.9	100	0	100	99.9914	99.9893	0
adr215	-62.2	-330	-61.9	-327	-72.2	-76.1	100	0	100	0	99.9859	99.1558
adr216	-59.5	-74.5	-63.7	-72.1	-72.9	-77.2	100	99.9524	99.9999	99.9876	99.9674	98.367
adr217	-71.7	-74.9	-63.3	-71.2	-66.6	-76.5	99.9919	99.9552	100	99.9958	99.9998	99.703
adr218	-71.5	-74.8	-62.9	-71.1	-66.8	-84.1	99.9929	99.9566	100	99.996	99.9998	0
adr219	-327	-74.7	-62.8	-70.9	-67	-87.3	0	99.9616	100	99.9967	99.9998	0
adr220	-62.5	-72.1	-65.6	-69.6	-74.6	-72.6	99.9999	99.9869	99.9979	99.9963	99.7669	99.4253
adr221	-74	-326	-69.9	-64	-74	-54.8	99.9376	0	99.9948	100	99.9448	100
adr222	-74.2	-326	-70.2	-64.5	-74.1	-53.3	99.9272	0	99.9936	100	99.9412	100

Subscriber	DL Received Power [dBm]						Availability [%]					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Matina
adr223	-74.2	-326	-325	-64.3	-74.1	-53.9	99.9296	0	0	100	99.9409	100
adr224	-74.1	-326	-325	-64.1	-74.1	-54.5	99.9319	0	0	100	99.9406	100
adr225	-74	-325	-69.9	-63.5	-74.1	-56	99.9347	0	99.9942	100	99.9349	100
adr226	-74.3	-326	-70.2	-64.4	-74.1	-53.7	99.9233	0	99.9929	100	99.9363	100
adr227	-74.2	-326	-325	-319	-74.2	-54.2	99.9279	0	0	0	99.9382	100
adr228	-74.1	-325	-70	-63.7	-74.2	-55.7	99.9308	0	99.9936	100	99.9324	100
adr229	-328	-322	-69.3	-49.5	-75.1	-65.6	0	0	99.9956	100	99.8665	99.9965
adr230	-74.5	-69.9	-71	-63.4	-74.9	-58.5	99.8166	99.9974	99.9576	100	99.7496	99.9999
adr231	-74.5	-69.5	-71	-62.8	-75	-59.8	99.8479	99.9981	99.9688	100	99.7776	99.9999
adr232	-75.7	-327	-72.4	-67.2	-75.1	-59.1	99.8298	0	99.9746	99.9997	99.8951	100
adr233	-73.2	-321	-70.4	-47.9	-75.7	-65.9	99.9344	0	99.9809	100	99.7009	99.9924
adr234	-331	-326	-72.2	-66.7	-75.2	-59.1	0	0	99.9738	99.9998	99.8804	100
adr235	-76.1	-327	-72.8	-68.2	-75.6	-60.7	99.8187	0	99.9727	99.9994	99.8993	100
adr236	-73.3	-64.4	-71	-51.4	-76.2	-67.3	99.852	99.9999	99.9811	100	99.6214	99.9568
adr237	-73.5	-63.9	-71.2	-53.7	-76.3	-86.7	99.8419	100	99.9694	100	99.4812	0
adr238	-329	-63.8	-329	-69.5	-94.9	-86.9	0	99.9999	0	99.9928	0	0
adr239	-329	-59.1	-329	-68	-95	-85.6	0	100	0	99.997	0	0
adr240	-74.2	-63.9	-330	-70	-90.5	-85.2	99.8947	99.9999	0	99.9766	94.2071	0
adr241	-329	-63.4	-74.6	-69.9	-81.9	-82.8	0	99.9999	99.9022	99.9833	98.5187	0
adr242	-74.3	-63.9	-330	-70	-82.2	-83.5	99.8952	99.9999	0	99.9789	98.4079	0
adr243	-329	-63.5	-74.7	-69.9	-82.3	-82.7	0	99.9999	99.8954	99.9803	98.3839	0
adr244	-329	-63.5	-74.8	-70	-82.1	-81.8	0	99.9999	99.8986	99.984	98.4841	0
adr245	-74.4	-63.9	-74.8	-70.1	-81.8	-81.7	99.8996	99.9998	99.8984	99.984	98.5476	0
adr246	-330	-56.2	-329	-68.1	-88.3	-86.8	0	100	0	99.9937	96.5882	0
adr247	-330	-50.5	-329	-67	-88.9	-82.3	0	100	0	99.9983	95.9951	0
adr248	-74.7	-62.3	-74.9	-69.8	-90.7	-79.3	99.8679	100	99.8866	99.984	93.8842	95.0597
adr249	-75	-55.3	-330	-323	-80.5	-76.7	99.8221	100	0	0	98.8052	98.637
adr250	-331	-56.2	-330	-67.5	-80.8	-76.5	0	100	0	99.997	98.5931	98.7714

Table 24: Values of distance, LOS and traffic factor of all connections between sites and nodes

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr1	14286.4	21386	9334.89	16155.5	1044.1	13013.9	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr2	9060.92	16130.7	3535.65	11146.3	4920.43	9693.3	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.22
adr3	7907.63	15449.6	2524.11	10623.1	6046.56	9800.51	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr4	9079.67	15685	3280.4	10670.5	5166.32	9192.39	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr5	9055.41	15495.2	3162.44	10473.8	5303.85	9007.78	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr6	8757.3	15402.9	2920.74	10423.5	5522.73	9128.53	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr7	12010.4	16249.6	5748.93	10956.7	4275.54	7816.01	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr8	7217.39	14534.4	1526.9	9800.52	7000.08	9430.28	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr9	7705.87	14455.5	1703.24	9618.73	6735.78	8988.89	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr10	13801.5	16950	7467.28	11625	4609.8	7611.83	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr11	11501.7	15747.1	5197.14	10469.5	4684.03	7566.38	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr12	7402.77	14286.4	1414.81	9504.75	7029.32	9069.75	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr13	14100.4	16880.8	7731.77	11560.3	4972.95	7375.64	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr14	9502.11	14540	3157.62	9411.16	5907.66	7707.79	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr15	14305.6	16761	7910.14	11447.7	5316.04	7130.92	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr16	8609.32	14040.7	2236.25	9025.52	6606.86	7925.91	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr17	14412.5	16664.4	8002.51	11356.9	5536.26	6964.2	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr18	8570.9	13346.2	2121.54	8318.66	7220.16	7378.35	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr19	13852.1	15822.2	7410.82	10511.9	5984.16	6236.99	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr20	10866.5	14182.4	4418.19	8905.06	6229.79	6332.46	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr21	10767.1	14135.4	4318.62	8863.97	6262.61	6360.03	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr22	8980.56	13389.9	2531.98	8297.59	7072.53	7083.08	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr23	14268.9	15915.4	7823.06	10621.7	6258.61	6140.03	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr24	9503.69	13393.3	3059.51	8228	6983.58	6664.83	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr25	10111.9	13551.8	3667.51	8321.66	6802.97	6315.85	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr26	10324.7	13550.7	3883.39	8300.6	6815.46	6146.55	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr27	8222.56	12427.8	1941.93	7454.53	8160.93	7029.23	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr28	10492.4	13241.2	4080.52	7970.57	7151.26	5738.47	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr29	10630.2	13112.6	4238.01	7829.43	7305.52	5515.44	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr30	8297.03	12143.3	2126.33	7156.82	8405.41	6801.48	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr31	8998.9	12293.1	2746	7180.53	8112.36	6280.13	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr32	8132.07	11985.4	2052.11	7034.92	8602.37	6862.23	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr33	12041.6	13674.1	5632.15	8348.66	7170.14	4949.76	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr34	11258.8	13240.1	4870.38	7925.91	7324.65	5124.45	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr35	10988.2	13000	4623.88	7694.16	7500.01	5126.4	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr36	8981.11	11661.9	2970.02	6551.34	8732.17	5946.44	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr37	8919.66	11531.7	2973.35	6432.73	8868.51	5941.39	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr38	13897.5	14018.6	7527.29	8772.7	8030.57	4123.11	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr39	13800.4	13951.7	7433.05	8700	8022.48	4100	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr40	14115.6	14080.2	7749.21	8852.69	8149.86	4080.44	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr41	13727.7	13810.5	7373.65	8558.62	8115.45	3981.21	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr42	9902.04	11538.2	3894.99	6296.83	8823.87	5044.81	1	1	0	1	1	1	0.2	0.33	0	0.22	0.22	0.22
adr43	14140	14007.2	7783.33	8786.36	8249.25	3984.97	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr44	4326.9	10242.1	4882.91	7387.88	13306.1	10756.4	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.33	0.22
adr45	11449.1	11954.1	5325.56	6628.75	8732.2	3891.07	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr46	8015.67	9656.6	3612.72	4916.33	10955.4	6484.63	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.33	0.22
adr47	16757.4	11672.6	11107.3	7454.54	13209.9	2282.64	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr48	16858.6	11583.2	11245.1	7433.06	13408.3	2385.5	1	1	1	1	1	1	0.3	0.33	0.33	0.22	0.33	0.22
adr49	17066.1	11412.7	11526.1	7406.09	13805.1	2624.95	1	1	1	1	1	1	0.3	0.33	0.33	0.22	0.33	0.22
adr50	17172.4	11331.8	11669.2	7400.68	14003.6	2758.65	1	1	1	1	1	1	0.3	0.33	0.33	0.22	0.33	0.22

