ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Frequency Assignment Problem Optimization of GSM Network in the case of Addis Ababa

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Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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Place: <u>Addis Ababa</u>

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Date of submission

This thesis has been submitted for examination with my approval as a university advisor.

<u>Dr.Yalemzewud Negash</u> ____________________________

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Abstract

In GSM systems, radio frequencies are repeatedly used in order to efficiently use assigned frequency bands. To expand the network capacity, one solution is to reuse the limited frequency resources. Currently the 4x3 frequency reuse technologies for GSM network is in common use here in Addis Ababa. For this reuse model “4” indicates the number of Base Transceiver Stations (BTSs) in the reuse clusters, and “3” indicates the number of cells (sectors) under each BTS. As the number of users increases from time to time, the number of cells increases. Thus, the search space which is the possible range where optimum solution is attained increases. Furthermore, attaining optimum frequencies under each cell is challenging task.

This thesis presents group frequency assignment method for the frequency assignment problem in Addis Ababa using genetic algorithm technique. Without violating the 4x3 frequency reuse used currently, the optimization was performed in Addis Ababa with 933 DCS (Digital Communication) 1800 MHz bandwidth cells (sectors). With proper optimization five frequencies can be used under each cell with a group of 24 cells and 125 generations or iterations using the algorithm. This assignment enhanced us to use two more frequencies under each cell than ethio telecom assignment which uses Mentum planet as optimization tool. And thus, capacity of the system increased.

Key words: Frequency Assignment Problem Optimization; Genetic Algorithm

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Abbreviations

AGCH	Access Grant Channel
AMPS	Analogue Mobile Phone System
ARFCN	Absolute Radio Frequency Carrier Number
BCC	Base Station Color Codes
BCCH	Broadcast Channel
BS	Base Station
BSIC	Base Station Identification Code
BTS	Base Transceiver Station
CAP	Channel Assignment Problem
CBCH	Cell Broadcast Channel
CCCH	Common Control Channel
CCH	Common/Control Channel
CDMA	Code Division Multiple Access
DCA	Dynamic Channel Assignment
DCCH	Dedicated Control Channel
DCH	Dedicated Channel
DCS	Digital Communication Systems
EFS	Enhanced Full Rate Speech
ETA	Ethiopian Telecommunication Agency

FACCH	Fast Associated Control Channel
FAP	Frequency Assignment Problem
FCA	Fixed Channel Assignment
FCCH	Frequency Correction Channel
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
GA	Genetic Algorithm
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
IMSI	International Mobile Subscriber Identity
ISDN	Integrated Services Digital Network
LAI	Location Area Identity
LAC	Location Area Code
MS	Mobile Station
MSC	Mobile Station Center
NCC	National Color Code
PCH	Paging Channel
PGSM	Primary GSM
PLMN	Public Land Mobile Network
RACH	Random Access Channel

RSSI	Radio Signal Strength Indicators
SACCH	Slow Associated Control Channel
SCH	Synchronous Channel
SDCCH	Stand-Alone Dedicated Control Channel
SDMA	Space Division Multiple Access
SMSCB	Short Message Service Cell Broadcast
TA	Timing Advance
TACS	Total Access Communications System
TCH	Traffic Channel
TDMA	Time Division Multiple Access
TMSI	Temporary Mobile Subscriber Identity
TRX	Transmit/Receive Module
WCDMA	Wideband Code Division Multiple Access

CHAPTER I: Introduction

1.1 Introduction

Global System for Mobile communications (GSM) is one of the currently available technologies for mobile communication in Ethiopia including Addis Ababa. A high connection quality is a major competitive edge for telecommunication providers. But limited availability of frequencies is one of the most important problems for radio network operators. A high level of interference encountered due to reuse of frequencies, can have substantial impact on the quality of received signals; sometimes a proper reception may even be impossible. Thus, the operator has to assign frequencies to the radio cells in a way that prevents interference among the frequencies. Moreover, the expected traffic must be served for each radio cell. In addition to precluding interference, the frequency plan should also make efficient use of spectrum. Now, a general frequency assignment problem is to assign the required number of frequencies to each cell such that the above constraints are satisfied. In this thesis, we deal with frequency assignment problem of GSM network in the case of Addis Ababa.

Mobile and other parties make a communication link through a public telecommunication network by means of a radio link to some stationary antenna which is part of a large infrastructure. Each radio network provider acquires a certain spectrum from a national regulation authority, Ethiopian Telecommunication Agency (ETA). This spectrum is divided into so called channels which are the available channels of the company. For each stationary antenna, a certain number of transmitter or receiver units (TRXs) are installed, where one channels has to be assigned to each of these TRXs. Since the number of employed TRXs is typically much larger than the number of available channels, the reuse of frequencies cannot be avoided. It is common that the same channel operated by many TRXs in the network.

Interference and separation requirements are very important factors that limit the reuse of frequencies. Severe interference may occur if the same channel (co-channel) or neighboring channels (adjacent channels) are assigned to different TRXs. The level of interference depends on a lot of factors as different as the distance between both transmitters, the power of the signals, geographical and vegetation aspects, and weather, to name only a few. Separation requirements are defined for pairs of transmitters and enforce a minimum separation in the electromagnetic spectrum between the channels assigned to both TRXs. Furthermore, not each channel of spectrum may be available for every TRX. The problem of assigning channels to TRXs while taking additional requirements in to account is called Frequency Assignment Problem (FAP). Our optimization goal is to minimize the sum of all co- and adjacent channel interferences and efficiently utilizing available resources.

1.2 GSM Frequency Band Allocation

GSM cellular system can be divided into GSM900M and DCS1800M (Digital communication systems 1800M) according to frequency band, with carrier frequency interval of 200 KHz and up and down frequencies shown in table 1.1

	Frequency band(MHz)	**Bandwidth(MHz)**	**Frequency number**	**Carrier frequency number (pair)**
GSM900	Up 890–915 Down 935–960	25	1–124	124
DCS1800	Up 1710–1785 Down1805–1880	75	512–885	374

Table 1.1 GSM frequency allocations [4]

“Up” and “down” are classified according to base station. Base station transmitting - mobile station receiving is “down”; mobile station transmitting - base station receiving is up. It uses Frequency Division Duplexing (FDD) where the uplink and the downlink of each channel operate on a different frequency. Therefore, two frequency bands were allocated to GSM, 20MHZ apart i.e. for GSM900 (935-915=20MHZ) and for DCS (1805-1785=20MHZ).

Primary GSM (GSM900): each band (uplink sub band and the downlink sub band) in P-GSM is divided in to a number of carriers, with each carrier having a 200 KHZ bandwidth. Therefore, 124 carrier are available within each of the up and down link bands (allowing for guard bands which is 100 KHZ wide that is there is 100 KHZ guard band from the left most and right most end of 890-915 and 935-960).

The channel pair allocation has been arranged such that the two frequencies comprising a channel pair apart 45 MHz (for example, 935-890 =45 or 960-915=45MHZ).

Each frequency pair is identified by an 'Absolute Radio Frequency Carrier Number (ARFCN)' which is in the range of 1-124.

Uplink and downlink channel frequencies (in MHz) can be calculated as follows [4]

Uplink frequencies: $F_u(n) = 890 + 0.2n \ (1 \le n \le 124)$ …………………………… (1.1)

Downlink frequencies: $F_d(n) = F_u(n) + 45$……………………………………. (1.2)

Where 'n' refers to Absolute Radio Frequency Carrier Number

Digital communication system (DCS): 1800 introduced a further 1800 MHz spectrum range for GSM. The characteristics of radio frequencies in this range are such that DCS-1800 is typically used for smaller microcells overlaid over existing GSM-900 macro cells. The up and downlink bands are 75MHz each and have a 20 MHz separation.

Each band is divided in to 200 KHz carriers, as with GSM-900. Therefore, 374 carriers are available within each of the up and downlink bands (allowing for guard bands). Channel numbers are in the range 512-885 (ARFCNs).

The channel pair allocation has been arranged such that the two frequencies comprising a channel pair are 95 MHz apart.

DCS-1800 up and down channel frequencies (in MHz) can be calculated as follows [4]

Uplink frequencies: $F_u(n) = 1710.2 + 0.2(n-512)$ $(512 \leq n \leq 885)$ ………………. (1.3)

Downlink frequencies: $F_d(n) = F_u(n) + 95$……………………………………… (1.4)

As frequency increases, wavelength (λ) decreases which results in decrease of coverage and increase of capacity. Similarly, as the frequency decreases wavelength increases which results in decrease of capacity and increase of coverage. Due to this in P-GSM (GSM-900): more coverage and low capacity where as in DCS-1800: more capacity and low coverage. Ethio telecom co-locates both technologies here in Addis Ababa, Ethiopia to use the advantages of the two systems.

1.3 GSM Multiple Access Technology

In cellular mobile communications system, since many mobiles stations communicate with other mobiles stations through one base station, it is necessary to distinguish the signals from different mobile stations and base stations for them to identify their own signals. The way to this problem is called multiple access technology. There are now five kinds of Multiple access technology, namely: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Space Division Multiple Access (SDMA), and Polar Division Multiple Accesses (PDMA).

GSM multiple access technology focuses on TDMA, and takes FDMA as complement. The following only introduces FDMA and TDMA technologies.

FDMA

FDMA divides the whole frequency band into many single radio channels (transmitting and receiving carrier frequency pairs). Each channel transmits one path of speech or control information. Any subscriber has access to one of these channels under the control of the system.

Analog cellular system is a typical example of FDMA application. Digital cellular system also uses FDMA, but not the pure frequency allocation. For example, GSM takes FDMA technology.

TDMA

TDMA divides a broadband radio carrier into several time division channels according to time (or timeslot). Each subscriber takes one timeslot and sends or receives signals only in the specified timeslot. TDMA is applied in digital cellular system and GSM. GSM adopts a technology combined with FDMA and TDMA.

TDMA Frame

The basic conception of GSM in terms of radio path is burst. Burst is a transmission unit consists of over one hundred of modulation bits. It has a duration limit and takes a limited radio frequency. They are exported in time and frequency window which is called slot. To be specific, in system frequency band, central frequency of slot is set in every 200 KHz (in FDMA). Slot occurs periodically in each 15/26 ms, which is about 0.577 ms (in TDMA).The interval between two slots is called timeslot. Its duration is used as time unit, called burst period (BP).

