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Optimization of Base Station Location in 3G Networks using Mads and Fuzzy C-means

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Abstract
Distribution of Base Transceiver Stations (BTS) with an aim of maintaining high Quality of Service and coverage is important to mobile operators. Rapid expansion of telecommunication industry results in stiff competition among service providers which in turn leads to greater focus on quality of services delivered. Increase in number of mobile phone usage has also led to unprecedented network expansion. Coupled to these challenges is rapid change in telecommunication technology from 2G to 4G in a short space of time. A combination of MADS and FUZZY C- MEANS is used to aid in planning Base Station Transceivers (BTS) location efficiently in order to curb capital and maintenance costs.
Keywords: BTS placement, MADS, Fuzzy C-Means

1. Introduction

In 2003 mobile penetration in Kenya was 5%, 42% in 2008 and over 78% in 2012. There are 5 mobile operators in Kenya with Safaricom and Airtel dominating the sector. Local mobile traffic according to CCK is estimated to amount to 7.3 billion minutes. Mobile internet/data penetration is 41.1% and increasing especially since most of the new mobile phone models support internet access. Mobile internet data subscription accounts for about 99% of total internet subscription in the country. (Communication Commission of Kenya, 2012)
These rapid increases in mobile subscriptions in a short space of time create expansion challenges for operators and regulators as well. One result of rapid expansion is multiplication of BTS towers which litter the sky. In some areas towers are many and close together due to unanticipated growth shifts in population. Another reason is that mobile operators don't share equipment such as towers or other equipment due to sabotage mistrust.
Mobile operators have had to contend with changing technology and equipment ranging from 2G to 2.5G to 2.75G and now 3G with 4G around the corner in a space of about 12 year (Motorola, 2008). These changes occur faster than mobile operators can capitalize and profit from existing equipment. Consequently small mobile operators may not be able to cope with such costs in the long term. (Waburi, 2009)
Mobile operators face two types of costs.

1. Capital – Initial expenditure in acquiring and deploying equipment and licenses for rolling out new technologies. These are one off expenditures.
2. Operational costs – These are costs of maintenance and replacement which are spread out over the life of the technology and equipment.

For an operator to be profitable he must have enough time to realize sales that offset both types of cost. If technology changes too fast, capital costs will mount very high and drive the operator out of business.
Since the rate of change of technology is not completely in the hands of a mobile operator, then it is paramount to fully utilize whatever resources available to him. Operators must try to achieve more with less. This calls for proper distribution of resources in order to maximize on equipment productivity and minimize operational costs.
A program built on MADS and FUZZY c-means is used to aid in network dimensioning. This program is fully automated and takes Mobile Station distribution as its only input. The aim is to keep path loss low and therefore reduce amount of power used in transmission while keeping Quality of Service high to avoid dropped calls.

2. Mathematical formulation to arrive at HATA distance Link budget

2.1 A link budget equation is given below: (Radio-Electronics.com)

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{FS} - L_{FM} - L_{RX} \qquad (2)$$

Where:
PRX= received power (dBm)
PTX = transmitter output power (dBm)
GTX = transmitter antenna gain (dBi)

GRX = receiver antenna gain (dBi)
LTX = transmit feeder and associated losses (feeder, connectors, etc.) (dB)
LFS = free space loss or path loss (dB)
LFM = many-sided signal propagation losses due to the transmission medium(dB)
LRX = receiver feeder losses (dB)
Free space loss is given by:

$$L_{FreePathloss} = 32 + 20 \cdot Log(f) + 20oLg(d) \quad (3)$$

Where: d = Distance in meters
Downlink power should be equal or less than uplink power. When downlink power is greater than the uplink power, the range cells increase. Calls at the edge of the cell are dropped because BTS will be out of range of MS transmitter.