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr51	15546.8	22273	10489.1	17000.1	2051.94	13520.4	1	1	1	1	1	1	0.3	0	0.22	0.33	0.22	0.33
adr52	12882.6	21009.2	8440.41	15892.9	1910.64	13345.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr53	13551.8	21207.9	8861.75	16032.9	1341.88	13203.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr54	15487.1	21964.9	10307.8	16682.1	1886.95	13138.2	1	1	1	1	1	1	0.3	0	0.22	0.33	0.22	0.33
adr55	15394.2	21918.2	10230.4	16638.6	1802.95	13124.1	1	1	1	1	1	1	0.3	0	0.22	0.33	0.22	0.33
adr56	12343.5	20496.5	7881.65	15402	2012.57	12987	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr57	9360.05	19597.3	6493.86	14905.4	5375.9	13835.1	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.33
adr58	13656.6	20957.3	8769.32	15754.5	854.89	12800.1	0	1	1	1	1	1	0	0.33	0.22	0.33	0.22	0.33
adr59	12567.5	20505.7	7981.26	15384.5	1700.13	12856.2	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr60	11942	20270.6	7571.69	15208.3	2341.06	12940.3	1	1	1	1	1	0	0.3	0.33	0.22	0.33	0.22	0
adr61	11853.3	20238.7	7516.68	15185.6	2435.26	12955.4	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr62	13159.1	20669.5	8354.68	15495.3	1063.31	12709.9	0	0	1	1	1	1	0	0	0.22	0.33	0.22	0.33
adr63	12704.8	20483.5	8028.1	15344.5	1476.63	12739.4	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr64	9183.71	19301.9	6198.4	14605.5	5333.87	13555.8	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.33
adr65	12488.8	20167.7	7733.72	15028.4	1456.15	12448.7	0	1	1	1	1	1	0	0.33	0.22	0.33	0.22	0.33
adr66	14866.1	21159.1	9560.37	15877.8	1237.13	12391.2	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr67	12907.8	20261.7	7993.15	15084.2	948.94	12314.7	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr68	15400.4	21359.2	9986.53	16059.1	1811.27	12379.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr69	13519.3	20450.3	8422.04	15228	284.04	12200.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr70	12592.5	20055.3	7715.6	14896.1	1216.72	12233.2	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr71	14862.8	20942	9462.59	15652.6	1300.2	12106.3	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr72	14831.4	20854.2	9404.82	15563.2	1304.03	12007.1	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr73	14579.8	20582.9	9126.36	15294.9	1140.35	11783.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr74	14484.5	20535.5	9044.36	15250.7	1044.22	11772.1	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr75	14073.1	20260.7	8660.85	14988.4	721.36	11634.9	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr76	12775.8	19515.3	7516.68	14302.5	922.19	11407.1	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr77	12301.7	19079.2	7017.86	13884.3	1421.38	11128.8	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr78	12206.6	19039.6	6942.64	13851.4	1500.1	11136.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr79	14333.9	19796.1	8645.26	14494.2	1628.02	10890.4	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr80	14140.1	19697.9	8472.34	14401.5	1500.16	10866.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr81	13269.9	19275.3	7710.42	14011.9	1200.22	10804.2	0	1	1	1	1	1	0	0.33	0.22	0.33	0.22	0.22
adr82	14990.7	20066.5	9213.07	14749.3	2220.48	10904.2	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr83	14504.2	19809.5	8771	14501.5	1838.58	10819	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr84	13050.7	19096.2	7488.69	13839.9	1315.46	10700.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr85	12954.2	19051.9	7406.11	13800.5	1334.32	10700.1	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr86	13606.3	19282.5	7940.44	13999	1456.21	10623.2	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr87	13121.8	19051.6	7516.68	13788.5	1403.73	10601.9	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr88	13291	19054	7632.2	13780.2	1503.46	10507.7	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr89	14024.7	19262.8	8229.85	13959	1923.64	10369.7	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr90	13244.3	18876.8	7529.3	13599	1703.05	10307.8	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr91	13417.2	18882.9	7653.78	13595.7	1824.93	10217.7	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr92	13005	18606.8	7256.05	13333.1	1902.69	10102	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr93	14337.8	19123.2	8417.28	13806.3	2469.94	10028.5	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr94	14221.5	18985.7	8285.57	13669.4	2506.13	9914.21	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr95	13729.6	18729.8	7829.45	13423.9	2308.75	9850.94	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr96	13514.8	18543.3	7605.93	13241.3	2353.76	9732.97	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr97	12987.7	18124.7	7068.27	12835.2	2500.08	9504.79	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr98	1300	15328.8	6229.77	12402	12788.3	14705.5	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.33	0.33
adr99	1835.77	15673.3	8178.64	13406.4	14893	16311	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.33	0.33
adr100	6527.64	14500.1	1403.57	9918.2	7516.65	9920.19	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr101	7017.85	14493.2	1431.8	9800.57	7161.01	9544.13	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr102	8005.64	14533.2	1941.66	9642.15	6511.54	8832.35	1	1	1	0	1	1	0.2	0.33	0.22	0	0.22	0.22

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr103	7202.78	14241.6	1280.62	9500.56	7184.01	9183.69	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr104	6303.18	13678.2	608.28	9135.13	8140.02	9426.04	1	1	1	1	1	0	0.2	0.33	0.22	0.22	0.22	0
adr105	6612.12	13533	447.21	8914.07	8028.08	9078.56	1	1	1	1	1	0	0.2	0.33	0.22	0.22	0.22	0
adr106	7343.71	13291.1	900	8502.4	7778.18	8324.08	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr107	3008.33	14676.9	9300.01	13124.4	16635.5	16715.6	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.33	0.33
adr108	4295.35	12800.4	2202.3	8886.52	10262.6	10480.9	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr109	4464.3	12501.6	2137.79	8570.31	10347	10220.1	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.33	0.22
adr110	8354.64	12775.8	1969.78	7778.2	7800.64	7140.03	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr111	8080.84	12587.3	1749.36	7642	8060.4	7247.07	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr112	9865.63	13151.9	3448.21	7937.97	7201.41	6171.76	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr113	5882.18	11994.2	1280.63	7648.56	9700	8823.84	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr114	10590.6	13288.5	4176.14	8011.33	7116.9	5700.92	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr115	8732.14	12500.1	2418.69	7433.1	7961.16	6640.06	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr116	7472.62	12103.8	1442.22	7300.73	8732.13	7495.34	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr117	9924.75	12881.1	3546.86	7655.17	7473.31	5905.99	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr118	9148.3	12146.4	2941.21	7009.47	8236.56	6060.65	1	1	0	1	1	1	0.2	0.33	0	0.22	0.22	0.22
adr119	7749.2	11552.1	2012.46	6703.03	9140.02	7009.29	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr120	7971.21	11513.6	2195.45	6612.16	9102.2	6794.13	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr121	8170.68	11258	2505.99	6319.85	9291.39	6519.21	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr122	7245.01	10770.9	2402.08	6129.49	10104.5	7267.06	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0	0.22
adr123	9304.85	11372	3397.06	6209.74	8989.44	5517.27	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr124	7648.53	10770.4	2549.51	6003.37	9940.32	6881.87	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.22	0.22
adr125	9230.93	11016.9	3500	5869.46	9347.73	5448.86	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr126	7741.45	10358.2	2927.46	5608.06	10322.8	6741.67	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.33	0.22
adr127	7964.93	10316.1	3059.41	5500.95	10290.3	6519.21	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.22	0.22
adr128	9080.2	10623.2	3584.69	5510.95	9752.95	5481.8	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.22	0.22