Time/frequency map illustrates the concept of slot. Each slot is expressed as one little rectangle with 15/26ms length and 200 KHz width. See fig 1.1. Similarly, the 200 KHz bandwidth in GSM is called frequency slot, equal to radio frequency channel in GSM protocol.

Burst represents different meaning in different situation. Sometimes it concerns time – frequency "rectangle" unit, and sometimes not. Similarly, timeslot sometimes concerns time value, and sometimes means using one of every eight slots periodically.

Using a given channel means transmitting burst with a particular frequency at particular time, that is, a particular slot. Generally, the slot of a channel is not continuous in time.

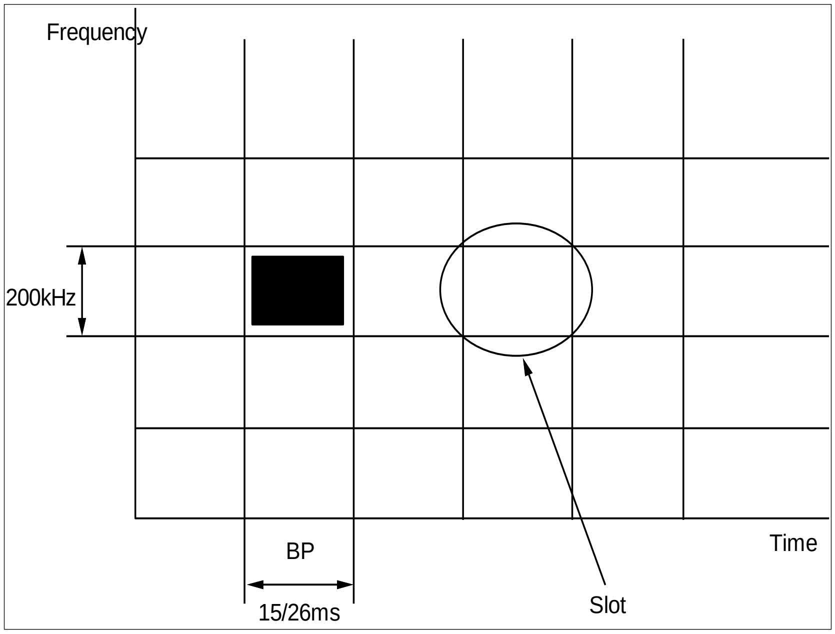


Figure 1.1 Timeslot [4]

Physical channel combines frequency division multiple access and time division multiple access together. It consists of timeslot flow that connects base station (BS) and mobile station (MS).The position of these timeslots in TDMA frame is fixed. TDMA frame is a repetitive “physical” frame in radio link.

One TDMA frame consists of eight basic timeslots, about 60/13≈4.615ms in total. Each timeslot is a basic physical channel with 15/26≈0.557ms.

There are two kinds of multi frames, consisting of 26 and 51 continuous TDMA frames respectively. Multi frames are applied when different logical channels are used in one physical channel.

The 26 multi frame, with a period of 120 ms, is used in traffic channel and associated control channel. Among the 26 bursts, 24 are used in traffic and 2 are used in signaling.

The 51 multi frame, with a period of 3060/13≈235.385 ms, is specially used in control channel.

Many multi frames together form a super frame. Super frame is a continuous 51×26TDMA frame; that is to say, a super frame consists of fifty-one 26 TDMA multi frames or twenty-six 51 TDMA multi frames. The period of super frame is 1,326 TDMA frames, or 6.12 s.

Many super frames together form a hyper frame. A hyper frame consists of 2,048 super frames with a period of 12,533.7s, or 3 hours and 28' 53''. It is used in encrypted voice and data. Each period of hyper frame consists of 2,715,648 TDMA frames numbered from 0 to 2,715,648. The frame number is transmitted in sync channel.

Burst

Burst is the message layout of a timeslot in TDMA channel, which means each burst is sent to a timeslot of TDMA frame. Different message in the burst determines its layout.

There are five kinds of bursts:

- ✓ Normal burst: used to carry messages in TCH(traffic channel), FACCH(fast associated control channel), SACCH(slow associated control channel), SDCCH(stand-alone dedicated control channel), BCCH(broadcast channel), PCH(paging channel) and AGCH(access grant channel) channels
- ✓ Access burst: used to carry message in RACH(random access channel) channel
- ✓ Frequency correction burst: used to carry message in FCCH(frequency correction channel) channel
- ✓ Synchronization burst: used to carry message in SCH(synchronous channel) channel
- ✓ Dummy burst: transmitted when no specific message transmission request from system (In cells, standard frequency sends message continuously)

Each kind of burst includes the following elements:

Tail bits: Its value is always 0 to help equalizer judge start bit and stop bit to avoid lost synchronization.

Information bits: It is used to describe traffic and signaling information, except idle burst and frequency correction burst.

Training sequence: It is a known sequence, used for equalizer to generate channel model (a way to eliminate dispersion). Training sequence is known by both transmitter and receiver. It can be used to identify the location of other bits from the same burst and roughly estimate the interference situation of transmission channel when the receiver gets this sequence. Training sequence can be divided into eight categories in normal burst. It usually has the same BCC setting with cells, but when accessed to burst and synchronization bust, training sequence is fixed and does not change with cells. For example, in access burst, training sequence is fixed (occupying 41 bits). The 36-bit message digit of the random access burst includes BSIC (base station identification code) information of the cell. BSIC settings of the same BCCH should be different, in order to avoid mis-decoding of random access burst from neighboring cells into local access.

Guard period: It is a blank space. Since each carrier frequency can carry a maximum of eight subscribers, it is necessary to guarantee the non-overlapping of each timeslot in transmission. Although timing advance technology is used, bursts from different mobile stations still show little slips; therefore, protection interval is adopted to allow transmitter to fluctuate in a proper range in GSM. On the other hand, GSM requires protection bits to keep constant transmission amplitude of the effective burst (except protection bits) and properly attenuate the transmission amplitude of mobile station. The amplitude attenuation of two sequential bursts as well as proper modulation bit stream can reduce the interference to other RF channels.

The following is a detailed introduction to the structure and content of burst:

Access burst

It is used for random access (channel request from network and switchover access). It is the first burst that the base station needs in uplink modulation. Access burst includes a 41-bit training sequence, 36-information bit, and its protection interval is 68.25 bits. There is only one kind of training sequence in access burst. Since the possibility of interference is rather little, it is unnecessary to add extra kinds of training sequences. Both training sequence and protection interval are longer than normal bursts in order to offset the bug of timing advance ignorance in the first access of mobile station (or switch over to another BTS) and improve demodulation ability of the system.

Frequency correction burst

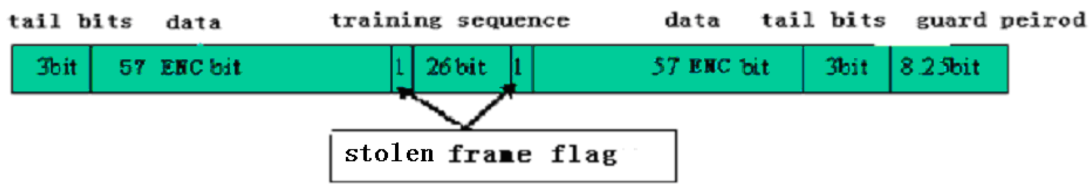
It is used for frequency synchronization in mobile station, equal to an unmodulated carrier. This sequence has 142 constant bits for frequency synchronization. Its structure is pretty simple with all constant bits being 0. After modulated, it becomes a pure sine wave. It is used in FCCH channel for mobile station to find and modulate synchronization burst of the same cell. When mobile station gets the frequency through this burst, it can read the information of following bursts (such as SCH and BCCH) in the same physical channel. Protection interval and tail bit are the same with that of normal burst.

Synchronization burst

With a 64-bit training sequence and two 39-bit information fields, synchronization burst is used for time synchronization of mobile station in SCH channel. It belongs to downlink. Since it is the first burst required to be modulated by mobile station, its training sequence is relatively long and easy to be detected.

Normal burst

It has two 58-bit groups used in message field. To be more specific, two 58-bit groups are used to transmit subscriber data or voice together with two stealing flags. Normal burst is used to describe whether the transmitted is traffic information or signaling information. For example, to distinguish TCH and FACCH (when TCH channel is used as FACCH channel to transmit signaling, the stealing flag of the 8 half bursts should be set to 1. It has no other use in channels except in TCH channel, but can be regarded as the extension of training sequence and always set to 1.Normal burst also includes two 3-bit tails and a protection interval of 8.25 bits. The only bug is that the receiver has to store the preceding part of burst before modulation. Normal burst has a total of 26 bits, 16 of which are information bits. In order to get 26 bits, it copies the first five bits to the end of the training sequence and the last five bits to the head of the training sequence. There are eight kinds of such training sequence (these eight sequences have the least relevancy with each other). They correspond to different base station color code (BCC, 3 bits) respectively to distinguish the two cells using the same frequency.



Dummy burst

This kind of bust is sometimes sent by BTS without carrying any information. Its format is the same with normal burst. The encrypted bits are changed into mixed bits with certain bit model.

1.4 GSM Logical Channel

In real networking, each cell has several carrier frequencies and each frequency has eight timeslots, proving eight basic physical channels. Logical channel carries out time multiplexing in one physical channel. It is classified according to the type of information in physical channel. Different logical channel transmits different type of information between BS and MS, such as signaling and data service. GSM defines different burst type for different logical channel.

In GSM, logical channel is divided into dedicated channel (DCH) and common channel (CCH), or traffic channel (TCH) and control channel (CCH) sometimes.