2.1.2 Uplink budget:

Transmission from MS to BTS

$$EIRP = P_{TX} + L_{AF} + G_{ME} \quad (4)$$

Where:
EIRP = Effective Isotropic Radiated Power
P_{TX} = Power transmitted by the MS
L_{AF} = Antenna feeder and connector losses
G_{ME} = MS antenna gain

2.1.2 Receiver side: BTS is receiver

$$R_S = EIRP – L_P-I_M – F_M -L_C +G_{BTS} \quad (5)$$

Where:
R_S = Receiver sensitivity
L_P = Path loss
I_M = Interference
F_M = Fast fade margin
L_C = Connector losses
G_{BTS} = BTS antenna gain

2.2 Path loss calculation

Path loss can be calculated from the above equation by making L_P subject..
From Hata model path loss equation: (Directorate-General for Communications Networks,Content and Technology,European Commission, 1999)

$$L_P = 69.55 + 26.16Log10 (f_{MHz}) -13.82Log10 (h_b) – a(h_m) + [44.9-6.55Log10 (h_b)]Log10 (d_{km}) – K \quad (6)$$

To get maximum cell size, make distance d subject of Hata path loss equation to yield Hata maximum distance equation:

$$d = antiLog10 \{[P_t + G_{tot} - R - 69.55 - 26.16Log10 (f_{MHz}) + 13.82Log10 (h_b) + a(h_m) + K] / [44.9 – 6.55Log10(h_b)]\} \quad (7)$$

Where:
G_{tot} = Total gain
h_b = Base antenna height over street level in meters
h_m = Mobile station antenna height in meters
h_B = Nominal height of building roofs in meters

TABLE 1. List of constants in Hata path loss equation

AREA	**a(h_m)**	**K**
Open	[1.1Log10(fMHz)-0.7]hm - [1.56Log10(fMhz)-0.8]	4.78[Log10(fMHz)]2 – 18.33Log10(fMHz) + 40.94
Suburban	[1.1Log10(fMHz)-0.7]hm - [1.56Log10(fMhz)-0.8]	2[Log10(fMHz/28)]2 + 5.4
Small city	[1.1Log10(fMHz)-0.7]hm - [1.56Log10(fMhz)-0.8]	0
Large city	3.2[Log10(11.75hm)]2 – 4.97	0

Minimizing distance d between the BTS and MS while keeping path loss less than 140 dB has the following advantages:

- Number of BTS is reduced to a minimum
- Power required to run BTS and MS reduces
- Number of calls dropped due to high path loss values reduces.

The problem of BS location is approached in three stages:
First, allocate an initial number of BS locations which can be minimized.
Second, minimize distance of BTS to the furthest MS while keeping the path loss below 140 dB. This distance, is used to determine how many BTS are necessary to cover an area. Minimization is done using Mesh Adaptive Direct Search (MADS).
Third, BTS are distributed among the population using fuzzy c-means (FCM) which is a highly efficient method of clustering data. Clusters are assigned based on distance between data points and clusters.

3. BS allocation procedure

There are two components of BS location problem i.e.

3.1 Assignment of initial BTS number

This is achieved by in three steps:
Calculate area of interest and allocate initial number of BS based on the maximum area that a single BS covers.
E.g. if we take maximum radius covered by BS = 1.5 Km, and the area of interest = 100 Km^2

$$\frac{100\ Km^2}{(\pi * 1.5)Km^2} = 14.147$$

Initial number of required BS in this case is 15.
Determine total number of subscribers in the area and allocate BS based on maximum subscribers each BS can serve. One E1 has 32 channels at a speed of 64 kbps. E1 supports 30 users after subtracting channels used for maintenance. E.g. number of users = 1000,

$$\frac{1000}{30} = 33.333$$

Initial number of required BS in this case is 34.
Once initial BS numbers are calculated using both area and subscriber density, we allocate the larger of the two numbers to be used and an initial BS number.
Fuzzy C-Means is then used to distribute initial BS in the MS population. Objective function being minimized in FCM is (Algorithms, 2012)

$$J(U,V) = \sum_{i=1}^{n} \sum_{j=1}^{c} (u_{ij})^m ||x_i - v_j||^2 \tag{8}$$

Where,
$||x_i - v_j||$ is the Euclidean distance between i^{th} data and j^{th} cluster center.
n = number of data points.
$v_j = j^{th}$ cluster center
m = fuzziness index m € [1, ∞]
c = number of cluster center.
u_{ij} = membership of i^{th} data to j^{th} cluster center.
$U = (u_{ij})n*c$ is the fuzzy membership matrix.
J = objective function.