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr129	15305.6	13623.6	9078.57	8609.4	9749.38	3124.22	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr130	15337.9	13559.3	9124.17	8558.73	9847.87	3048.08	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr131	15243.4	13482.7	9035.51	8472.42	9831.1	2983.43	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr132	15321.3	13087.5	9192.4	8141.33	10309.7	2545.67	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.33	0.22
adr133	14300	12249.6	8266.2	7186.84	10207.8	1931.35	1	1	0	1	1	1	0.3	0.33	0	0.22	0.22	0.22
adr134	13382.5	11526.1	7465.25	6360.09	10217.6	1824.88	1	1	0	1	1	1	0.3	0.33	0	0.22	0.22	0.22
adr135	14154.9	12034.2	8160.89	6964.28	10302	1772.12	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr136	13971.4	11887.1	8000	6795.65	10300	1726.34	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr137	6168.48	8149.25	6594.73	6103.28	14991.3	10507.6	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.33	0.22
adr138	14269.6	11627.6	8386.9	6624.26	10800.5	1265	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr139	14221.5	11280.6	8429.12	6306.39	11100.5	922	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr140	16191.4	12455.7	10280.1	7844.87	11837.7	2121.54	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr141	15384.8	11706.9	9577.58	6989.33	11734.6	1237.01	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr142	14338.8	10542.4	8772.69	5700.9	11906.7	141.48	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr143	15008.3	10846.7	9404.79	6168.51	12201.6	538.61	1	1	0	1	1	1	0.3	0.33	0	0.22	0.33	0.22
adr144	15297.7	10707.1	9762.17	6161.22	12603.6	848.61	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr145	14956.6	10373.1	9492.1	5772.4	12600.4	632.57	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr146	14367	9800.58	9042.68	5096.12	12625.4	781.07	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr147	10080.2	5913.59	7310.96	1627.91	14494.1	6549.05	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.33	0.22
adr148	13921.6	728.01	13049.6	5597.33	20484.2	11011.4	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0	0.33
adr149	20738.6	10028.5	16371	9143.87	20036	8139.41	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0.33	0.22
adr150	20671.3	9929.81	16324.8	9068.65	20030.2	8121.58	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0.33	0.22
adr151	14682	21785	9759.15	16546.4	1432.1	13330.5	0	1	1	1	1	1	0	0	0.22	0.33	0.22	0.33
adr152	15192.2	21606.2	9963.99	16325	1565.54	12813.4	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr153	12120.3	20180.3	7580.29	15086.5	1992.67	12701.3	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.33
adr154	10336.9	18764.2	5916.98	13793.2	3423.55	12007.2	0	0	1	1	1	1	0	0	0.22	0.33	0.22	0.33

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr155	10204.5	18640.2	5780.19	13678.2	3535.63	11937	0	0	1	1	1	1	0	0	0.22	0.33	0.22	0.33
adr156	10531	18660.3	5907.67	13650	3157.63	11738.9	0	0	1	1	1	1	0	0	0.22	0.33	0.22	0.33
adr157	12127.7	18208.4	6490.03	12980.9	2147.2	10124.3	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr158	9808.23	17330.5	4686.22	12316.8	3894.97	10565.1	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.22
adr159	11108.6	17623.4	5560.61	12462	2900.08	10045	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr160	10914.3	17548.4	5403.74	12404.1	3041.46	10080.8	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr161	9244.51	16896.3	4140.09	11936.6	4477.77	10440.4	1	0	1	1	1	1	0.2	0	0.22	0.33	0.22	0.22
adr162	8640.08	16639	3721.61	11761.5	5053.76	10570.3	1	1	1	1	1	0	0.2	0.33	0.22	0.33	0.22	0.22
adr163	8805.75	16594.1	3744.41	11684.3	4924.5	10400.1	1	1	1	1	1	0	0.2	0.33	0.22	0.33	0.22	0.22
adr164	10630.2	17102.7	5000.01	11964.2	3465.57	9729.38	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.22
adr165	8876.99	16524.7	3720.26	11597.5	4887.79	10269.4	1	1	1	1	1	0	0.2	0.33	0.22	0.33	0.22	0.22
adr166	12576.6	17847.6	6664.13	12571.9	2630.71	9400.63	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr167	11574.2	17314.3	5730.69	12090.6	3041.52	9364.94	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr168	9552.54	16286.6	3905.18	11238	4534.37	9519.01	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.22
adr169	10692.1	16439.7	4741.37	11258	3966.2	8905.16	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.22	0.22
adr170	6609.87	15092.2	2002.52	10517.2	7206.95	10404.4	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr171	2683.28	16256.1	9024.41	14159.8	15597.8	17154	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.33	0.33
adr172	13544.8	17533	7349.9	12211.6	3667.56	8459.45	1	1	1	1	1	0	0.3	0.33	0.22	0.33	0.22	0.22
adr173	12349.2	16920	6198.46	11627.7	3634.69	8402.51	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr174	13629.8	17418.8	7398.02	12095.2	3883.4	8273.56	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr175	10438.9	15901.4	4346.33	10720.7	4494.52	8464.73	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr176	9027.21	15211	3001.69	10179	5517.26	8732.17	1	1	1	1	1	0	0.2	0.33	0.22	0.22	0.22	0.22
adr177	11515.7	16101.4	5288.72	10833.9	4301.23	7963.14	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr178	14303.2	17321.8	7976.27	12000.1	4648.76	7810.38	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr179	6576.49	12924.9	223.63	8321.71	8495.89	8700.03	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr180	3544.01	14749.3	9802.04	13384.3	17173.5	17102.6	1	1	1	1	1	1	0.2	0.33	0.22	0.33	0.33	0.33

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	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr181	4026.16	15009.7	10301.9	13780.1	17646	17568.5	1	1	0	1	1	0	0.2	0.33	0	0.33	0.33	0.33
adr182	9067.01	13519.4	2617.29	8417.34	6934	7119.76	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr183	13263.9	15381	6818.42	10060.5	6013.4	6040.85	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr184	14378.5	15902.4	7930.99	10615.2	6378.92	6073.01	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr185	14091.2	15634.1	7642.04	10339.4	6413.33	5894.21	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr186	14400.8	15749.5	7951.16	10469.1	6573.5	5882.34	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr187	14003.6	15493.4	7553.86	10198.2	6493.91	5772.5	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr188	14764.9	15572.6	8318.71	10327.8	7130.99	5515.6	1	1	1	1	1	1	0.3	0.33	0.22	0.22	0.22	0.22
adr189	13417.2	14058.6	7021.46	8772.86	7605.99	4440.95	0	1	1	1	1	1	0	0.33	0.22	0.22	0.22	0.22
adr190	10754.1	11130.7	4879.55	5818.14	9360.56	4046.02	1	1	0	1	1	1	0.2	0.33	0	0.22	0.22	0.22
adr191	10885.3	5859.25	7710.38	854.53	14499.7	5824.95	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr192	14520.7	9152.68	9430.27	4653.02	13345.4	1526.51	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr193	10486.2	5442.46	7810.26	1303.85	14937.5	6628.73	1	1	1	1	1	1	0.2	0.22	0.22	0.22	0.33	0.22
adr194	11453	3827.58	9353.62	1878.84	16546.9	7632.17	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr195	17805.9	5903.43	14430.9	6171.72	19714.5	7937.88	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0.33	0.22
adr196	15076.5	2163.33	14684	7375.65	22235.3	12720.1	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0	0.33
adr197	16400.3	2692.59	14300	5842.09	20808.7	9902.03	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0	0.22
adr198	15880.8	1581.14	14512.1	6407.82	21523.3	11172.3	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0	0.33
adr199	21010.7	10423.6	16560.5	9449.38	20063.9	8222.55	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0.33	0.22
adr200	19663.7	8200.07	15766.4	7964.95	20212.1	8209.76	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0.33	0.22
adr201	11130.8	20234.1	7291.96	15289.8	3478.89	13439.3	1	0	0	0	1	0	0.3	0	0	0	0.22	0
adr202	15134.9	21648.3	9949	16372.1	1527.2	12899.8	1	1	0	1	1	0	0.3	0	0	0.33	0.22	0
adr203	15338	21185.4	9873.84	15882.6	1800.7	12182.5	1	0	1	0	1	1	0.3	0	0.22	0	0.22	0.33
adr204	13471.6	19902.5	8121.71	14654.2	502.04	11504.1	0	1	1	1	1	1	0	0.33	0.22	0.33	0.22	0.33
adr205	7518.13	17479.9	4404.71	12909.9	6296.96	12394.5	1	0	1	1	1	0	0.2	0	0.22	0.33	0	0
adr206	7513.47	17296.7	4210.86	12706.5	6237.11	12171	1	0	0	0	1	0	0.2	0	0	0	0	0