TCH (traffic channel)

TCH carries coded voice or subscriber data. It is divided into full rate TCH (TCH/F) and half rate TCH (TCH/H) with 22.8 Kbit/s information and 11.4 Kbit/s information respectively. Using half of the timeslots in TCH/F can get TCH/H. A carrier frequency can provide eight kinds of TCH/F or sixteen kinds of TCH/H. Voice channel types are as follows:

Enhanced full rate speech TCH (TCH/EFS)

Full rate speech TCH (TCH/EFS)

Full rate 9.6 Kbit/s TCH (TCH/F9.6)

Full rate 4.8 Kbit/s TCH (TCH/F4.8)

Full rate ≤2.4 Kbit/s TCH (TCH/F2.4)

CCH (control channel)

Control channel is used to transmit signaling or synchronous data. It mainly consists of broadcast channel (BCCH), common control channel (CCCH), and dedicated control channel (DCCH)

FCCH (frequency correction channel)

It carries the information for frequency correction in mobile station. Through FCCH, mobile station can locate a cell and demodulate other information in the same cell, and recognize whether this carrier frequency is BCCH or not

SCH (synchronous channel)

After FCCH decoding, mobile station has to decode SCH information. This information contains mobile station frame synchronization and base station identification. Base station identification code (BSIC) occupies six bits, three of which are PLMN color codes ranging from zero to seven, and the other three are base station color codes (BCCs) ranging from zero to seven. Reduced TDMA frame (RFN) occupies 22 bits.

BCCH (broadcast channel)

Generally, each BTS has a transceiver containing BCCH in order to broadcast system information to mobile station. System information enables mobile station to work efficiently in null state.

PCH (paging channel)

Paging channel is a downlink channel used to page mobile station. When the network wants to communicate with a certain mobile station, it sends paging information marked as TMSI (temporary mobile subscriber identity) or IMSI (international mobile subscriber identity) through PCH to all the cells in LAC (location area code) area according to the current LAC registered in mobile station.

AGCH (access grant channel)

Access Grant Channel is a downlink channel used for base station to respond to the network access request of mobile station, that is, to allocate a SDCCH (stand-alone dedicated control channel) or TCH directly. AGCH and PCH share the same radio resource. Keep a fixed number of blocks for AGCH or just borrow PCH when AGCH requires without keeping special AGCH block.

RACH (Random Access Channel)

RACH is an uplink channel used for mobile station to request SDCCH allocation in random network access application. The request includes the reason to build 3-bit (call request, paging response, location update request and short message request) and 5-bit reference random number for mobile station to identify its own access grant message.

SDCCH (Stand-alone Dedicated Control Channel)

SDCCH is a bi-directional dedicated channel used to transmit information of signaling, location update, short message, authentication, encrypted command, channel allocation, and complementary services.

SACCH (Slow Associated Control Channel)

SACCH works with traffic channel or SDCCH to transmit subscriber information and some specific information at the same time. Uplink mainly transmits radio measurement report and the first layer head information; downlink mainly transmits part system information and the first layer head information. The information includes quality of communications, LAI (location area identity), CELL ID, BCCH signal strength in neighboring cells, NCC (national color code) limit, cell options, TA (timing advance), and power control level.

FACCH (Fast Associated Control Channel)

FACCH works with TCH to provide signaling information with a rate and timeliness much higher than that provided by SACCH.

There is another control channel called cell broadcast channel (CBCH) besides the three control channels mentioned above. It is used in downlink and carries short message service cell broadcast (SMSCB) information. CBCH uses a physical channel same as SDCCH.

1.5 Channel Assignment Strategies

Cellular mobile communication systems are expected to have a high degree of capacity that is they have to serve the maximum number of calls even though the number of channels per cell is limited. Moreover, cells in the same cluster cannot use the same channel because of an increased possibility of co- channel interference that occurs mainly during the busy hours of the system [2]. Hence the process of channel assignment, that determines the channels that are to be used in each cell, is very important for the operation and reliability of cellular systems. There are mainly two types of channel assignment strategies:

1. **Fixed channel assignment (FCA):** in such systems channels are assigned to the cells initially during system design itself. Thus the total number of channels in every cluster will be equal to the total number of channels in the cellular system. Every cell in the system uses the same set of predetermined set of channels. Any call attempt within the cell can only be served by the not used channels in that particular cell. All the channels in that area are occupied, the call is blocked and subscriber does not receive service. Several variations of fixed channel assignment strategy exist. In one approach, called borrowing strategy, a cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied. The MSC supervises such borrowing procedures and ensures that the borrowing of a channel does not disrupt or interfere with any of the calls in progress in the donor cell. This classic scheme is very simple in design and efficient for uniform traffic distributions. But it is not considered as a good option for real non

uniform type of traffic distributions, as the number users keep varying. It also leads to poor spectrum utilization.

2. **Dynamic channel assignment (DCA):** it is the opposite of fixed channel assignment. In this scheme, all the available channels are placed in a common pool. Whenever a call arrives at a particular cell, it requests a channel from the common pool and returns it back to the pool after the call is terminated i.e. each time a call request is made, the serving base station requests a channel from the MSC. And then MSC allocates a channel to the requested cell following an algorithm that takes into account the likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions. In this way the system works efficiently even during non-uniform traffic and promotes effective spectrum utilization. An important property of channel assignment is channel reassignment, which further raises its quality of service. But all this advantages have to be balanced with the high implementation complexity associated with dynamic channel assignment since it requires the MSC to collect real time data on channel occupancy, and radio signal strength indicators (RSSI) of all channels on continuous basis. This increases the storage and computational load on the system.

Currently ethio telecom is using fixed frequency assignment strategies for GSM network throughout Ethiopia including Addis Ababa. But the number of mobile users under this network have highly increased and unable to have satisfactory service. Hence ethio telecom needs to have a solution to satisfy users under this network using fixed frequency assignment with no need of additional cost for dynamic frequency assignment.

1.6 GSM frequency reuse

Frequency resource is scarce for the mobile communication, so how to maximize the spectrum utilization ratio is a great concern for many carriers, equipment providers, and scholars. And their research into this problem has accelerated the development of the communication technologies. By now, the mobile communication has experienced different phases: analog TACS/AMPS, GSM/CDMA IS95, and WCDMA/CDMA2000, LTE (long term evolution) [4].

The purpose of enhancing the spectrum utilization ratio is to expand the network capacity based on the limited spectrum resource while ensuring the network quality. If not considering adding frequencies to the network, you can expand the capacity of a GSM network using the two methods. One is to increase the number of base stations in the network; the other is to use the frequency reuse technologies.

To expand the network capacity, one solution is to reuse the limited frequency resources. Though frequency reuse is beneficial for network expansion, it brings into another problem. That is, it deteriorates the conversation quality. The more aggressive the frequencies are reused, the greater the interference will arise in the network. Therefore, how to seek a balance between network capacity and conversation quality is a demanding task in frequency planning.

Currently, the 4 x 3, 3 x 3, 2 x 6, 1 x 3, and 1 x 1 are the GSM frequency reuse technologies in common use. For the 4 x 3 frequency reuse pattern, the frequency utilization ratio is relatively low, but higher carrier-to-interference ratio (C/I) can be obtained, so you can enjoy better conversation quality. Compared with the 4 x 3 frequency reuse pattern, the 1 x 3 frequency reuse pattern ensures a relatively high frequency utilization ratio, but the reuse distance is shorter, so interference is greater and the conversation quality is poorer.

C/I: Carrier to Interference Ratio

In the GSM system, frequency reuse will cause intra-frequency interference (co-channel interference). The intra-frequency is related to both the reuse distance and the cell radius. Here under is an example. Fig 1.3 shows the intra-frequency reuse of the Omni-directional base station.

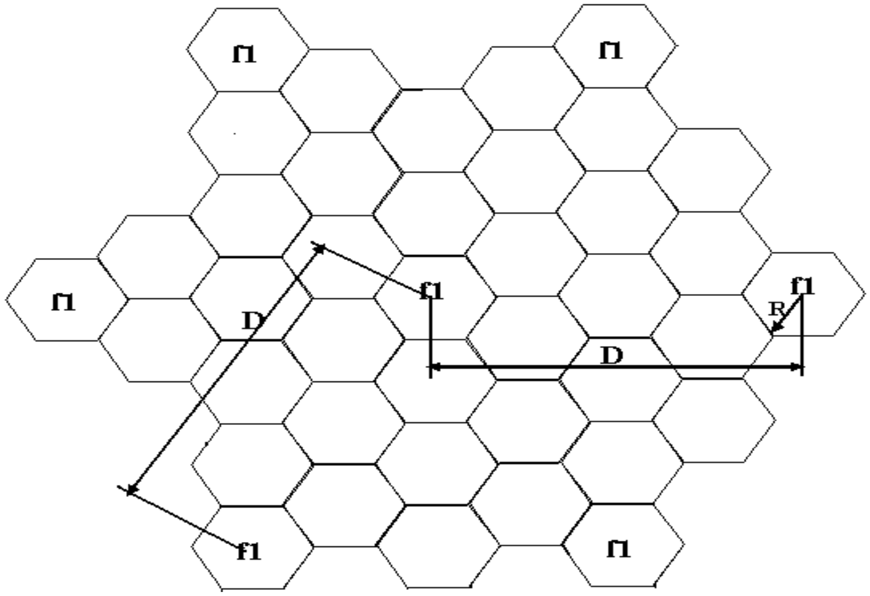


Figure 1.2 Intra-frequency reuse of the Omni-directional base station [4]

Suppose that the coverage radius of all base stations is the same, the relationship of the intra-frequency reuse distance (D), the cell radius (R), and number of each frequency reuse cluster (N) can be expressed by the following equation:

$$q = D / R = \sqrt{3N} \quad \text{.......} \quad (1.5)$$

Here,

$N = i^2 + ij + j^2$ (*"i" and "j"* are positive integers)

"q" is the intra-frequency interference attenuation factor.

For the directional cell, the physical meaning of the N stands for the number of base stations in the frequency reuse clusters.