Algorithmic steps for Fuzzy c-means clustering (James C. Bezdek, 1999) (JAMES C. BEZDEK, 1984)

If X = {x1, x2, x3 ..., xn} is set of data points and V = {v1, v2, v3 ..., vc} the set of centers.

1) Select c cluster centers randomly.
2) Calculate the fuzzy membership u_{ij} using:

$$u_{ij} = 1/\sum_{k=1}^{c} (d_{ij}/d_{ik})^{(\frac{2}{m}-1)} \tag{9}$$

Where:
k = iteration step.
d_{ij} = Euclidean distance between i^{th} data and j^{th} cluster center.

3) Compute the fuzzy centers v_j using:

$$v_j = \frac{\left(\sum_{i=1}^{n} (u_{ij})^m x_i\right)}{\sum_{i=1}^{n} (u_{ij})^m}, \forall j = 1,2, \dots c \tag{10}$$

4) Repeat step 2) and 3) until the minimum J value is achieved or $||U^{(k+1)} - U^{(k)}|| < \beta$.
Where:
β = termination criterion between [0, 1].
Advantages of Fuzzy-C-Means

1. Gives best result for overlapped data set and comparatively better then k-means algorithm.
2. Unlike k-means where data point must exclusively belong to one cluster center here data point is assigned membership to each cluster center as a result of which data point may belong to more then one cluster center.

3.2. Choice of minimum number of BTS required

Pattern search algorithm: Mesh Adaptive Direct Search (MADS) is used to perform this minimization task. MADS works by selecting a random starting point and calculates objective function at that point. It then polls mesh points by computing the objective function at those points in a bid to find one that is lower than the current one. If the poll is successful, mesh size is increased by an expansion factor. Otherwise, mesh size is reduced by a contraction factor. (Mathworks, 2004–2012)
MADS calculates optimum path loss or distance and if it goes beyond threshold 140 dB, the number of BS is increased otherwise it is decreased if too low. The processes of site placement and site selection are repeated until an optimum number of BS is found which limits number of BS while guaranteeing necessary quality of service.