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr207	14709.3	19621.1	8856.76	14303.4	2334.99	10473.9	0	1	1	1	1	1	0	0.33	0.22	0.33	0.22	0.22
adr208	13497.5	18456.6	7564.49	13153.1	2451.85	9633.39	1	1	1	1	1	1	0.3	0.33	0.22	0.33	0.22	0.22
adr209	9459.51	16698.1	4103.83	11690.4	4383.1	10057	1	0	1	0	1	0	0.2	0	0.22	0	0.22	0.22
adr210	6597.11	15472.1	2400.23	10922.6	7111.36	10789.9	0	0	0	0	1	0	0	0	0	0	0.22	0
adr211	4295.44	14600.5	2780.36	10604.4	9402.16	11667.5	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.33
adr212	4197.74	14600.2	2860.17	10632.2	9493.73	11738.9	1	0	1	1	1	1	0.2	0	0.22	0.22	0.22	0.33
adr213	4258.07	14400.5	2662.83	10412.2	9484.78	11527.9	1	0	1	0	1	1	0.2	0	0.22	0	0.22	0.33
adr214	4159.44	14400.2	2746	10440.4	9575.53	11600.1	1	0	1	1	1	0	0.2	0	0.22	0.22	0.22	0
adr215	3471.47	14417.2	3354.2	10662.7	10215.7	12116.6	1	0	1	0	1	1	0.2	0	0.22	0	0.22	0.33
adr216	2549.63	14290	4111	10826	11123.4	12682.3	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.33	0.33
adr217	10300.6	14946.8	3962.51	9740.86	5412.18	7528.76	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.22	0.22
adr218	10100.6	14865	3765.83	9677	5507.42	7589.61	1	1	1	1	1	0	0.2	0.33	0.22	0.22	0.22	0.22
adr219	10104.6	14682.2	3733.88	9487.08	5682.61	7400.18	0	1	1	1	1	0	0	0.33	0.22	0.22	0.22	0
adr220	3584.7	10846.7	5142.96	8156.63	13484.8	11494.8	1	1	1	1	1	1	0.2	0.33	0.22	0.22	0.33	0.33
adr221	13566.6	9154.98	8431.52	4272.24	12615.1	1486.87	1	0	1	1	1	1	0.3	0	0.22	0.22	0.33	0.22
adr222	13869.8	9323.82	8683.92	4522.38	12677.6	1253.29	1	0	1	1	1	1	0.3	0	0.22	0.22	0.33	0.22
adr223	13787.7	9245.73	8626.74	4427.41	12689	1341.91	1	0	0	1	1	1	0.3	0	0	0.22	0.33	0.22
adr224	13705.9	9168.07	8570.33	4332.66	12701.2	1432.04	1	0	0	1	1	1	0.3	0	0	0.22	0.33	0.22
adr225	13461.8	8937.75	8405.98	4049.91	12742.5	1708.99	1	0	1	1	1	1	0.3	0	0.22	0.22	0.33	0.22
adr226	13927	9261.94	8765.87	4492.42	12777	1304.1	1	0	1	1	1	1	0.3	0	0.22	0.22	0.33	0.22
adr227	13845.3	9183.33	8709.22	4396.81	12788.3	1389.51	1	0	0	0	1	1	0.3	0	0	0	0.33	0.22
adr228	13601.5	8950.05	8544.03	4111.17	12827	1655.49	1	0	1	1	1	1	0.3	0	0.22	0.22	0.33	0.22
adr229	11411	6129.67	7877.2	807.18	14317.2	5166.29	0	0	1	1	1	1	0	0	0.22	0.22	0.33	0.22
adr230	14353.4	8376.25	9538.34	4005.07	13904.3	2280.37	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr231	14252.4	8015.73	9571.32	3700.1	14142.1	2624.91	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr232	16402.8	10072.4	11182.6	6207.44	14308.8	2435.35	1	0	1	1	1	1	0.3	0	0.33	0.22	0.33	0.22

Subscriber	Distance						LOS						Traffic Factor					
	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na	Atin	Aweer	Falah	Khawaneej	Sharjah	Oud Mati-na
adr233	12306.5	5456.35	8895.51	671.41	15182.2	5322.61	1	0	1	1	1	1	0.3	0	0.22	0.22	0.33	0.22
adr234	16140.1	9666.62	11020.9	5813.95	14400.4	2433.26	0	0	1	1	1	1	0	0	0.33	0.22	0.33	0.22
adr235	17089.3	10640.7	11779.7	6918.31	14549.6	2915.72	1	0	1	1	1	1	0.3	0	0.33	0.22	0.33	0.22
adr236	12453.5	4468.86	9518.93	1005.07	16082.3	6264.98	1	1	1	1	1	1	0.3	0.22	0.22	0.22	0.33	0.22
adr237	12702.8	4245.11	9818.35	1303.95	16362.5	6414.05	1	1	1	1	1	0	0.3	0.22	0.22	0.22	0.33	0
adr238	13000	4159.39	13776.8	8006.26	21843.3	13738.3	0	1	0	1	0	0	0	0.22	0	0.22	0	0
adr239	13507.4	2418.77	13448.1	6780.13	21232.5	12403.6	0	1	0	1	0	0	0	0.22	0	0.22	0	0
adr240	13800.4	4201.21	14534.5	8490.58	22553.5	14177.8	1	1	0	1	1	0	0.3	0.22	0	0.22	0	0
adr241	13900.4	4005.01	14536.2	8376.16	22522.2	14047.1	0	1	1	1	1	0	0	0.22	0.33	0.22	0	0
adr242	13900.4	4204.78	14624	8544	22635.6	14223.9	1	1	0	1	1	0	0.3	0.22	0	0.22	0	0
adr243	14000.4	4011.25	14626.4	8431.49	22604.9	14094.3	0	1	1	1	1	0	0	0.22	0.33	0.22	0	0
adr244	14100.4	4019.96	14716.7	8487.64	22687.7	14142.1	0	1	1	1	1	0	0	0.22	0.33	0.22	0	0
adr245	14100.4	4219.01	14803.4	8653.32	22800.2	14317.8	1	1	1	1	1	0	0.3	0.22	0.33	0.22	0	0.33
adr246	14615.4	1746.49	14148.2	6868.04	21700.2	12264.2	0	1	0	1	1	0	0	0.22	0	0.22	0	0.33
adr247	15192.1	905.76	13974.3	6041.53	21129.4	11053.5	0	1	0	1	1	0	0	0.22	0	0.22	0	0
adr248	14616.8	3517.12	14930.9	8309.63	22779.4	13875.5	1	1	1	1	1	1	0.3	0.22	0.33	0.22	0	0.33
adr249	15219.1	1562.1	14481	6881.86	21868.9	12088	1	1	0	0	1	1	0.3	0.22	0	0	0	0.33
adr250	16035.3	1746.52	14588	6425.73	21540.7	11103.6	0	1	0	1	1	1	0	0.22	0	0.22	0	0.33

Table 25: The served nodes and corresponding serving sites of scenarios 1, 2, 3 and 4

Demand Node	Sc 4: 4 Sites and 80 Nodes				Sc 3: 4 Sites and 70 Nodes				Sc 2: 4 Sites and 50 Nodes				Sc 1: 3 Sites and 20 Nodes		
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3
adr1	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0
adr2	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
adr3	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0
adr4	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
adr5	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
adr6	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
adr7	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0
adr8	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
adr9	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
adr10	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0
adr11	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0
adr12	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
adr13	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0
adr14	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
adr15	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0
adr16	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0
adr17	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
adr18	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0
adr19	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
adr20	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0
adr21	0	1	0	0	0	1	0	0	0	0	1	0			
adr22	1	0	0	0	1	0	0	0	1	0	0	0			
adr23	0	0	0	0	0	0	0	0	0	0	1	0			
adr24	0	1	0	0	0	1	0	0	0	1	0	0			
adr25	0	1	0	0	0	1	0	0	0	1	0	0			
adr26	0	1	0	0	0	1	0	0	0	1	0	0			
adr27	0	1	0	0	0	1	0	0	0	1	0	0			
adr28	0	1	0	0	0	1	0	0	0	1	0	0			
adr29	0	1	0	0	0	1	0	0	0	1	0	0			
adr30	1	0	0	0	1	0	0	0	0	1	0	0			
adr31	1	0	0	0	1	0	0	0	1	0	0	0			
adr32	0	1	0	0	0	1	0	0	0	1	0	0			
adr33	0	0	0	0	0	0	0	0	0	0	1	0			
adr34	0	1	0	0	0	1	0	0	0	0	1	0			
adr35	0	1	0	0	0	1	0	0	0	0	1	0			
adr36	1	0	0	0	1	0	0	0	1	0	0	0			
adr37	1	0	0	0	1	0	0	0	1	0	0	0			
adr38	0	0	0	1	0	0	0	1	0	0	0	1			
adr39	0	0	0	1	0	0	0	1	0	0	0	1			
adr40	0	0	0	1	0	0	0	1	0	0	0	1			
adr41	0	0	0	1	0	0	0	1	0	0	0	1			
adr42	0	0	0	0	0	0	0	0	0	0	1	0			
adr43	0	0	0	1	0	0	0	1	0	0	0	1			
adr44	1	0	0	0	1	0	0	0	1	0	0	0			

