

# MASTER'S THESIS

## Network Planning Tool for Ka-Band Terrestrial Wireless and Broadband LEO Networks

*by Sachin S. Tatake*

*Advisor: John S. Baras*

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Project report for the  
Masters in Telecommunications Systems program

## **Abstract**

Technologies capable of providing high data rates have a lot of business potential. Comprehensive planning goes behind setting up networks for service provision. It is necessary to consider alternative techniques of service provision and market characteristics before designing the network. We prepare a optimization tool to aid business analysts in designing networks for selected markets. It compares the performance expected of LMDS, Broadband LEO and Fiber Optic networks.

Characteristics of each technology make it suitable for markets with certain characteristics, and unsuitable for some. A Geographical Information System and a mathematical programming package are integrated to form a tool which writes algorithms for selected regions for each technology. They are optimized to predict performance of each technology in the form of cost versus performance trade - offs. Using these results, the analyst can design an optimum network.

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# Chapter 1

## Introduction

End users demand better services and want solutions to their problems without learning too much technology. Customers have access to voice and data applications in any part of the world. Today's high end services become tomorrow's basic services. Users expect to have anyplace access to video and multimedia applications before the beginning of the new millennium. Wireless communications is a critical and promising link to connect to the future, because they can be deployed faster than alternative technologies.

In this chapter we consider technological advancements anticipated for fulfilling the commonly held vision of the future. Then we look at systems available today, focusing on Local Multipoint Distribution Service(LMDS). Studying each technology gives us an idea of potential it has of being the bandwagon to the next era of telecommunications.

### 1.1 Technology needs to take us into the future

Important topics into which we need to make advancements are:

Wideband channels;

High order modulation techniques;

Microcells and picocells;

Increased robustness, interference cancellation and smart antennas;

Audio/video compression.

|        | Macrocell<br>> 600 m                 | Microcell<br>60 to 600 m                          | Picocell<br>6 to 60 m              |                                   |
|--------|--------------------------------------|---|------------------------------------|-----------------------------------|
| Video  | Interactive Cable                    |   |                                    | HDTV                              |
| Visual | Videophone                           | Videoconference                                   |                                    | Packet<br><br><br><br><br>Circuit |
| Image  | Medical Imaging                      |   |                                    |                                   |
| Data   | FAX                                  | PDA's   | WANs                               |                                   |
|        | E-mail                               | Computer-computer                                 |                                    |                                   |
| Voice  | Telemetry                            |   |                                    |                                   |
|        | Voice messaging                      |   |                                    |                                   |
|        | POTS                                 |   |                                    |                                   |
|        | Narrowband<br>(Copper)<br><= 64 Kbps | Wideband<br>(copper/fiber)<br>64 kbps to 1.5 Mbps | Broadband<br>(fiber)<br>>= 45 Mbps |                                   |

Figure 1.1: Relationships between service type and data rate, cell size, and methods of transmission and switching [1]

These goals can be reached with the help of:

**Mobility Management:** To enable users to take their service wherever they go.

**Networking:** Convergent wireless and wireline systems.

**Software Development:** Make multimedia and data warehouses available.

**Computing:** Providing base stations with greater power, using smart cards.

## 1.2 Current technologies

Among the various technologies for wireless communications, a couple of promising ones are Multichannel Multipoint Distribution Service (MMDS) and LEO satellite networks.

### 1.2.1 MMDS

**About this system:** This is a technique being used primarily for transmitting video channels. It is a way of providing wireless cable TV. It uses a cellular configuration, with cell radii approximately 25 to 35 miles [2]. The network consists of a main transmitter and

multiple repeaters, which transmit the signal to antennae on subscriber's rooftops. They are routed to the descrambler using a coaxial cable.

The MMDS system is very quick and cheap to set up. It is inexpensive to run and has low maintenance costs. This makes the services it provides very cheap, and it, a strong competitor for wireline cable.

It uses the AM VSB format, which in 500 MHz, allows it to transmit up to 50 channels. If it uses MPEG-2 compression or 64-QAM techniques, it can accommodate up to 180 channels of high quality. Thus it can have more channels for pay-per-view services, and provide near video on demand. Most MMDS providers are heading in this direction.

**Advantages:** It uses the 2.150 to 2.682 GHz band of the spectrum. At this portion of the spectrum, the signal quality is not affected due to weather interference like rainfall. This is an advantage it has over LMDS.

This system has a cellular configuration, which enables it to transmit regional programming channels. This is an advantage over LEO networks as it can practice market segmentation by customizing its programs locally depending on market demographics.

**Disadvantages:** MMDS has no provision for upstream transmission, from the subscriber. Today, for pay-per-view and video on demand, it uses the telephone line. Thus from the future perspective, this system cannot be used for real time communications, which needs much more bandwidth capability.

### 1.2.2 Direct Broadcast Satellite

**About this system:** This innovative system uses the satellite to transmit signals at very high speeds to small dish receivers (direct to home). They are 21 inches in diameter, and inconspicuous when mounted on rooftops.