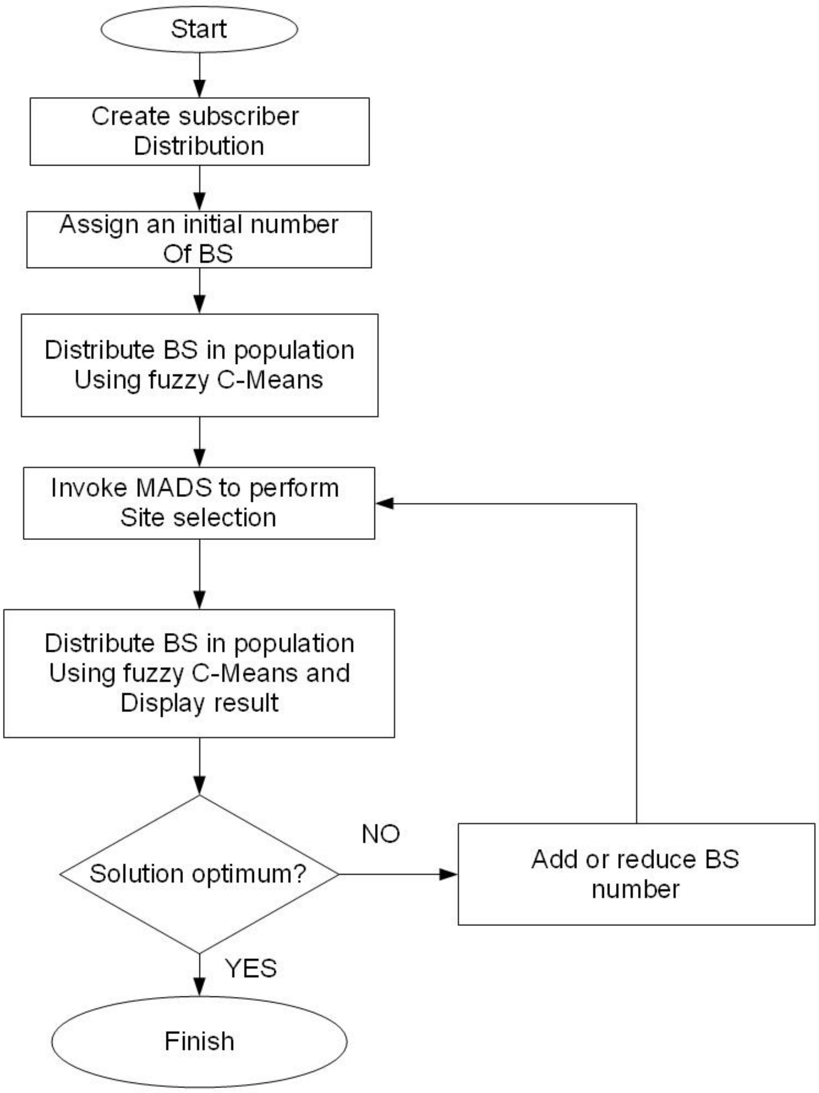


Figure 1. Felow diagram of algorithm

4. Results

Typical operating conditions are:

Table 2. List of operating conditions

PARAMETER	**VALUE**
Max power by BTS	30 W
Max power by Mobile Station	1 W
Spreading Factor	128
Target Path loss	140 dB
Mobile station antenna height	1.5
Mobile station antenna height	30
Noise power	2×10^{-14} W

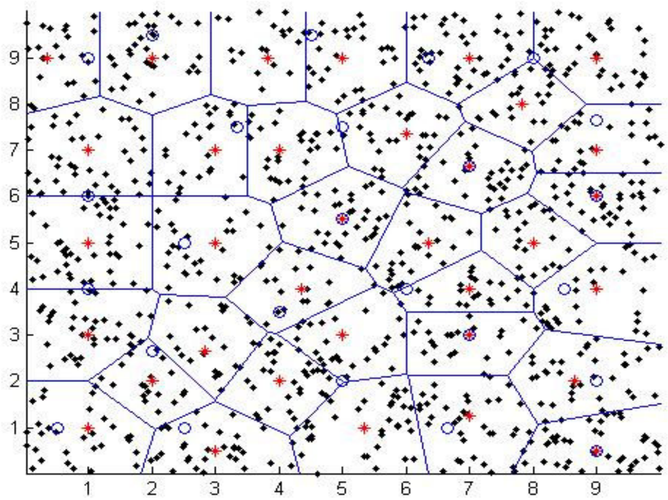
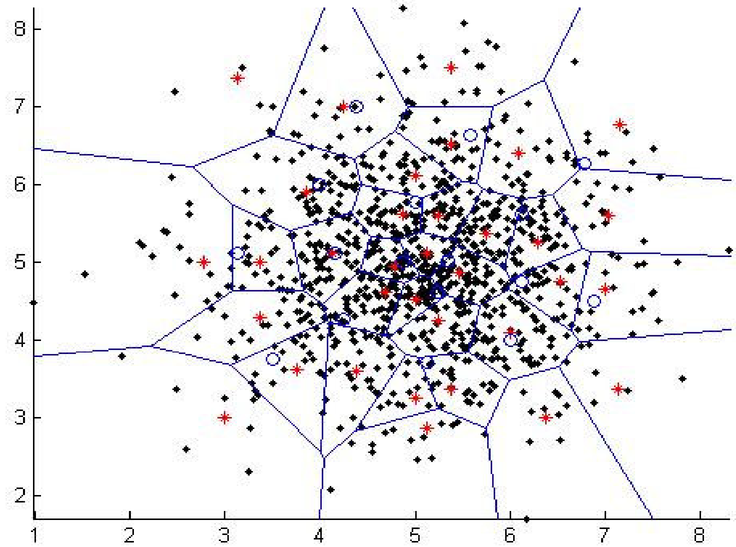