Demand Node	Sc 4: 4 Sites and 80 Nodes				Sc 3: 4 Sites and 70 Nodes				Sc 2: 4 Sites and 50 Nodes				Sc 1: 3 Sites and 20 Nodes		
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3
adr45	0	0	0	1	0	0	0	1	0	0	0	1			
adr46	1	0	0	0	1	0	0	0	1	0	0	0			
adr47	0	0	0	1	0	0	0	1	0	0	0	1			
adr48	0	0	0	1	0	0	0	1	0	0	0	1			
adr49	0	0	0	1	0	0	0	1	0	0	0	1			
adr50	0	0	0	1	0	0	0	1	0	0	0	1			
adr51	0	0	1	0	0	0	1	0							
adr52	0	0	1	0	0	0	1	0							
adr53	0	0	1	0	0	0	1	0							
adr54	0	0	1	0	0	0	1	0							
adr55	0	0	1	0	0	0	1	0							
adr56	0	0	1	0	0	0	1	0							
adr57	1	0	0	0	1	0	0	0							
adr58	0	0	1	0	0	0	1	0							
adr59	0	0	1	0	0	0	1	0							
adr60	0	0	1	0	0	0	1	0							
adr61	0	0	1	0	0	0	1	0							
adr62	0	0	1	0	0	0	1	0							
adr63	0	0	1	0	0	0	1	0							
adr64	1	0	0	0	1	0	0	0							
adr65	0	0	1	0	0	0	1	0							
adr66	0	0	1	0	0	0	1	0							
adr67	0	0	1	0	0	0	1	0							
adr68	0	0	1	0	0	0	1	0							
adr69	0	0	1	0	0	0	1	0							
adr70	0	0	1	0	0	0	1	0							
adr71	0	0	1	0											
adr72	0	0	1	0											
adr73	0	0	1	0											
adr74	0	0	1	0											
adr75	0	0	1	0											
adr76	0	0	1	0											
adr77	0	0	1	0											
adr78	0	0	1	0											
adr79	0	0	1	0											
adr80	0	0	1	0											

Table 26: The served nodes and corresponding serving sites of scenarios 5, 6, 7 and 8

Demand Node	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr2	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
adr3	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
adr4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
adr5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
adr6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
adr7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
adr9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
adr10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
adr17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
adr25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
Demand Node	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
adr32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
adr33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
adr35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
adr39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
adr40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
adr41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
adr42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
adr43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
adr44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
adr45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
adr46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
adr47	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1
adr48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
adr49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
adr50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
adr51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
adr52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr53	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
adr55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0

Demand Node	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr57	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
adr58	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr60	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr61	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr62	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr63	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr64	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
adr65	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr66	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr67	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
adr69	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr70	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr71	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr72	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr73	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr74	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr75	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr76	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr77	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr78	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
adr80	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr81	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0

Demand Node	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr84	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr85	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr86	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr87	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr88	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
adr89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr90	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr92	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr96	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr97	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr98	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
adr99	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
adr100	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
adr101	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr102	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr103	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr104	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr105	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr106	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr107	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0					
adr108	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0					
adr109	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr110	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0					
adr111	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0					

Demand Node	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr112	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr113	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr114	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1					
adr115	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr116	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0					
adr117	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr118	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr119	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0					
adr120	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr121	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr122	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr123	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr124	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr125	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr126	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr127	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr128	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0					
adr129	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1					
adr130	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1					
adr131	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1					
adr132	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr133	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr134	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr135	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr136	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr137	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0					
adr138	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr139	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					

Demand Node	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr140	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr141	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr142	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr143	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr144	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr145	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr146	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1					
adr147	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0					
adr148	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0					
adr149	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
adr150	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0					
adr151	0	0	1	0	0	0	0	0	1	0	0	0											
adr152	0	0	0	0	1	0	0	0	0	0	1	0											
adr153	0	0	1	0	0	0	0	0	1	0	0	0											
adr154	0	0	1	0	0	0	0	0	1	0	0	0											
adr155	0	0	0	0	0	0	0	0	0	0	0	0											
adr156	0	0	0	0	0	0	0	0	0	0	0	0											
adr157	0	0	0	0	0	0	0	0	0	0	0	0											
adr158	0	0	0	0	0	0	0	0	0	0	0	0											
adr159	0	0	0	0	0	0	0	0	0	0	0	0											
adr160	0	0	0	0	0	0	0	0	0	0	0	0											
adr161	0	0	0	0	0	0	0	0	0	0	0	0											
adr162	0	0	0	0	0	0	0	0	0	0	0	0											
adr163	0	0	0	0	0	0	0	0	0	0	0	0											
adr164	0	0	0	0	0	0	0	0	0	0	0	0											
adr165	0	0	0	0	0	0	0	0	0	0	0	0											
adr166	0	0	0	0	0	0	0	0	0	0	0	0											
adr167	0	0	0	0	0	0	0	0	0	0	0	0											

	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
Demand Node	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr168	0	0	0	0	0	0	0	0	0	0	0	0											
adr169	0	0	0	0	0	0	0	0	0	0	0	0											
adr170	0	0	0	0	0	0	0	0	0	0	0	0											
adr171	0	0	0	0	0	0	0	0	0	0	0	0											
adr172	0	0	0	0	0	0	0	0	0	0	0	0											
adr173	0	0	0	0	0	0	0	0	0	0	0	0											
adr174	0	0	0	0	0	0	0	0	0	0	0	0											
adr175	0	0	0	0	0	0	0	0	0	0	0	0											
adr176	0	0	0	0	0	0	0	0	0	0	0	0											
adr177	0	0	0	0	0	0	0	0	0	0	0	0											
adr178	0	0	0	0	0	0	0	0	0	0	0	0											
adr179	0	0	1	0	0	0	0	0	1	0	0	0											
adr180	0	0	0	0	0	0	0	0	0	0	0	0											
adr181	0	0	0	0	0	0	0	0	0	0	0	0											
adr182	0	0	0	0	0	0	0	0	0	0	0	0											
adr183	0	0	0	0	0	0	0	0	0	0	0	0											
adr184	0	0	0	0	0	0	0	0	0	0	0	0											
adr185	0	0	0	0	0	0	0	0	0	0	0	0											
adr186	0	0	0	0	0	0	0	0	0	0	0	0											
adr187	0	0	0	0	0	0	0	0	0	0	0	0											
adr188	0	0	0	0	0	0	0	0	0	0	0	0											
adr189	0	0	0	0	0	0	0	0	0	0	0	0											
adr190	0	0	0	0	0	0	0	0	0	0	0	0											
adr191	0	0	0	0	0	0	0	0	0	1	0	0											
adr192	0	0	0	0	0	0	0	0	0	0	0	0											
adr193	0	0	0	0	0	0	0	0	0	0	0	0											
adr194	0	0	0	0	0	0	0	0	0	0	0	0											
adr195	0	0	0	0	0	0	0	0	0	0	0	0											

	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
Demand Node	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr196	0	0	0	0	0	0	0	1	0	0	0	0											
adr197	0	0	0	0	0	0	0	0	0	0	0	0											
adr198	0	0	0	0	0	0	0	1	0	0	0	0											
adr199	0	0	0	0	0	0	0	0	0	0	0	0											
adr200	0	0	0	0	0	0	0	0	0	0	0	0											
adr201	0	0	0	0	1	0																	
adr202	0	0	0	0	1	0																	
adr203	0	0	0	0	1	0																	
adr204	0	0	0	0	1	0																	
adr205	1	0	0	0	0	0																	
adr206	1	0	0	0	0	0																	
adr207	0	0	0	0	1	0																	
adr208	0	0	1	0	0	0																	
adr209	1	0	0	0	0	0																	
adr210	0	0	0	0	1	0																	
adr211	1	0	0	0	0	0																	
adr212	1	0	0	0	0	0																	
adr213	1	0	0	0	0	0																	
adr214	1	0	0	0	0	0																	
adr215	1	0	0	0	0	0																	
adr216	1	0	0	0	0	0																	
adr217	0	0	0	1	0	0																	
adr218	0	0	0	1	0	0																	
adr219	0	0	1	0	0	0																	
adr220	1	0	0	0	0	0																	
adr221	0	0	0	0	0	1																	
adr222	0	0	0	0	0	1																	
adr223	0	0	0	0	0	1																	