DirecTV is a service which has the capacity of providing over 200 channels with very good quality picture and sound. It uses MPEG 2 compression. Signals are transmitted from a broadcast center to the geosynchronous satellite, from where they are broadcast all over the continent.

DirecPC is an inexpensive way of connecting to the Internet at speeds of the order of 400 Kbps for reception. The Networks Operations Center (NOC) transmits data from the server to the satellite. This is then broadcast to the dish directly.

DirecDuo provides the above two services, on the same dish (antenna), using three high-power satellites.

**Advantages:** Using telephone lines for upstream data, this technology gives the fastest access to the internet today at reasonably low cost. It has immense bandwidth, and can offer bandwidth on demand. In addition, due to the low infrastructure required to be set up, time for deployment is very low.

It can provide services to regions like Alaska which are very tough to access for setting up terrestrial networks.

**Disadvantages:** These systems need a direct line of sight to the south, where their geosynchronous satellites are located. In areas with a large number of high rise buildings, all residences cannot have this.

These systems need a telephone line for upstream transmissions. This is their drawback, which will affect their ability to provide interactive services.

They can cover the entire continent with their programming. It is extremely difficult and expensive to provide local programming. These features are a major product differentiator from cellular(data) wireless services.

### 1.2.3 LEO satellite networks

**About this system** These global networks are pioneers of providing untethered voice and data services. They use hundreds of satellites, and this involves high fixed costs. They are designed to provide new applications to rural markets.

**Advantages** Subscribers can take their service wherever they go. They do not need a NOC or Gateway to contact the satellite. Due to the low altitude of the satellites, they can be reached directly from the ground. Distance does not matter anymore.

In areas with low population densities or poor communications infrastructures, it is not feasible to install terrestrial networks, as the fixed costs exceed the returns. Here LEO networks hold the edge.

**Disadvantages** Each satellite has a huge footprint. This reduces the number of satellites required to some extent. Also, it means that each satellite must have the bandwidth capacity to provide services to the subscribers of the entire supercell. This capacity is limited, and it imposes a hard constraint on the data rates that can be provided with one satellite. This limits the number of subscribers possible and the capacity of LEO systems.

### 1.2.4 ADSL and VDSL:

As telephone companies face competition, they are pushing development into ADSL and VDSL. These use entrenched telephone lines for two way transmission of signals at very high rates. ADSL/VDSL modems are attached to both ends of the twisted pair going to the subscribers house. They create three channels over this wire. The part of the spectrum on the DC end up to 4 KHz is reserved for voice signals. ISDN signals take 80 KHz of the DC end. These signals which form the POTS comprise one channel. The second channel is a band of frequencies of the order of 200 KHz, and the third is a band of frequencies stretching from a guard band above this channel up to 1 MHz, which is the outer edge of the spectrum being used by ADSL and VDSL. The data rates available on these two outer channels depends on the modem configurations used and the length of the line to the subscriber.

The second band is used for two way transmission, and is capable of providing speeds up to 64 Kbps. The third band can provide downstream signals at 6.1 Mbps. The downstream rates depend on a number of factors, the major factors being the length of the copper line, its wire gauge, presence of taps etc. Line attenuation increases with the length of the wire, and decreases as the diameter of the wire increases.

**Advantages:** ADSL and VDSL are high prospect technologies, as the infrastructure is already in place in millions of homes and offices. It is an ideal way of LECs to protect their monopolies and CLECs to steal marketshare from them.

ADSL can provide up to 9 Mbps downstream and 640 Kbps upstream, and VDSL can give up to 52 Mbps downstream and 2.3 Mbps upstream. Thus data rates will not be a problem for providing services.

**Disadvantages:** High data rate applications can be provided, but they require a fiber optic infrastructure to the curb to carry these signals to the subscriber. This makes these networks very expensive. Handling packet switched data is very demanding to the ADSL and VDSL modems. This makes hardware more expensive.

## 1.3 Fiber Optic Networks:

**About this system** They are the most cost intensive networks. A lot of research goes into them due the incredible bandwidth capacity they have, which is the need of the times.

**Advantages:** Using light as a carrier, they can provide very high data rates. Using WDM the capacity can be further enhanced. A single strand can carry as much as 10 Gbps, which is 4 signals, each carrying 2.5 Gbps.

Once the network is in place, costs involved with depreciation or maintenance are very low. At high orders of penetration, these make ideal networks.

**Disadvantages:** The wide array of competitive services available to subscribers today makes it difficult for any technology to achieve really high orders of penetration. In such competitive environments fiber optic networks may not break even.

This makes investing so heavily in these networks very risky.

## 1.4 LMDS:

Local Multipoint Distribution Service is the latest addition to the techniques of service available to provide the markets with all future killer applications. It is a simple wireless transmission technology, using a cellular configuration. Each cell has a high-powered, directionalized, millimeter wave transmitter, utilizing Ka - band(28 to 38 GHz) frequencies [2] to distribute multichannel video programming services throughout an area. The transmitters are networked to a central office which broadcasts the signals to each transmitter via fiber. The central office receives signals via satellite or fiber.