Figure 2. Randomly distributed users. Mobile Stations: 1000 Base Stations: 34



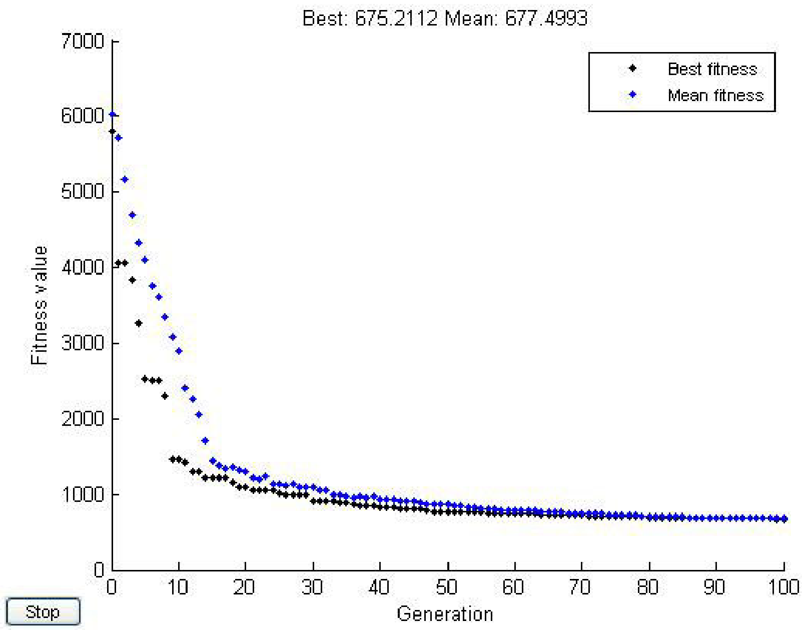
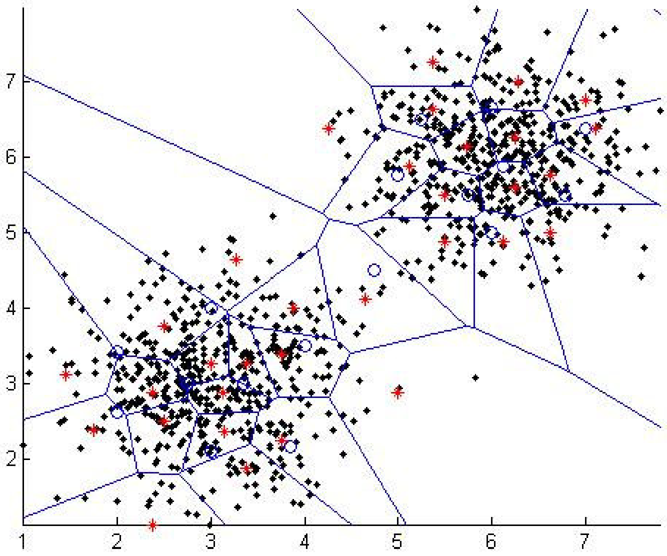


Figure 3 Gaussian distributed users around one centers. Mobile Stations: 1000 Base Stations: 34