If the intra-frequency cell and the service cell work at the same time, the MS located in the center of the service cell will receive both the useful signals from this service cell and the interfering signals from the intra-frequency cells. In this case, the C/I can be expressed by the following equation [4]:

$$\frac{C}{I}=\frac{C}{\sum_{i=1}^{k} I_k} \quad \text{.......... (1.6)}$$

Here, I_k is the Kth interfering signal. This equation can also be expressed as:

$$\frac{C}{I}=\frac{1}{\sum_{i=1}^{k} (q_k)^{-r}} \quad \text{.......... (1.7)}$$

Here,

q_k: is the intra-frequency interference attenuation factor of the Kth intra-frequency interference cell.

r: is the path loss slop according to actual geographical environment. In moving environment, it ranges from 3 to 5. Generally, it is 4.

As shown in Figure 1.3, for the Omni-directional base station with regular frequency reuse, there are 6 intra-frequency interference sources at the first layer, namely, the 6 intra-frequency reuse cells in orange. There are 12 intra-frequency interference sources at the second layer, namely, the 12 intra-frequency reuse cells in yellow. However, the 12 intra-frequency interference sources have only a little effect on the 6 interference sources at the first layer, so it can be neglected.

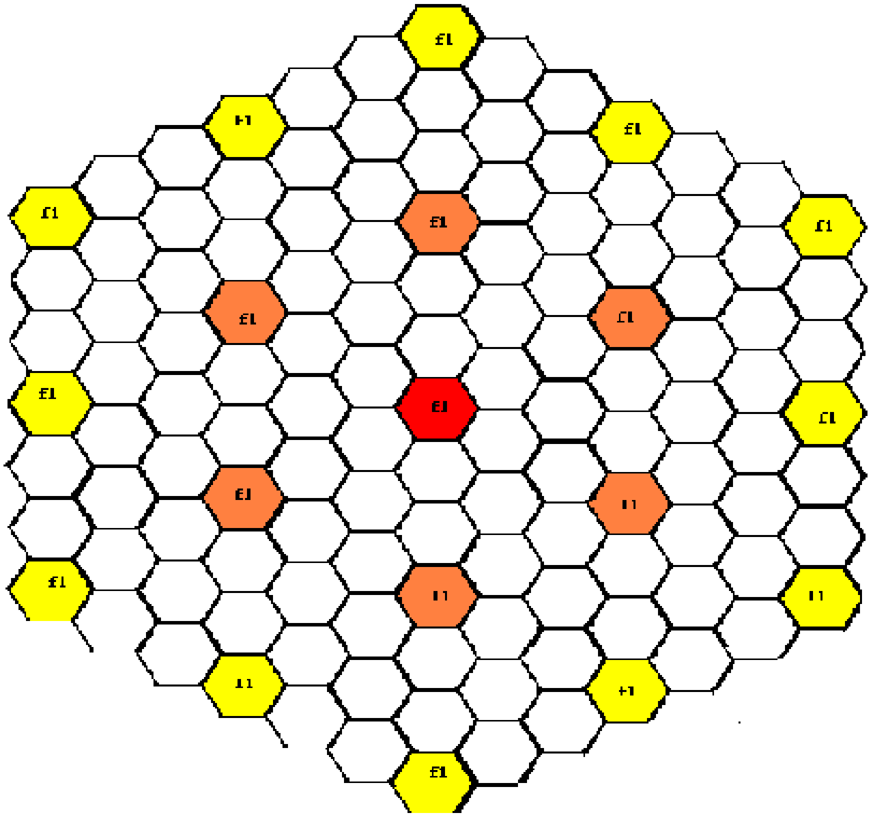


Figure 1.3 Intra-frequency interference for the Omni-directional base station [4]

If the radio propagation environment between the 6 intra-frequency reuse cells and the service cell is kept stable, the following three equations are present [4]:

$$\frac{C}{I} = \frac{1}{6q^{-r}} \quad \text{(1.8)}$$

$$q = (6 \times \frac{C}{I})^{\frac{1}{r}} \quad \text{(1.9)}$$

$$\frac{C}{I} = \frac{q^{r}}{6} \quad \text{(1.10)}$$

Based on the three equations, the relationship between the C/I and the number of the base station in the frequency reuse clusters can be expressed by the following equation:

$$\frac{C}{I} = \frac{(\sqrt{3N})^r}{6} \quad \text{...} \quad (1.11)$$

When the MS is located at the edge of the service cell, it will receive the poorest signals from the service cell but the strongest interfering signals. In this case, the needed C/I can be expressed by the following equation:

$$\frac{C}{I} = \frac{(q-1)^r}{6} \quad \text{...} \quad (1.12)$$

If the cellular layout is improperly designed, the interfering sources will increase and the C/I will decrease. According to the previous equations, the more the cells in each cluster, the greater the C/I and the better the network quality are, but the frequency utilization ratio will be lower. In addition, the GSM interference is related to the traffic load. The intra-frequency interference reaches the greatest when the traffic load reaches the peak.

Generally, the 4 x 3 frequency reuse pattern is used in GSM frequency planning. For the areas where the traffic is great, you can use other frequency reuse patterns, such as 3 x 3 and 1 x 3. No matter which frequency reuse pattern you take, you must meet the requirement on interference-to-protection ratio.

In the GSM system, the requirements on the C/I are listed in the following:

For intra-frequency C/I, it must be equal to or greater than 9 dB. In actual projecting, a margin of 3 dB is needed, namely, it is equal to or greater than 12 dB.

For adjacent-frequency C/I, it must be equal to or greater than -9 dB. In actual projecting, a margin of 3 dB is needed, namely, it is equal to or greater than -6 dB.

When the carrier offset reaches 400 KHz, the C/I must be equal to or greater than -41 dB.

1.6.1 4 x 3 Frequency Reuse Pattern

The spectrum utilization ratio can be expressed by frequency reuse degree, which reveals the aggressiveness of the frequency reuse. The frequency reuse degree can be expressed by the following equation [4]:

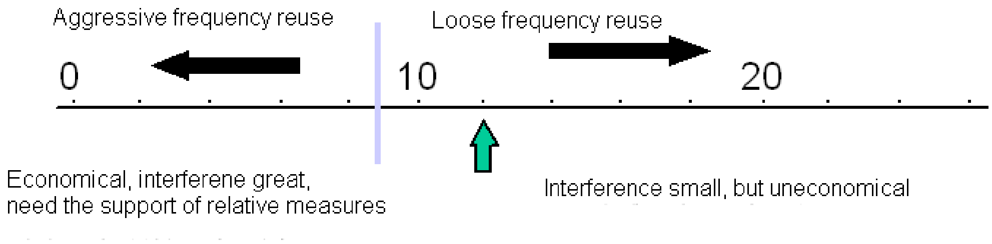
$$f_{reuse} = \frac{N_{ARFCN}}{N_{TRX}} \qquad \text{(1.13)}$$

Here N_{ARFCN} is the total number of the available channel numbers, and N_{TRX} is the number of TRXs configured for the cell.

For the n x m frequency reuse pattern, "n" indicates the number of the base transceiver stations in the reuse clusters, and "m" indicates the number of the cells under each base transceiver station. In this case, the frequency reuse degree can be expressed by the following equation:

$$f_{reuse} = n \times m \qquad \text{(1.14)}$$

In actual planning, however, the allocated number of channel numbers will be greater than n x m, so the actual f_{reuse} is usually greater than n x m. Therefore, the smaller the f_{reuse}, the more aggressive the frequency is reused and the higher the frequency utilization ratio is. As the aggressiveness of the frequency reuse grows, however, it will bring greater interference to the network. In this case, you must enable the technologies, including DTX and power control, to solve this problem. The more aggressive the frequency is reused, the lower the spectrum utilization ratio is, but the conversation quality is better at this time.



The purpose of the frequency planning is to reach a balance between the frequency utilization ratio and the network capacity. Based on the assurance of the network quality, you must take measures to maximize the network capacity.

In the GSM system, the 4 x 3 frequency reuse pattern is in basic use. Here “4” indicates 4 base transceiver stations (each base transceiver station consists of 3 cells), and “3” indicates the 3 cells under the control of each base transceiver station. Therefore, there are 12 sectors. And the 12 sectors makes up of a frequency reuse cluster, but the frequency in the same cluster cannot be reused.

For the 4 x 3 frequency reuse pattern, the intra-frequency spacing is great, so it can meet GSM system’s requirement on the intra-frequency interference protection ratio and adjacent frequency interference protection ratio. As a result, this frequency reuse pattern is good for the network quality and security. Under the 4 x 3 frequency reuse pattern, the frequency reuse aggressiveness is 12.

For the aggressive reuse introduced here under, because the BCCH plays an important role in the network and you cannot use to apply the anti-interference measures, such as downlink power control and DTX, to the BCCH, you must apply the 4 x 3 frequency reuse pattern or looser reuse patterns to the BCCH carriers.

Figure 1.5 shows the normal 4 x 3 frequency reuse pattern.

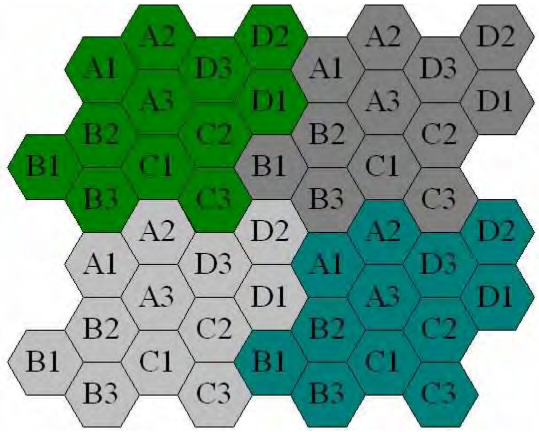


Figure 1.4 Normal 4 x 3 frequency reuse pattern [4]

Under this frequency reuse pattern, N is 4, so the following equation is present:

$$q = \sqrt{3N} = \sqrt{3 \times 4} = 3.46 \quad \ldots\ldots (1.15)$$

Under this frequency reuse pattern, each cell is a 120º-directional cell. At this time, the number of the interference source is reduced by 2, so the C/I in the poorest condition can be expressed by the following equation:

$$C/I = \frac{1}{(q+0.7)^{-4} + q^{-4}} = 20dB \quad \ldots\ldots (1.16)$$

In actual conditions, because the base transceiver station are irregularly distributed, the antenna height is different, and the effect from the radio environment, the C/I cannot reach a so high value.