	Scenario 8: 6 Sites and 250 Nodes						Scenario 7: 6 Sites and 200 Nodes						Scenario 6: 6 Sites and 150 Nodes						Scenario 5: 5 Sites and 100 Nodes				
Demand Node	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5
adr224	0	0	0	0	0	1																	
adr225	0	0	0	0	0	1																	
adr226	0	0	0	0	0	1																	
adr227	0	0	0	0	0	1																	
adr228	0	0	0	0	0	1																	
adr229	0	0	0	1	0	0																	
adr230	0	0	0	0	0	1																	
adr231	0	1	0	0	0	0																	
adr232	0	0	0	0	0	1																	
adr233	0	0	0	1	0	0																	
adr234	0	0	0	0	0	1																	
adr235	0	0	0	0	0	1																	
adr236	0	0	0	1	0	0																	
adr237	0	0	0	1	0	0																	
adr238	0	1	0	0	0	0																	
adr239	0	1	0	0	0	0																	
adr240	0	1	0	0	0	0																	
adr241	0	1	0	0	0	0																	
adr242	0	1	0	0	0	0																	
adr243	0	1	0	0	0	0																	
adr244	0	1	0	0	0	0																	
adr245	0	1	0	0	0	0																	
adr246	0	1	0	0	0	0																	
adr247	0	1	0	0	0	0																	
adr248	0	1	0	0	0	0																	
adr249	0	1	0	0	0	0																	
adr250	0	1	0	0	0	0																	