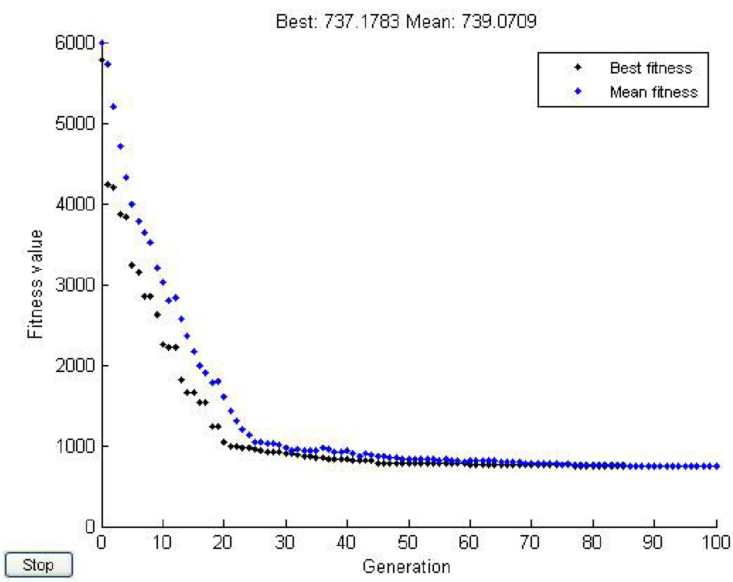


Figure 4 Gaussian distributed users around two centers. Mobile Stations: 1000 Base Stations: 34

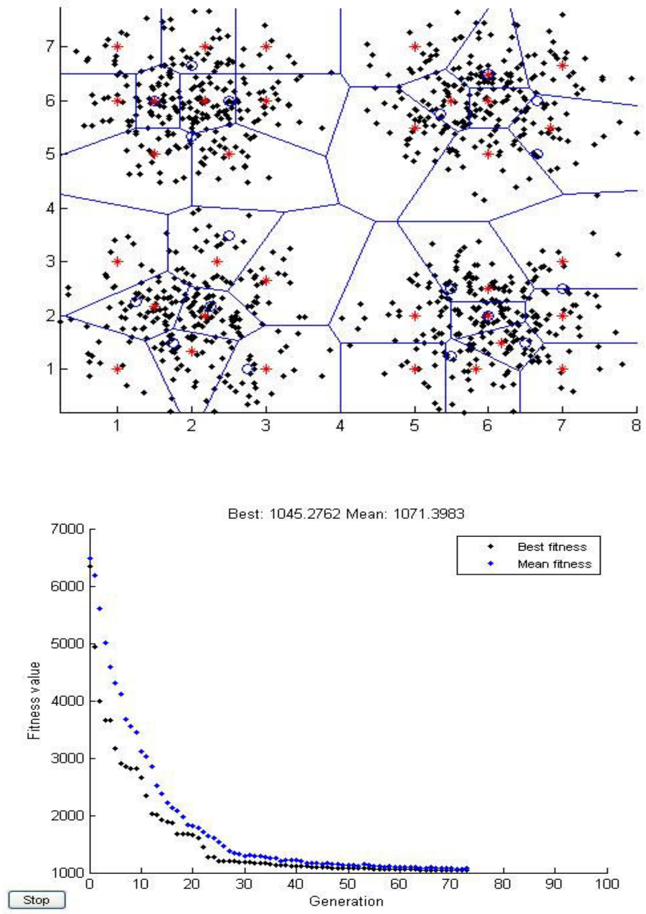


Figure 5 Gaussian distributed users around four centers. Mobile Stations: 1000 Base Stations: 34

5. Explanation of results

Results from simulations are consistent when population distribution is changed. Each BTS is to serve about 30 mobile stations and a radius of 1.5 km. Red asterisks are present BTS locations while black dots are mobile stations. This approach has certain advantages:

- There are very few settings on the part of the user. Simulations only require MS population distribution as input.
- Combining the optimization and clustering methods allows us to overcome disadvantages of both strategies if they were used alone while enhancing advantages. Optimization methods are not designed for clustering and therefore one has to write their own clustering functions which may not be very efficient. Clustering methods such as Fuzzy C-Means, K-Means etc have a big weakness in that they cannot determine optimum number of cluster centers themselves.
- Optimization method takes input from clustering method and determines if number of BTS allocated minimizes distance between BTS and furthest MS in cells. Output of the optimization is fed to cluster method in order re-cluster. This loop continues until an optimum number of BTS which minimizes distance is arrived at.

In doing this, the number of optimum BTS required is found automatically rather than being entered by the user through trial and error.

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