In general, Ethio telecom in Addis Ababa is currently using 4x3 frequency reuse pattern to obtain higher carrier to interference ratio(C/I), so that enjoy with better conversation quality.

1.7 Interferences in GSM system

Interference is crucial factor in limiting the performance of radio systems. There are different sources of interference such as another mobile in the same cell, a call in progress in a neighboring cell, other base stations operating in the same frequency band, or any non-cellular system which inadvertently leaks energy in to the cellular frequency band. Interference on voice channels causes cross talk, where the subscriber hears interference in the background due to an undesired transmission. On control channels, interference leads to missed and blocked calls due to errors in the digital signaling. GSM systems experience two types of interferences. They are co channel and adjacent channel interferences.

1.7.1 Co- channel interference

When we repeat channels that can be used in another cell sites the capacity of the system increases. However, if this repeated use is followed in cells that lie close to each other, they would experience co channel interference. The cells that use the same frequency are called co channel cells. Thus, in order to minimize the co channel interference, co channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation. Cells may only use the same channels provided that the distance between their centers is equal to or a multiple of minimum distance (reuse distance). If the above condition is satisfied, then cells are said to belong to the same reuse scheme. The co channel interference is the prime source of noise in cellular systems and depends on cellular traffic. During busy hours of cellular system the possibility of co channel interference appears to be greater.

1.7.2 Adjacent channel interference

Cells that are placed close to each other also should not use adjacent i.e. channels adjacent in the frequency spectrum cannot be assigned to adjacent radio cells simultaneously. This will lead to adjacent channel interference. Though this interference is not as severe as the previous one, it has a major role in controlling the performance of the cellular system. The problem can be particularly serious if an adjacent channel user is transmitting very close range to a subscriber, while the receiver attempts to receive a base station on the desired channel. This is referred to the near-far effect, where a nearby transmitter (which may or may not be of the same type as that used by the cellular system) captures the receiver of subscriber. Alternatively, the near far effect occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile.

As Ethio telecom uses 4x3 frequency reuse pattern co-channels can be assigned when the separation is equal to 3 cells and adjacent channels can be assigned only when the separation is equal to 2 cells.

At the beginning of nineties, frequency planning in GSM networks was often performed manually due to lack of adequate, commercially available software tools. Because of the fast network installations in the middle of nineties, this practice came to its limits. New software for automatic frequency planning has been developed, and since the end of nineties, significantly improved planning tools were successfully employed. However, further capacity extensions and particularly the introduction of new technologies like GPRS make frequency planning to be more and more important again. Thereby, determining any best solution of the frequency assignment problem becomes problematic.

In this thesis, genetic algorithm has been applied to frequency assignment problems, i.e., problems where one kind of resources (frequencies) has to be assigned to another kind of resources (users) while respecting additional constraints.

1.8 Statement of the problem

Ethio- telecom is well known Ethiopian communication company that has been providing a mobile service from more than a decade. The network (specifically GSM network) of this company is expanded all over the country which covers almost all the major cities. However, still customer rate increases for the company at faster rate and there are many customers that are waiting for the good service throughout the country including Addis Ababa, Ethiopia which is the target city for our research. If frequencies are not assigned to users properly, different types of interferences such as co channel and adjacent channel interferences can be experienced and available bandwidth cannot be efficiently used, which directly affects the capacity of the system. Ethio-telecom is currently using a fixed frequency assignment strategy with 4x3 frequency reuse model in Addis Ababa, Ethiopia. With this assignment strategy and frequency reuse, our bandwidth cannot be efficiently utilized. Hence we proposed a group frequency assignment by not violating 4x3 frequency reuse model. By so doing we grouped some cells and increase the number of frequencies under each cell. This in turn has increased capacity of the system.

1.9 Thesis Objective

I. General objective

The main objective of this thesis is to optimize the frequency assignment problem encountered in GSM network of Addis Ababa. This work mainly focused on optimization of number of frequencies, number of cells, and the number of generations in the network by grouping cells here in Addis Ababa.

II. Specific objectives

- ✓ Investigate the existing frequency assignment in GSM network of Addis Ababa.
- ✓ Study and apply genetic algorithm for frequency assignment problem optimization of GSM network
- ✓ Simulate frequency assignment problem optimization using genetic algorithm developed with MAT LAB programming
- ✓ Analyze and evaluate computation result

1.10 Contribution

In this thesis we have studied frequency assignment strategies in existing GSM network of Addis Ababa. This enabled us to get significant inputs to conduct our research and identifies areas that need knowledge contribution as well.

There are no researches done in Addis Ababa on group frequency assignment under fixed frequency assignment strategies to enable mobile users to have more free channels in the group. For this reason, we conducted a research which investigates that any mobile user to use free channel under the group.

Furthermore, our research motivates the possibility of carrying out an extensive research in the area of group frequency assignment for dynamic frequency assignment strategy since dynamic frequency assignment strategy will be near future plan of ethio-telecom.

1.11 Thesis Organization

With the objectives of the study stated above, the thesis is organized as follows: chapter I give the introduction of the overall thesis work followed by literature review in chapter II. Frequency assignment problem representations as well as genetic algorithm are presented in chapter III. Analysis and simulation results are discussed in chapter IV. Finally, conclusion and recommendation are presented in chapter V.

Chapter 2 : Literature Review

The literature on frequency assignment problems, has grown quickly over the past few years. This is mainly due to the fast implementation of wireless telephone networks (eg.,GSM networks) and satellite communication projects.But also the renewed interest in other applications like TV broadcating and military communication problems inspired new research. This applications lead to many different models, and within the models to many different types of instances. However, all of them share two common features:

I. A set of wireless communication connections (or a set of antennae) must be assigned frequencies such that data transmission between the two endpoints of each connection (the receivers) is possible. The frequencies should be selected from a given set that may differ among connections.

II. The frequencies assigned to two connections may incure interferrence to one another, resulting in quality loss of the signal.

Frequency assignment problems (FAPs) first appeared in the 1960s [16]. The development of new wireless services such as the first celluar phone networks led to scarcity of usable frequencies in the radio spectrum. Frequencies were licensed by the government who charged operators for the usage of each single frequency separately. This introduced the need for operators to develope frequency plans that not only avoided high interferrence levels, but also minimized the license costs .It turned out that it was far from obvious to find such a plan.At this point, operations research techniques and graph theory were introduced.[16]usually receives the credits for pointing out the opportunities to use mathematical optimization, especially graph coloring techniques[11], for this purpose.

In the late 20th century, most important contributions on frequency assignment used heuristics based on the related graph theoretic approach[11], the use of simulated annealing [6] approach and the use of neural networks[12] approach. Each of these approaches was shown to have its own limitations.

The neural network approach [12],[13] was shown to be inappropriate for frequency assignment as it generates poor solutions even in simple cases. The use of simmulated annealing [6] can avoid being trapped by the local minimum solutions but at the expense of very high running time complexity. Besides, the solution quality is very diffcult to control. Further research in this direction is needed.

The graph theoretic approach has been extensively studied and a lot of research results have been reported.In the following the most important ones are summarized based on the heuristic of assigning frequencies to the cell with the highest assignment diffculty. First, Box[8] proposed an iterative algorithm with an intail set of randomly generated numbers to represent the assignment difficulties of individual cells. This algorithm was shown to have slow convergence rate and a high running time complexity especially when the system size is large.

In [9], a heuristic measure of the assignment diffculty was proposed and cells are ordered in to a list by either node-color ordering or node-degree ordering. Based on the list, channels are assigned by either frequency exhaustive (F) or requirement exhausitive(R) strategies. Later in [11], an improved heuristic measure for channel assignment diffculty was proposed and a new cell ordering method called column- wise cell ordering was also introduced. It has been shown that algorithms proposed in [11]give the best performance overall existng algorithms on the 21-cell landmark examples adopted.

Since the heuristic algorithms give no information on the quality of the solution, some lower bounds on channel assignment problems were derived in [10] by considering decoupled sub-network of the orginal system. Recently, a tighter lower bound under certain conditions was derived in [14],[15]. Two algorithms based on graph coloring approach were also proposed.

Interferrence minimization in GSM networks with a fixed spectrum of available channels in a more recent developments [1],[3],[6],[7]. In this thesis, we focus on fast and familiar assignment heuristics. The heuristics developed is intended to be used by ethio telecom for frequency assignments in GSM networks. The heuristics proposed have been implemented using matlab programming language.