APPENDIX C: MATLAB PROGRAM

```
%%% WiMAX Deployment Model: 6 Sites and 250 Nodes %%%
clear all
close all
 [A,B]=xlsread('C:\NewMATLAB701\work\MATLAB Results for WiMAX Mod-
el\Input 6 Sites and 250 Nodes.xlsx');
clear B
Mod_RSSI = 7.94E-6;
AVL_TH = 0.9999;
DST_Th = 10000;
Budget = 300000;
BS_Cost = 25000;
Num_Freq_Channels = 3;
Reuse_Fac = 1;
Max_BS_Num = Num_Freq_Channels * Reuse_Fac;
QAM64_RSSI = 3.16E-5;
BS_Ant_Gain = 25.11886;
Node_Ant_Gain = 50.1187;
Beta1=0.33 ;
Beta3=0.33 ;
Beta4=0.33 ;
Num_Nodes = length(A(:,1));
x=1;
y=Num_Nodes;
Cont_Ratio = 1;
BS_Net_Throughput =10;
DCP=0.2;
BS_Data_Rate = (Cont_Ratio * BS_Net_Throughput * (1-DCP)) +
(BS_Net_Throughput * DCP);
S1_Nodes(1 : Num_Nodes)= 0;
S2_Nodes(1 : Num_Nodes)= 0;
S3_Nodes(1 : Num_Nodes)= 0;
S4_Nodes(1 : Num_Nodes)= 0;
```

```
S5_Nodes(1 : Num_Nodes)= 0;
S6_Nodes(1 : Num_Nodes)= 0;
Nodes(1 : Num_Nodes)= 0;
S1_Cur_Traffic(1 : Num_Nodes)=0;
S2_Cur_Traffic(1 : Num_Nodes)=0;
S3_Cur_Traffic(1 : Num_Nodes)=0;
S4_Cur_Traffic(1 : Num_Nodes)=0;
S5_Cur_Traffic(1 : Num_Nodes)=0;
S6_Cur_Traffic(1 : Num_Nodes)=0;
Demand = [A(x:y,6)];
Revenue = [A(x:y,7)];
S1_Pr = [A(x:y,14)];
S2_Pr = [A(x:y,15)];
S3_Pr = [A(x:y,16)];
S4_Pr = [A(x:y,17)];
S5_Pr = [A(x:y,18)];
S6_Pr = [A(x:y,19)];
S1_DST = [A(x:y,26)];
S2_DST = [A(x:y,27)];
S3_DST = [A(x:y,28)];
S4_DST = [A(x:y,29)];
S5_DST = [A(x:y,30)];
S6_DST = [A(x:y,31)];
S1_AVL = [A(x:y,50)];
S2_AVL = [A(x:y,51)];
S3_AVL = [A(x:y,52)];
S4_AVL = [A(x:y,53)];
S5_AVL = [A(x:y,54)];
S6_AVL = [A(x:y,55)];
S1_LOS = [A(x:y,62)];
S2_LOS = [A(x:y,63)];
S3_LOS = [A(x:y,64)];
S4_LOS = [A(x:y,65)];
S5_LOS = [A(x:y,66)];
```

```
S6_LOS = [A(x:y,67)];
S1_TF = [A(x:y,68)];
S2_TF = [A(x:y,69)];
S3_TF = [A(x:y,70)];
S4_TF = [A(x:y,71)];
S5_TF = [A(x:y,72)];
S6_TF = [A(x:y,73)];
TR_Index=1;
for m = 1 : Num_Nodes
Cur_Demand(m) = (Demand(m,1)*S1_TF(m,1));
  %% Define nodes in column instead of rows %%
      S1_Nodes_TR = S1_Nodes';
      S2_Nodes_TR = S2_Nodes';
      S3_Nodes_TR = S3_Nodes';
      S4_Nodes_TR = S4_Nodes';
      S5_Nodes_TR = S5_Nodes';
      S6_Nodes_TR = S6_Nodes';
      S1_Cur_Traffic(m) = sum(Demand.*S1_TF.*S1_Nodes_TR) ;
      S2_Cur_Traffic(m) = sum(Demand.*S2_TF.*S2_Nodes_TR) ;
      S3_Cur_Traffic(m) = sum(Demand.*S3_TF.*S3_Nodes_TR) ;
      S4_Cur_Traffic(m) = sum(Demand.*S4_TF.*S4_Nodes_TR) ;
      S5_Cur_Traffic(m) = sum(Demand.*S5_TF.*S5_Nodes_TR) ;
      S6_Cur_Traffic(m) = sum(Demand.*S6_TF.*S6_Nodes_TR) ;
Max_Mod_RSSI(m) = max(A(m,14:19));
  if (S1_Pr(m)>=Mod_RSSI) & (S1_LOS(m)== 1) & (S1_AVL(m)>=AVL_TH) &
(S1_DST(m)<=DST_Th) & ((S1_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))& ( (S1_Pr(m)==Max_Mod_RSSI(m)))
      S1_Nodes(m) = 1;
  elseif (S2_Pr(m)>=Mod_RSSI) & (S2_LOS(m)== 1) & (S2_AVL(m)>=AVL_TH)
& (S2_DST(m)<=DST_Th) & ((S2_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))& ( (S2_Pr(m)==Max_Mod_RSSI(m)))
      S2_Nodes(m) = 1;
```

```
  elseif (S3_Pr(m)>=Mod_RSSI) & (S3_LOS(m)== 1) & (S3_AVL(m)>=AVL_TH)
& (S3_DST(m)<=DST_Th) & ((S3_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))& ( (S3_Pr(m)==Max_Mod_RSSI(m)))
      S3_Nodes(m) = 1;
  elseif (S4_Pr(m)>=Mod_RSSI) & (S4_LOS(m)== 1) & (S4_AVL(m)>=AVL_TH)
& (S4_DST(m)<=DST_Th) & ((S4_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))& ( (S4_Pr(m)==Max_Mod_RSSI(m)))
      S4_Nodes(m) = 1;
  elseif (S5_Pr(m)>=Mod_RSSI) & (S5_LOS(m)== 1) & (S5_AVL(m)>=AVL_TH)
& (S5_DST(m)<=DST_Th) & ((S5_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))& ( (S5_Pr(m)==Max_Mod_RSSI(m)))
      S5_Nodes(m) = 1;
  elseif (S6_Pr(m)>=Mod_RSSI) & (S6_LOS(m)== 1) & (S6_AVL(m)>=AVL_TH)
& (S6_DST(m)<=DST_Th) & ((S6_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))& ( (S6_Pr(m)==Max_Mod_RSSI(m)))
      S6_Nodes(m) = 1;

  elseif (S1_Nodes(m) == 0)&(S2_Nodes(m) == 0)&(S3_Nodes(m) ==
0)&(S4_Nodes(m) == 0)&(S5_Nodes(m) == 0)&(S6_Nodes(m) == 0)
      if (S1_Pr(m)>=Mod_RSSI) & (S1_LOS(m)== 1) & (S1_AVL(m)>=AVL_TH) &
(S1_DST(m)<=DST_Th) & ((S1_Cur_Traffic(m)+ Cur_Demand(m)) <=
(0.22*BS_Data_Rate*Max_BS_Num))
          S1_Nodes(m) = 1;
          elseif (S2_Pr(m)>=Mod_RSSI) & (S2_LOS(m)== 1) &
(S2_AVL(m)>=AVL_TH) & (S2_DST(m)<=DST_Th) & ((S2_Cur_Traffic(m)+
Cur_Demand(m)) <= (0.22*BS_Data_Rate*Max_BS_Num))
          S2_Nodes(m) = 1;
          elseif (S3_Pr(m)>=Mod_RSSI) & (S3_LOS(m)== 1) &
(S3_AVL(m)>=AVL_TH) & (S3_DST(m)<=DST_Th) & ((S3_Cur_Traffic(m)+
Cur_Demand(m)) <= (0.22*BS_Data_Rate*Max_BS_Num))
          S3_Nodes(m) = 1;
          elseif (S4_Pr(m)>=Mod_RSSI) & (S4_LOS(m)== 1) &
(S4_AVL(m)>=AVL_TH) & (S4_DST(m)<=DST_Th) & ((S4_Cur_Traffic(m)+
Cur_Demand(m)) <= (0.22*BS_Data_Rate*Max_BS_Num))
```

```
          S4_Nodes(m) = 1;
          elseif (S5_Pr(m)>=Mod_RSSI) & (S5_LOS(m)== 1) &
(S5_AVL(m)>=AVL_TH) & (S5_DST(m)<=DST_Th) & ((S5_Cur_Traffic(m)+
Cur_Demand(m)) <= (0.22*BS_Data_Rate*Max_BS_Num))
          S5_Nodes(m) = 1;
          elseif (S6_Pr(m)>=Mod_RSSI) & (S6_LOS(m)== 1) &
(S6_AVL(m)>=AVL_TH) & (S6_DST(m)<=DST_Th) & ((S6_Cur_Traffic(m)+
Cur_Demand(m)) <= (0.22*BS_Data_Rate*Max_BS_Num))
          S6_Nodes(m) = 1;
      else
      S1_Nodes(m) = 0;
      S2_Nodes(m) = 0;
      S3_Nodes(m) = 0;
      S4_Nodes(m) = 0;
      S5_Nodes(m) = 0;
      S6_Nodes(m) = 0;
      end
  else
      S1_Nodes(m) = 0;
      S2_Nodes(m) = 0;
      S3_Nodes(m) = 0;
      S4_Nodes(m) = 0;
      S5_Nodes(m) = 0;
      S6_Nodes(m) = 0;
  end
      SS1_Nodes_TR = S1_Nodes';
      SS2_Nodes_TR = S2_Nodes';
      SS3_Nodes_TR = S3_Nodes';
      SS4_Nodes_TR = S4_Nodes';
      SS5_Nodes_TR = S5_Nodes';
      SS6_Nodes_TR = S6_Nodes';
      SS1_Cur_Traffic(m) = sum(Demand.*S1_TF.*SS1_Nodes_TR) ;
      SS2_Cur_Traffic(m) = sum(Demand.*S2_TF.*SS2_Nodes_TR) ;
      SS3_Cur_Traffic(m) = sum(Demand.*S3_TF.*SS3_Nodes_TR) ;
```

```
SS4_Cur_Traffic(m) = sum(Demand.*S4_TF.*SS4_Nodes_TR) ;
SS5_Cur_Traffic(m) = sum(Demand.*S5_TF.*SS5_Nodes_TR) ;
SS6_Cur_Traffic(m) = sum(Demand.*S6_TF.*SS6_Nodes_TR) ;
SS1_Cur_BSs_Number(m) = ceil(SS1_Cur_Traffic(m)/ (0.22*BS_Data_Rate));
SS2_Cur_BSs_Number(m) = ceil(SS2_Cur_Traffic(m)/ (0.22*BS_Data_Rate));
SS3_Cur_BSs_Number(m) = ceil(SS3_Cur_Traffic(m)/ (0.22*BS_Data_Rate));
SS4_Cur_BSs_Number(m) = ceil(SS4_Cur_Traffic(m)/ (0.22*BS_Data_Rate));
SS5_Cur_BSs_Number(m) = ceil(SS5_Cur_Traffic(m)/ (0.22*BS_Data_Rate));
SS6_Cur_BSs_Number(m) = ceil(SS6_Cur_Traffic(m)/ (0.22*BS_Data_Rate));
BS_Cur_Num(m)=
SS1_Cur_BSs_Number(m)+SS2_Cur_BSs_Number(m)+SS3_Cur_BSs_Number(m)+
SS4_Cur_BSs_Number(m)+SS5_Cur_BSs_Number(m)+SS6_Cur_BSs_Number(m);
All_BS_Cur_Cost(m) = BS_Cur_Num(m) * BS_Cost;
if (SS1_Cur_BSs_Number(m) > Max_BS_Num)
  S1_Nodes(m) = 0;
end
if (SS2_Cur_BSs_Number(m) > Max_BS_Num)
  S2_Nodes(m) = 0;
end
if (SS3_Cur_BSs_Number(m) > Max_BS_Num)
  S3_Nodes(m) = 0;
end
if (SS4_Cur_BSs_Number(m) > Max_BS_Num)
  S4_Nodes(m) = 0;
end
if (SS5_Cur_BSs_Number(m) > Max_BS_Num)
  S5_Nodes(m) = 0;
end
if (SS6_Cur_BSs_Number(m) > Max_BS_Num)
  S6_Nodes(m) = 0;
end
if (All_BS_Cur_Cost(m) > Budget)
S1_Nodes(m) = 0;
S2_Nodes(m) = 0;
```

```
      S3_Nodes(m) = 0;
      S4_Nodes(m) = 0;
      S5_Nodes(m) = 0;
      S6_Nodes(m) = 0;
      end
  if (S1_Nodes(m) == 1)|(S2_Nodes(m) == 1)|(S3_Nodes(m) == 1)|(S4_Nodes(m) ==
1)|(S5_Nodes(m) == 1)|(S6_Nodes(m) == 1)
     Nodes(m)= 1;
  else
     Nodes(m)= 0;
  end
            m=m+1;
TR_Index = m-1;
end
%%%  Model Outputs %%%
S1_Tot_Nodes = sum(S1_Nodes);
if (S1_Tot_Nodes>=1)
Site1=1;
else
Site1=0;