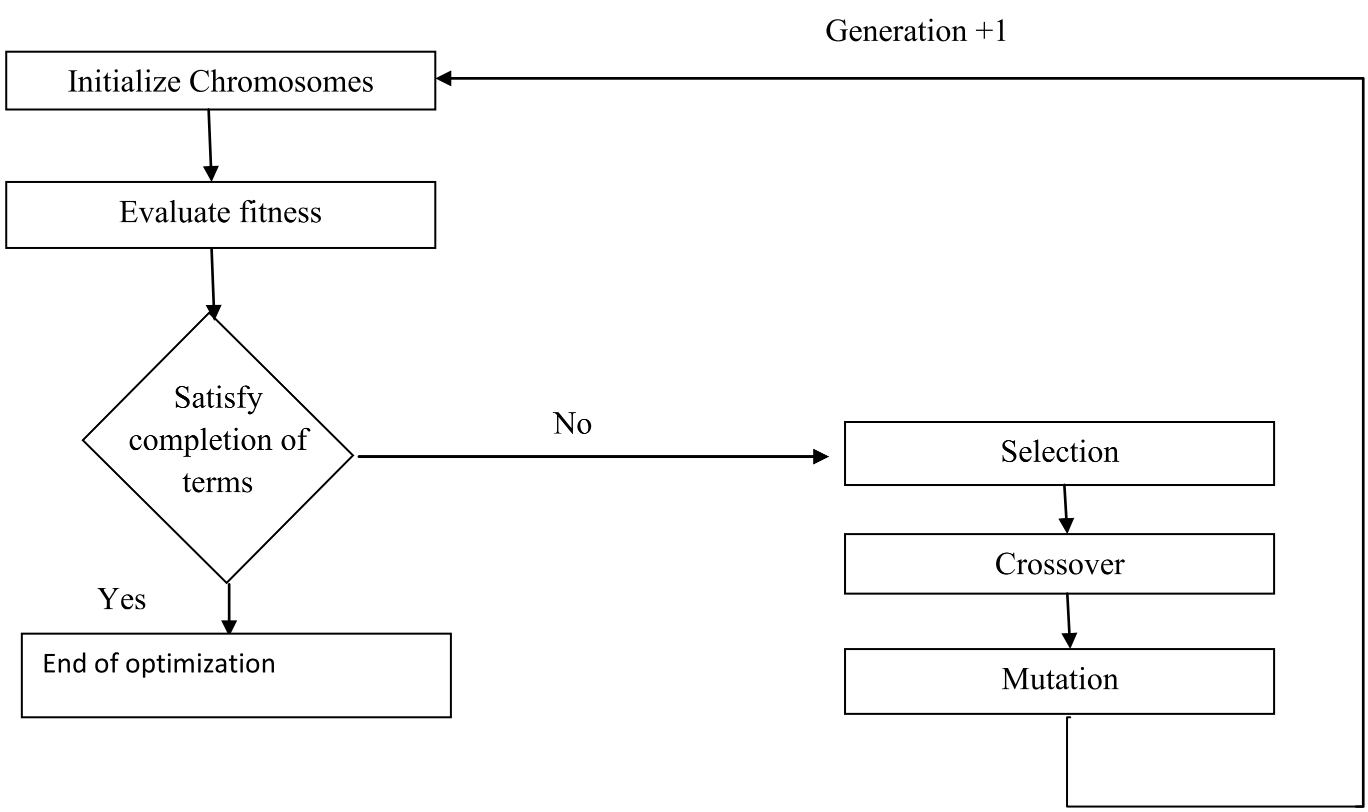
Chapter 3 : Genetic algorithm and frequency assignment problem representation

Genetic algorithms are a class of probabilistic algorithms that attempt to emulate the fundamental instruments of evolution; survival of the fittest and genetic operators. They start with a population of randomly generated candidates and evolve toward better solutions by applying genetic operators, modeled on the genetic processes occurring in nature.

In a genetic algorithm we maintain population solutions for a given problem; this population undergoes evolution in a form of natural selection. In each generation relatively good solutions reproduce, and bad solutions die, to be replaced by offspring of the good ones.

A basic genetic algorithm flow chart (fig 3.1) with frequency assignment problem representation is as follows:

Figure 3.1 flow chart of genetic algorithm



3.1 Initial chromosomes

At first, an initial population is generated randomly: a population is a group of all solutions considered in a certain moment and each solution is called individual or chromosome or string.

Chromosome: refers to a candidate solution to a problem, often encoded as a bit string.

Genes: are either single bits or short blocks of adjacent bits that encode a particular element of the candidate solution.

For example, initial population = 4 to mean

0 0 0…………………..0

1 0 0…………………..0

1 1 1………………….1

0 0 0………………….0

From this an individual expressed as a sequence of bits in population represents frequencies assignment. A population is a group of individuals or chromosomes.

Note:

0 0 0…………….0

This assignment represents one string or solution or chromosome, which means frequencies assignment in one cell.

3.2 Fitness function

The fitness function has to be formulated first before starting with genetic algorithm. This fitness function is very important part of genetic algorithm, and varies depending up on the application genetic algorithm is used in. The fitness function must be designed such that the best chromosome corresponds to the one with the high fitness value. In the evaluation phase, the fitness functions of all the chromosomes present in the initial population are calculated. This function will assign a value to each individual, and it is through this that we may indirectly determine the individual's probability of survival.

In general, a possible solution can be represented by a matrix S[X, Y] where X is the number of frequencies and Y the cells. Having '1' in position (i, j) that is Sij=1, it says that frequency 'i' can be used in cell 'j', while in position (i, j) that is Sij=0 means that it is forbidden to use frequency 'i' in cell 'j'

The fitness function, or objective function in this paper, can be defined as

$$\mathbf{E}= \frac{100}{x_1{}^{2+}\, x_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where $\boldsymbol{E}$ is always positive, x_1= the number of lacking frequencies to the required number, x_2= the number of exceeded frequencies to the required number. In equation 3.1 above, the square of the shortage in the number of assigned frequencies is to prevent the state where a noticeable frequency shortage for the specified cells occurs. For example, even for the same "n frequency shortage," lacking one frequency each in "n" cells does not become a major problem, but a large hole exists in all of the cells in the state where one cell lacks "n" frequencies. Thus, the decision to impose a large penalty on a shortage in the number of assigned frequencies acts in this square. There is no change in imposing a larger penalty on the shortage in the number of assigned frequencies and the excess in the number of assigned frequencies even when using, for example, the power of 3 or 4 and not the square.

The objective function refers to a solution in a matrix form, not in a chromosome form because it is simpler to represent the constraints. Each gene is a row of matrix S. If genes are X with Y elements for gene, we will have X*Y matrix.

The optimum assignment is calculated by using equation (3.1) above. Since ethio telecom uses fixed frequency assignment strategy the initial amount of allocated frequencies in each cell is predetermined. But here in our case we grouped a certain amount of cells and perform optimum assignment under fixed frequency assignment strategy.

After calculating the fitness value, we must check whether the individuals are optimal or not. If they are optimal end of optimization unless we will precede the next step to have optimal solution using the genetic algorithm operators like selection, crossover and mutation.

3.3 Selection

Once the fitness values have been calculated, the chromosome that corresponds to the higher fitness values can be selected. This phase is based on the chosen fitness: in fact the selection is done in a way that individuals with better fitness have more chance to reproduce. In this way, because a new individual is generated by another one chosen in the previous population p (t), individuals with higher fitness give more children and so the research near good solutions happens more heavily than near bad solutions.

Once a portion of the population has been selected, the number of chromosomes in the initial population decreases. But the population size must be maintained throughout. For this purpose, new chromosomes have to be generated from the existing ones. This is done with the help of two functions: crossover and mutation.

In our case we used tournament selection to select parents for reproduction or crossover.

Tournament selection: permutes the members of the population and separates them into two subgroups. The best (according to the fitness) member of each subgroup is chosen and used as parents for crossover. Tournament selection ensures the fittest member of the population will always be selected, and also precludes the list fit member from being used in crossover.

3.4 Crossover

Crossover is the process where two chromosomes are combined to form two new chromosomes. The chromosomes (strings) that are selected from the selected population for this purpose are called parent chromosomes. The off springs produced are called child chromosomes. Crossover is only performed amongst cells. Thus there are two crossover points, and these are chosen randomly among each pair of parents. In CAP, crossover serves to improve the co-channel conflicts. Yet these conflicts are far outnumbered by the co-cell conflicts. However, crossover probability=1.0 will only result in a discontinuity from the previous to the present populations, as none of individual members of the population from the previous generation will be retained in the new one. In this respect, it has been suggested that crossover probability less than 1.0. [14].

In our case we used two-point crossover

Two-point crossover: selects two random integers' m and n between 1 and number of variables. The algorithm selects genes numbered less than or equal to m from the first parent, selects genes numbered from "m+1"to "n" from second parent, and selects genes numbered greater than n from the first parent. The algorithm then concatenates these genes to form a single gene. For example:

P1= [1 1 0 0 1 1 0 0]

P2= [0 1 0 1 0 1 0 1]

Random crossover points = 3, 6

Child1= [1 1 0 1 0 1 0 0]

Child2= [0 1 0 0 1 1 0 1]

Cross rate= crossed population/ all population………………………………………………. (3.2)

3.5 Mutation

Mutation is the process where only one parent is involved to form a new chromosome. After the reproduction process based on the operators described so far, every single gene may undergo a further random change with a probability equal to the mutation rate. A mutation point is selected as the point where mutation occurs. At that point, 0 changes to 1 and vice versa. Usually the probability of mutation is chosen to be less than the probability of crossover. A low level of mutation serves to prevent any one element in the chromosome from remaining fixed to a single value in the entire population. On the other hand, a high level of mutation will essentially result in a random search. To maintain a balance between such extremes a good value for mutation probability is 0.01[14].The fitness value has to be calculated for new individuals. Thus a new population will be formed, by maintaining the population size.

0	1	0	0	1	1	1	0
0	**0**	0	0	1	1	1	**1**

Table 3.1 Example of mutation

Here in the second column "1" changes to "0" and in the eighth column "0" changes to "1"

We will continue in this manner until we get optimum solution with "n" number of generations.

Mutation rate= mutant gene number/ all gene number

3.6 Termination

The complete process from the population initialization to mutation resulting in the production of a new set of "candidate solution" can be referred to as one generation. The genetic algorithm run over several generations in order to determine the best set of solutions and typically ended at the best convergence; that is when the best fit converges to the average. There are however other stopping criteria which include:

- ✓ Fixed number of generations reached.
- ✓ An individual is found that satisfies minimum criteria.
- ✓ The highest ranking individual's fitness is reaching or has reached a plateau such that successive iterations are not producing better results any more.

Usually genetic algorithm is ended with an output display of data of best solutions.

3.7 Group frequency assignment

As the number of cells increases the search space to have optimum solution expands, and determining the frequency assignment in one operation in response to the number of requested channels for all of the cells is diffcult.And possiblity of determing optimum solution in wide search space is low. By dividing the cells which are subjects of this problem in to several appropriate groups, an efficient computation is devised. This is believed to narrow the search space by grouping, and increase the possiblity of deriving the optimum solution.

In this assignment the whole cells are grouped in appropriate manner and each one is optimized. Based on this manner, frequency assignment are performed for all of the cells. This kind of frequency assignment is called group frequency assignment. The search space considered for group frequency assignment is for a total of 933 cells as in ethio-telecom for GSM network in Addis Ababa. The cell group number is defined as the number of cells in a cell group. Let the number of frequencies be 50,then with no grouping:

Number of cells* Number of frequencies

933*50= 46650 bits

The search space becomes 2^{46650} bits. When grouped with a cell group number 311:

Number of cells* Number of frequencies

311*50= 15550

The search space becomes 2^{15550} bits, thus the search space is narrowed.

Ethio-telecom is currently using 4x3 frequency reuse model for GSM network in Addis Ababa.Eventhogh this frequency reuse model is better in conversation quality, it is poor in spectrum utilization. But we grouped the whole 933 cells in 39 groups each containg 24 cells and increased the number of frequencies per cell to 5 which is not seen in Ethio telecom which uses Mentum planet as optimization tool and the number of frequencies used under each cell is not more than 3.

Chapter 4 : Computational results

The proposed genetic algorithm is developed in MAT LAB (R2012a), and a computing time is within a few seconds to less than a minute, depending on the problem of interest. We have tried to optimize parameters: the number of cells (intial population), the number of frequencies (bitsize), and the number of generations(iterations). In part 1 we have tested by varying the number of cells, and making generations and frequencies constant to have optimum value of the number of cells in the group. In part2 we have tested by varying the number of frequencies, and making the number of cells and the number of generations constant to obtain optimum number of frequencies per cell. In part 3 we have tested by varying the number of generations, and making the number of cells and frequencies constant to have optimum number of generations. At the end we found that the best solutions can be found at number of cells in the group=32, number of frequencies per cell=7, and the number of generations= 125.

In order to generate more optimum solutions, we can do it in two ways: increase the population size or run the program a few more times. Through our practice, we found that are increase of population size typically leads to a longer computing time than to re-run the program a few times. This may be due to the fact that manipulations of large matrices or longer vectors usually take longer.

4.1 Optimization of the number of cells

In this part we got optimum number of cells (=32) by making the number of frequencies and generations constant and the number of cells varying. Here all 1's shows best solution and all 0's shows worst solution. As we see in the MAT LAB results below we got best solutions for the number of population (cells)=32, 28 and 24. But grouping more cells increases chance of having free channels for the users. Thus, the optimum value for initial population(cells) is 32.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::12

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1
1	1	1
1	1	0
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1

- ✓ Here all the frequencies can be used in all cells except the third cell. In third cell the third frequency can't be used hence grouping 12 cells is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::16

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1

- ✓ Here all the frequency can be used in all cells. But grouping more cells increase a chance of having more free frequencies hence grouping 16 cells is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::20

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

```
    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1

    0     0     1
```

0	0	1
0	0	1
0	0	1
0	0	1
0	0	1
0	0	1
0	0	1
0	0	1
0	0	1

- ✓ Here the first 2 frequencies of all cells cannot be used in their corresponding cells. Thus, grouping 20 cells is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1
1	1	1

1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1

- ✓ Here all the frequencies can be used in all cells. A group comprises 24 cells. Grouping more cells increase a chance of having more free frequencies for the users. Thus, grouping 24 cells is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::28

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

```
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
     1     1     1
```

1	0	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1

- ✓ Here all the frequencies can be used in all cells except the 14^{th} cell. In 14^{th} cell the second frequency can't be used hence grouping 28 cells is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::32

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1

1	0	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	0	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1

- ✓ Here all the frequencies can be used in all cells except the 18th and 24th cells. In both cells the second frequency can't be used. But increasing the number of frequencies per cell increases system capacity. Thus, grouping 32 cells is optimum solution.

4.2 Optimization of the number of frequencies

In this part we got optimum number of frequencies (=7) by making the number of cells and generations constant and the number of frequencies varying. Here all 1's shows best solution and all 0's shows worst solution. As we see in the MAT LAB results below we got best solutions at bitsize = 12 and 8. When our bitsize is equal to 12, seven frequencies per cell can be used and six frequencies per cell can be used when bitsize is equal to 8. Having more frequencies per cell increases capacity of the system. Thus, the optimum value for number of frequencies per cell is 7.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::3

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

```
1 1 1

1 1 1

1 1 1

1 1 1

1 1 1

1 1 1

1 1 1

1 1 1

1 1 1

1 1 1

1 1 1
```

1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	1
1	1	0

- ✓ Here all the three frequencies can be used in their corresponding cells except the 24^{th} cell. In this cell the third frequency can't be used. Since increasing the number of frequencies under each cell increases the system capacity, three frequencies per cell is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::4

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1

1	1	1	1
0	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1

- ✓ Here all the three frequencies can be used in their corresponding cells except the 21th cell. In this cell the first frequency can't be used. Since increasing the number of frequencies under each cell increases the system capacity, four frequencies per cell is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

1	1	1	1	1
1	0	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

- ✓ Here all the five frequencies can be used in their corresponding cells except the 7th cell. In this cell the second frequency can't be used. Since increasing the number of frequencies under each cell increases the system capacity, five frequencies per cell is not an optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::6

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

```
     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1

     1     1     0     0     0     1
```

1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1
1	1	0	0	0	1

- ✓ Here the three frequencies among six can't be used in all the 24 cells. Thus, 3 frequencies per cell is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::7

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	0	1	0	1	0	1
0	1	1	0	1	0	1
1	1	1	0	0	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1
1	1	1	0	1	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1
1	1	1	0	0	0	1
1	0	1	0	1	0	1
1	0	1	0	1	0	1
1	0	1	0	1	0	1
1	0	1	0	1	0	1
0	1	1	0	1	0	1
1	0	1	0	1	0	1
1	1	1	0	1	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1
0	1	1	0	1	0	1

1	0	1	0	1	0	1
0	1	1	0	1	0	1

- ✓ Here most of frequencies can't be used in their corresponding cells. Thus, bit size =7 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::8

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	0	1	1

1	0	0	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	1	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1
1	0	1	0	1	1	1	1

- ✓ Here 6 frequencies per cell can be used in all cells. But increasing the number of frequencies under each cell increases the system capacity. Thus, 6 frequencies per cell is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::9

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	0	0	0	1	1	1	0	1
1	0	0	0	0	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	0	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	0	1	1	0	1
1	0	0	1	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	0	1	0	1
1	0	0	0	0	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	1	1

1	0	0	0	1	1	1	0	1
1	0	1	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	1	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1
1	0	0	0	1	1	1	0	1

- ✓ Here many frequencies can't be used in their corresponding cells. Thus, bit size =9 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::10

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1

0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	1	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	0	1	0	0	1
0	1	1	0	0	1	1	0	0	0
0	0	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	1	0	1
0	1	0	0	0	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1

- ✓ Here 6 frequencies can't be used in their corresponding cells. Thus, 4 frequencies per cell is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::11

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

0	0	0	1	1	1	0	0	0	1	0
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	0	0	0	1	1	0	0	0	1	0
0	0	0	0	0	1	0	1	0	1	1
0	0	0	0	0	1	0	1	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	0	0	1	0	1	0	1	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	0	0	0	1	1	0	0	0	1	0
0	0	0	1	1	1	1	0	0	1	0

0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	1	0	1	1
0	0	0	0	0	1	0	1	0	1	1
0	0	0	1	1	1	0	0	0	1	0
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	0	0	0	0	1	0	1	0	1	1
0	1	0	0	0	1	0	0	0	1	1
0	1	0	0	0	1	0	0	0	1	1

- ✓ Here most of the frequencies can't be used in their corresponding cells. Thus, bit size =11 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::12

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	0	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
1	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
1	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1

0	1	0	1	1	1	0	1	1	0	0	1
0	1	0	1	1	1	0	1	1	0	0	1

- ✓ Here 7 frequencies can be used in all cells. But increasing the number of frequencies under each cell increases the system capacity. Thus, 7 frequencies per cell is an optimum solution. In ethio telecom not more than three frequencies are assigned under each cell by using 4x3 frequency reuse model as shown in appendix B. In the appendix B the demand shows the number of frequencies under each cell. But using our algorithm seven frequencies are assigned under each cell and thus, it is better assignment than their assignment.

4.3 Optimization of the number of generations

In this part we got optimum number of generations (=125) by making the number of cells and frequencies constant and the number of generations varying. Here all 1's shows best solution and all 0's shows worst solution. As we see in the MAT LAB results below we got best solutions for the number of generations(iterations)= 125,175,and 225.But the smaller number of generations,the lower computation time for the assignment.Thus, the optimum value for number of generations is 125.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::10

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1
1	0	1	0	1

1 0 1 0 1

1 0 1 0 1

- ✓ Here many frequencies can't be used in their corresponding cells. Thus, the number of generations or iterations equal to 10 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::20

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

0 0 0 1 1

0 0 0 1 1

0 0 0 1 1

0 0 0 1 1

0 0 0 0 1

0 0 0 1 1

0 0 0 1 1

1 0 0 1 1

0 0 0 1 1

0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
1	0	0	1	1
0	0	0	1	1
1	0	0	1	1
0	0	0	1	1
1	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1

- ✓ Here most of the frequencies can’t be used in their corresponding cells. Thus, the number of generations or iterations equal to 20 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::25

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0
1	1	0	1	0

1 1 0 1 0

1 1 0 1 0

1 1 0 1 0

1 1 0 1 0

1 1 0 1 0

1 1 0 1 0

- ✓ Here many frequencies can't be used in their corresponding cells. Thus, the number of generations or iterations equal to 25 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::50

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1 0 1 0 1

0 0 1 0 1

0 0 1 0 1

1 0 1 0 1

0 0 1 1 1

0	0	1	0	1
1	0	1	0	1
0	0	1	0	1
1	0	1	1	1
0	0	1	1	1
0	0	1	0	1
0	0	1	1	1
1	0	1	0	1
0	0	1	0	1
0	0	1	0	1
0	0	1	0	1
0	0	1	0	1
0	0	1	0	1
0	0	1	1	1
0	0	1	1	1
0	0	1	1	1
0	0	1	1	1
0	0	1	0	1
0	0	1	0	1

- ✓ Here many frequencies can't be used in their corresponding cells. Thus, the number of generations or iterations equal to 50 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::75

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	1
0	1	0	0	0
0	0	0	1	0
0	1	0	0	0

0	1	0	1	0
1	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0
0	1	0	1	0

- ✓ Here most of the frequencies can't be used in their corresponding cells. Thus, the number of generations or iterations equal to 75 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::100

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1	1	1

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	0	1
1	1	1	1	1
1	1	1	1	1
1	1	1	0	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

1 1 1 1 1

- ✓ Here the fourth frequencies in the 9th and 12th cells can't be used. Thus, the number of generations or iterations equal to 100 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::125

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1 0 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1 1 1 1 1

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

- ✓ Here all the frequencies in all cells can be used except the second frequency of the first cell. The lower the number of generations, the lower computation time for the assignment. Thus, the number of generations or iterations equal to 125 is optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::150

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	0	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1

1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1
1	1	0	1	1

- ✓ Here many frequencies can't be used in their corresponding cells. Thus, the number of generations or iterations equal to 150 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::175

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

1	0	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

- ✓ Here all the frequencies in all cells can be used except the second frequency of the 6^{th} cell. The lower the number of generations, the lower computation time for the assignment. Thus, the number of generations or iterations equal to 175 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::200

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

```
     1     1     0     0     0
     1     1     0     0     0
     1     1     0     0     0
     1     1     0     0     0
     1     1     0     0     0
     1     1     0     0     0
     0     1     0     0     0
     1     0     0     0     0
     1     1     0     0     0
     1     1     0     0     0
     1     1     0     0     0
     1     1     0     0     0
```

1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0
1	1	0	0	0

- ✓ Here most of the frequencies can't be used in their corresponding cells. Thus, the number of generations or iterations equal to 200 is not optimum solution.

Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm

Please enter the size of initial population::24

Please enter the bitsize of each strings::5

Please enter the lower limit of the variable x::1

Please enter the upper limit of the variable x::50

Please enter the number of iterations to perform the process of genetic algorithm::225

Please enter the number of times you want to perform tournament selection::5

The final best solution is given as....

Popu =

1	1	1	1	1
1	1	1	1	1
1	1	1	0	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

- ✓ Here all the frequencies in all cells can be used except the 4th frequency of the 3rd cell. The lower the number of generations, the lower computation time for the assignment. Thus, the number of generations or iterations equal to 225 is not optimum solution.

Chapter 5 : Conclusion and Recommendations

5.1 Conclusion

Global system for mobile communications (GSM) is one of the currently available technologies for mobile communication in Ethiopia including Addis Ababa. A high connection quality is a major competitive edge for telecommunication providers. But limited availability of frequencies is one of the most important problems for radio network operators.

In this thesis, the solving of a version of the frequency assignment problem (FAP) in GSM networks by means of genetic algorithm has been considered. And the theory of genetic algorithm has been studied. The genetic algorithm has been employed to optimize the number of frequencies and the number of cells for existing GSM network of Addis Ababa.

This thesis reveals that 4 more frequencies can be used under each cell by grouping the cells and using the algorithm. Furthermore, it increased the number of channels to 32 (4x8) under every cell. This is not seen in Ethio telecom that uses Mentum planet as optimization tool which uses 3 frequencies before.

5.2 Recommendations

Since a required frequency assignment changes time to time, periodical calculation of frequency assignment will be needed. Repeating and using the co-channel and adjacent channel to the required number of channels realizes reduction of channel interference, and efficient frequency assignment. Therefore, Ethio telecom should:

- ✓ Divide the total number of cells in to 29 groups containing 32 cells
- ✓ Make each cell contain 7 frequencies
- ✓ Make the number of iterations 125

Appendix A

%% MATLAB CODE FOR FREQUENCY ASSIGNMENT PROBLEM OPTIMIZATION USING GENETIC ALGORITHM

%DEVELOPED BY TADELE ABERA

%ADDIS ABABA UNIVERSITY

%SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

%COMMUNICATION ENGINEERING STREAM

clc;

clear all;

close all;

display('Program to find the solution of fitness function E=100/x1^2+x2 using genetic algorithm');

p_no=input ('Please enter the the size of initial population::');

bits=input(' Please enter the bitsize of each strings::') ;

final=[];

lower=input('Please enter the lower limit of the variable x::');

upper=input('Please enter the upper limit of the variable x::');

iterations=input('Please enter the number of iterations to perform the process of genetic algorithm::');

tournament_no=input('Please enter the number of times you want to perform tournament selection::');

```
p=rand(p_no,bits);

%% generate the bits randomly

for i=1:p_no

    for j=1:bits

        if (p(i,j)>=0.5)

            popu(i,j)=1;

        else

            popu(i,j)=0;

        end;

    end;

end;

popu;

for z=1:iterations

val=zeros(p_no,1);

%%calculate the value of strings

for i=1:p_no

      for j=bits:-1:1

          k=bits-j;

          val(i,1)=val(i,1)+100./pow2(popu(i,j),k);

      end;
```

```
end;

val;

%%calculate the values mapped in the range [lower upper]

for i=1:p_no

  val_mapped(i,1)=lower+(((upper-lower)*val(i,1))/(100./(pow2(bits)-1)));

end

val_mapped;

%% generate the random numbers to do the tournament selection

for i=1:tournament_no

   select(i,:)=[floor(1+rand(1)*(p_no-1)) ceil(1+rand(1)*(p_no-1))];

end;

select;

%% calculate the fitness value and perform tournament selection

for i=1:tournament_no

   tour(i,:)=[val_mapped(select(i,1),1) val_mapped(select(i,2),1)];

   tour_val(i,:)=100./power(tour(i,:),2);

         if (tour_val(i,1)>=tour_val(i,2))

         fitest(i,:)=popu(select(i,1),:);

         else

         fitest(i,:)=popu(select(i,2),:);
```

```
    end;
end;
tour;
tour_val;
fitest;
prob_crossover=0.8;
prob_mutation=0.01;
crossover_point=2;
for x=1:ceil(p_no/2)
%%selecting of parents
parents=[];
crossover=[];
crossover_val=[];
crossover_val_mapped=[];
crossover_fitness=[];
parents=[fitest(floor(1+rand(1)*(tournament_no-1)),:);    fitest(ceil(1+rand(1)*(tournament_no-1)),:)];
%%selecting of childrens
val_gen=rand(1);
child=[];
```

```
if (val_gen<prob_crossover)

   child=[[parents(1,1:crossover_point)
parents(2,(crossover_point+1):bits)];[parents(2,1:crossover_point)
parents(1,(crossover_point+1):bits)]];

end;

%%calculate the value of parents and children

crossover=[parents;child];

crossover_val=zeros(size(crossover,1),1);

for i=1:size(crossover,1)

      for j=bits:-1:1

          k=bits-j;

          crossover_val(i,1)=crossover_val(i,1)+100./pow2(crossover(i,j),k);

      end;

end;

crossover_val;

%%map the above value in the range [lower upper]

for i=1:size(crossover_val,1)

   crossover_val_mapped(i,1)=lower+(((upper-lower)*crossover_val(i,1))/(100./(pow2(bits)-1)));

end

crossover_val_mapped;

%% calculate the fitness value to select the the most suitable solution
```

```
crossover_fitness=100./power(crossover_val_mapped,2);
select_max1=max(crossover_fitness);
for i=1:size(crossover,1)
        if (select_max1==crossover_fitness(i,1))
            pos1=i;
            break;
        end;
end;
%%the position of the max fitness value after crossover
pos1;
%% to select the 2nd bst fitness value.
select_max2=crossover_fitness(1,:);
pos2=1;
if select_max2==select_max1
    select_max2=crossover_fitness(2,:);
    pos2=2;
end;
for i=1:size(crossover_fitness,1)
        if(select_max1==crossover_fitness(i,:))
            continue;
```

```
        elseif (crossover_fitness(i,:)>select_max2)
            select_max2=crossover_fitness(i,:);
            pos2=i;
        end;
end;
%% the values of 2nd best fitness values and its position
select_max2;
pos2;
%% taking the best 2 fitest solution and creating a different mating pool
final=[final;crossover(pos1,:);crossover(pos2,:)];
end;%% end of crossover
%%performing mutation over the solutions generated after crossover.
for i=1:size(final,1)
    for j=1:size(final,2)
    val_gen=rand(1);
        if (val_gen<prob_mutation)
          final1(i,j)=xor(final(i,j),1);
        else
          final1(i,j)=final(i,j);
        end;
```

```
    end;
end;
final=[];
popu=final1;
p_no=size(popu,1);
end;%%end to the number of iterations for the entire process;
display('The final best solution is given as....')
popu
```

Appendix B

Site ID	Sector ID	Carrier Type	Demand
102501_Burayu_01_G_DCS	1	BCCH1800	1
102501_Burayu_01_G_DCS	2	BCCH1800	1
102501_Burayu_01_G_DCS	3	BCCH1800	1
112170-D	1	BCCH1800	1
112170-D	1	TCH1800	1
112170-D	2	BCCH1800	1
112170-D	2	TCH1800	1
112170-D	3	BCCH1800	1
112170-D	3	TCH1800	1
112216-D	1	BCCH1800	1
112216-D	1	TCH1800	3
112216-D	2	BCCH1800	1
112216-D	2	TCH1800	3
112216-D	3	BCCH1800	1
112216-D	3	TCH1800	3
112226-D	1	BCCH1800	1
112226-D	1	TCH1800	3
112226-D	2	BCCH1800	1
112226-D	2	TCH1800	3
112226-D	3	BCCH1800	1
112226-D	3	TCH1800	3
117001-D	1	BCCH1800	1
117001-D	1	TCH1800	3
117001-D	2	BCCH1800	1
117001-D	2	TCH1800	3
117001-D	3	BCCH1800	1
117001-D	3	TCH1800	3
AA_ZTEG402_DCS	1	BCCH1800	1
AA_ZTEG402_DCS	2	BCCH1800	1
AA_ZTEG402_DCS	3	BCCH1800	1
AA_ZTEG403_DCS	1	BCCH1800	1
AA_ZTEG403_DCS	2	BCCH1800	1
AA_ZTEG403_DCS	3	BCCH1800	1
AA_ZTEG407_DCS	1	BCCH1800	1
AA_ZTEG407_DCS	2	BCCH1800	1
AA_ZTEG407_DCS	3	BCCH1800	1
AA_ZTEG410_DCS	1	BCCH1800	1
AA_ZTEG410_DCS	2	BCCH1800	1
AA_ZTEG410_DCS	3	BCCH1800	1

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