end
S2_Tot_Nodes = sum(S2_Nodes);
if (S2_Tot_Nodes>=1)
Site2=1;
else
Site2=0;
end
S3_Tot_Nodes = sum(S3_Nodes);
if (S3_Tot_Nodes>=1)
Site3=1;
else
Site3=0;
end
S4_Tot_Nodes = sum(S4_Nodes);
```

```
if (S4_Tot_Nodes>=1)
Site4=1;
else
Site4=0;
end
S5_Tot_Nodes = sum(S5_Nodes);
if (S5_Tot_Nodes>=1)
Site5=1;
else
Site5=0;
end
S6_Tot_Nodes = sum(S6_Nodes);
if (S6_Tot_Nodes>=1)
Site6=1;
else
Site6=0;
end
%%% Total Number of served Nodes
Total_Nodes = sum(Nodes);
%%% Traffic Utilizaed by Nodes connected to each site
S1_Nodes = S1_Nodes';
  S1_UtilizedTraffic = Demand.*S1_TF.*S1_Nodes;
  S1_Tot_Utiliz = sum(S1_UtilizedTraffic);
S2_Nodes = S2_Nodes';
  S2_UtilizedTraffic = Demand.*S2_TF.*S2_Nodes;
  S2_Tot_Utiliz = sum(S2_UtilizedTraffic);
S3_Nodes = S3_Nodes';
  S3_UtilizedTraffic = Demand.*S3_TF.*S3_Nodes;
  S3_Tot_Utiliz = sum(S3_UtilizedTraffic);
S4_Nodes = S4_Nodes';
  S4_UtilizedTraffic = Demand.*S4_TF.*S4_Nodes;
  S4_Tot_Utiliz = sum(S4_UtilizedTraffic);
S5_Nodes = S5_Nodes';
  S5_UtilizedTraffic = Demand.*S5_TF.*S5_Nodes;
```

```
   S5_Tot_Utiliz = sum(S5_UtilizedTraffic);
S6_Nodes = S6_Nodes';
   S6_UtilizedTraffic = Demand.*S6_TF.*S6_Nodes;
   S6_Tot_Utiliz = sum(S6_UtilizedTraffic);
%%% Number of Base Stations required at each Site (NOT necessary to be best serv-
er
S1_BSs_Number = ceil(S1_Tot_Utiliz / (0.22*BS_Data_Rate));
S2_BSs_Number = ceil(S2_Tot_Utiliz / (0.22*BS_Data_Rate));
S3_BSs_Number = ceil(S3_Tot_Utiliz / (0.22*BS_Data_Rate));
S4_BSs_Number = ceil(S4_Tot_Utiliz / (0.22*BS_Data_Rate));
S5_BSs_Number = ceil(S5_Tot_Utiliz / (0.22*BS_Data_Rate));
S6_BSs_Number = ceil(S6_Tot_Utiliz / (0.22*BS_Data_Rate));
Tot_Num_BSs =
S1_BSs_Number+S2_BSs_Number+S3_BSs_Number+S4_BSs_Number+S5_BSs_N
umber+S6_BSs_Number;
%%% Site Utilization and Overall Utilization
S1_Utilization = S1_Tot_Utiliz / (0.22 * S1_BSs_Number * BS_Data_Rate);
S2_Utilization = S2_Tot_Utiliz / (0.22 * S2_BSs_Number * BS_Data_Rate);
S3_Utilization = S3_Tot_Utiliz / (0.22 * S3_BSs_Number * BS_Data_Rate);
S4_Utilization = S4_Tot_Utiliz / (0.22 * S4_BSs_Number * BS_Data_Rate);
S5_Utilization = S5_Tot_Utiliz / (0.22 * S5_BSs_Number * BS_Data_Rate);
S6_Utilization = S6_Tot_Utiliz / (0.22 * S6_BSs_Number * BS_Data_Rate);
Tot_Utiliz = S1_Tot_Utiliz +
S2_Tot_Utiliz+S3_Tot_Utiliz+S4_Tot_Utiliz+S5_Tot_Utiliz+S6_Tot_Utiliz;
Overall_Utilization = Tot_Utiliz/(0.22*Tot_Num_BSs*BS_Data_Rate);
%%% Objective Function Value
  S1_Nodes_Pr = S1_Pr.*S1_Nodes;
    S1_Sum_Pr = sum(S1_Nodes_Pr);
  S2_Nodes_Pr = S2_Pr.*S2_Nodes;
    S2_Sum_Pr = sum(S2_Nodes_Pr);
  S3_Nodes_Pr = S3_Pr.*S3_Nodes;
    S3_Sum_Pr = sum(S3_Nodes_Pr);
  S4_Nodes_Pr = S4_Pr.*S4_Nodes;
    S4_Sum_Pr = sum(S4_Nodes_Pr);
```

```
S5_Nodes_Pr = S5_Pr.*S5_Nodes;
  S5_Sum_Pr = sum(S5_Nodes_Pr);
S6_Nodes_Pr = S6_Pr.*S6_Nodes;
  S6_Sum_Pr = sum(S6_Nodes_Pr);
Tot_S1_Pr = sum(S1_Pr);
Tot_S2_Pr = sum(S2_Pr);
Tot_S3_Pr = sum(S3_Pr);
Tot_S4_Pr = sum(S4_Pr);
Tot_S5_Pr = sum(S5_Pr);
Tot_S6_Pr = sum(S6_Pr);
 Obj_Power = (S1_Sum_Pr + S2_Sum_Pr + S3_Sum_Pr + S4_Sum_Pr +
S5_Sum_Pr + S6_Sum_Pr)/(Tot_S1_Pr + Tot_S2_Pr+ Tot_S3_Pr+ Tot_S4_Pr
+Tot_S5_Pr +Tot_S6_Pr);
 Obj_Nodes = Total_Nodes/Num_Nodes;
Nodes = Nodes';
Nodes_Revenue = Nodes.* Revenue;
 Sum_Node_Rev = sum(Nodes_Revenue);
 Profit = Sum_Node_Rev - (Tot_Num_BSs * BS_Cost);
 Tot_Rev = sum(Revenue);
 Obj_Profit = Profit/Tot_Rev;
 Obj_Func = (0.75 * ((Beta1*Obj_Profit) + (Beta3*Obj_Nodes) + (Be-
ta4*Obj_Power))) + (0.25*Overall_Utilization);
 S1_Far_Node_DST = max(S1_DST.*S1_Nodes);
 S2_Far_Node_DST = max(S2_DST.*S2_Nodes);
 S3_Far_Node_DST = max(S3_DST.*S3_Nodes);
 S4_Far_Node_DST = max(S4_DST.*S4_Nodes);
 S5_Far_Node_DST = max(S5_DST.*S5_Nodes);
 S6_Far_Node_DST = max(S6_DST.*S6_Nodes);
 S1_Tx_Power_W = (Site1 * (QAM64_RSSI/(BS_Ant_Gain*Node_Ant_Gain)) *
(4*3.14159*S1_Far_Node_DST/0.0857)^2 ) /1000000;
 S2_Tx_Power_W = (Site2 * (QAM64_RSSI/(BS_Ant_Gain*Node_Ant_Gain)) *
(4*3.14159*S2_Far_Node_DST/0.0857)^2 ) /1000000;
 S3_Tx_Power_W = (Site3 * (QAM64_RSSI/(BS_Ant_Gain*Node_Ant_Gain)) *
(4*3.14159*S3_Far_Node_DST/0.0857)^2 ) /1000000;
```

```
S4_Tx_Power_W = (Site4 * (QAM64_RSSI/(BS_Ant_Gain*Node_Ant_Gain)) * (4*3.14159*S4_Far_Node_DST/0.0857)^2 ) /1000000;
S5_Tx_Power_W = (Site5 * (QAM64_RSSI/(BS_Ant_Gain*Node_Ant_Gain)) * (4*3.14159*S5_Far_Node_DST/0.0857)^2 ) /1000000;
S6_Tx_Power_W = (Site6 * (QAM64_RSSI/(BS_Ant_Gain*Node_Ant_Gain)) * (4*3.14159*S6_Far_Node_DST/0.0857)^2 ) /1000000;
S1_Tx_Power_dBm = Site1 * (10 * log10(S1_Tx_Power_W * 1000));
S2_Tx_Power_dBm = Site2 * (10 * log10(S2_Tx_Power_W * 1000));
S3_Tx_Power_dBm = Site3 * (10 * log10(S3_Tx_Power_W * 1000));
S4_Tx_Power_dBm = Site4 * (10 * log10(S4_Tx_Power_W * 1000));
S5_Tx_Power_dBm = Site5 * (10 * log10(S5_Tx_Power_W * 1000));
S6_Tx_Power_dBm = Site6 * (10 * log10(S6_Tx_Power_W * 1000));
%% Result Matrix %%
Results(:,1)= S1_Nodes;
Results(:,2)= S2_Nodes;
Results(:,3)= S3_Nodes;
Results(:,4)= S4_Nodes;
Results(:,5)= S5_Nodes;
Results(:,6)= S6_Nodes;
Results(:,7)= Nodes;
Results(1,8)=Site1;
Results(1,9)=Site2;
Results(1,10)=Site3;
Results(1,11)=Site4;
Results(1,12)=Site5;
Results(1,13)=Site6;
Results(3,8)= S1_BSs_Number;
Results(3,9)= S2_BSs_Number;
Results(3,10)= S3_BSs_Number;
Results(3,11)= S4_BSs_Number;
Results(3,12)= S5_BSs_Number;
Results(3,13)= S6_BSs_Number;
Results(5,8)= S1_Tot_Nodes;
Results(5,9)= S2_Tot_Nodes;
```

```
Results(5,10)= S3_Tot_Nodes;
Results(5,11)= S4_Tot_Nodes;
Results(5,12)= S5_Tot_Nodes;
Results(5,13)= S6_Tot_Nodes;
Results(7,8)= S1_Utilization;
Results(7,9)= S2_Utilization;
Results(7,10)= S3_Utilization;
Results(7,11)= S4_Utilization;
Results(7,12)= S5_Utilization;
Results(7,13)= S6_Utilization;
Results(9,8)= S1_Tx_Power_W;
Results(9,9)= S2_Tx_Power_W;
Results(9,10)= S3_Tx_Power_W;
Results(9,11)= S4_Tx_Power_W;
Results(9,12)= S5_Tx_Power_W;
Results(9,13)= S6_Tx_Power_W;
Results(11,8)=S1_Tx_Power_dBm;
Results(11,9)=S2_Tx_Power_dBm;
Results(11,10)=S3_Tx_Power_dBm;
Results(11,11)=S4_Tx_Power_dBm;
Results(11,12)=S5_Tx_Power_dBm;
Results(11,13)=S6_Tx_Power_dBm;
Results(1,14)= Tot_Num_BSs;
Results(1,15)= Total_Nodes;
Results(1,16)= Overall_Utilization;
Results(1,17)= Obj_Func;
Results(1,18)= Profit;
xlswrite('C:\NewMATLAB701\work\MATLAB Results for WiMAX Model\Input 6
Sites and 250 Nodes Results.xlsx', Results, 'Sheet1');
```

VITA

Abdulhadi Mahmoud AbouAlmal was born on August 26, 1984, and brought up in the United Arab Emirates. He received most of his education in local schools of Sharjah but he finished his high school from Egypt in 2002. In the fall of the same year, he joined Ajman University of Science and Technology. He was the first class student of his batch who graduated suma cum laude in 2007 with a Bachelor of Science degree in Electrical Engineering/ Communication.

After his graduation, Abdulhadi joined the institutional research unit at Sharjah University. Then he worked as a lab instructor at the faculty of engineering of Ajman University. One year after, he received a graduate teaching assistantship to pursue the Master of Science degree in Engineering System Management at the Amirican University of Sharjah. After that, Abdulhadi joined the Emirates Telecommunication Corporation, Etisalat, as a radio network planner. He presented Etisalat and UAE administration officially in major meetings and conferences of the International Telecommunication Union (UN agent). He was awarded the Master of Science degree in 2011.