### 1.4.1 About the System:

Thus, the following is the path taken by the signals before they reach the subscriber.

- Satellites or fiber transmit their signals to the central office of a region. A region may consist of a state or a smaller region consisting of a number of cells.
- The central office sends these signals to the transmitters in each cell via fibers. There can also exist an omni-directional antenna in the central cell, which uses point to point microwave links to transmit signals to the transmitters in adjacent cells. This link will use the same 1.3 GHz frequency band, which is used for broadcasting the signals inside the cells. It is a beam only two degrees wide and uses opposite polarization, so it will not cause any interference or disturbance to the broadcast signals. Central office can additionally send programs customized for that local market which it covers, like weather, news and events information.
- These signals are broadcast all over the cells using the Ka band of frequencies. The signals from the transmitter are picked up by an antenna placed near the window.

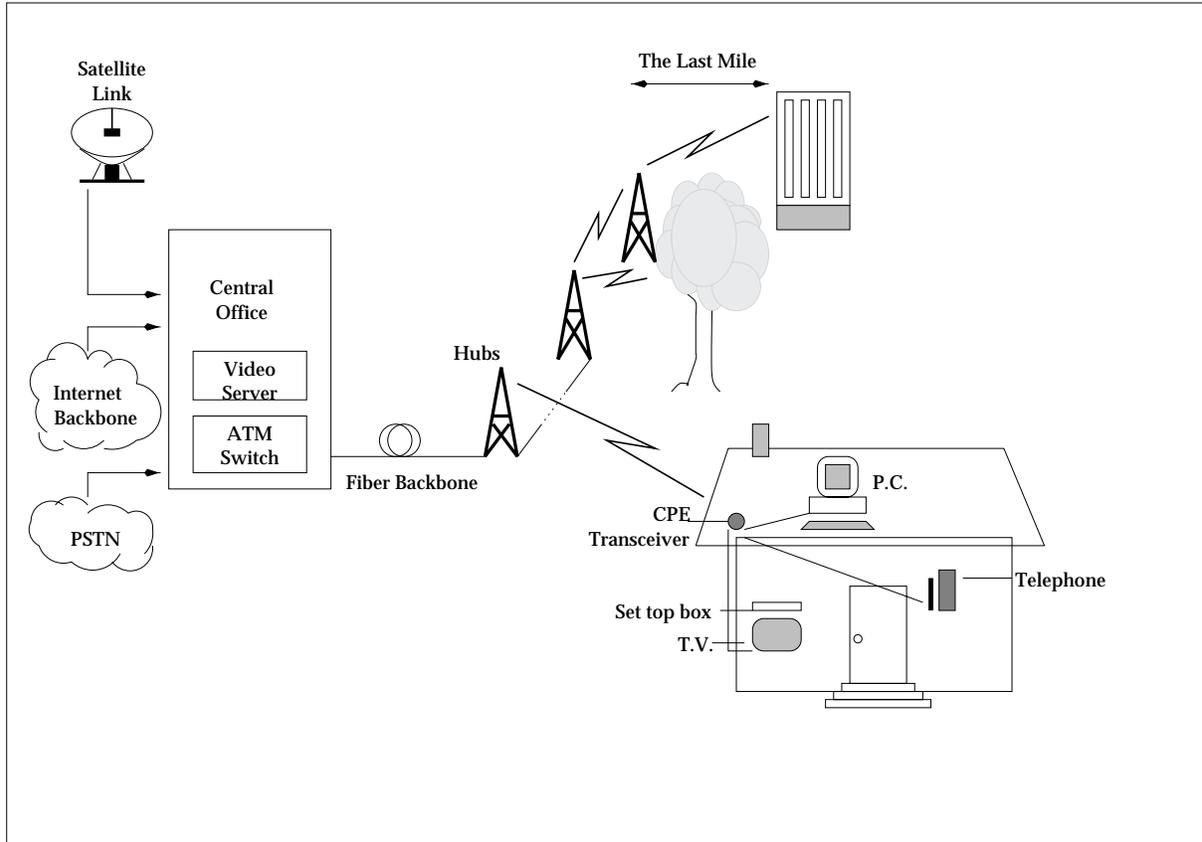


Figure 1.2: System infrastructure

The antennae used are  $6 \times 5/8''$  square and have a very narrow receive angle beam, to avoid multipath.

- These signals can contain voice, data or video signals, and will respectively be diverted into the telephone, computer or the TV. Here, information will be extracted from the signals depending on modulation and encryption techniques.
- LMDS is the most apt design for interactive multimedia services, and the antenna functions as a transceiver. Upstream transmission on reverse polarization to achieve frequency reuse, is being tried out.

#### 1.4.2 Spectrum characteristics:

The frequency allotted to this technology is 1.3 GHz, which is split up in the Ka band as:

$$27.5 \text{ to } 28.35 \text{ GHz} = 850 \text{ MHz}$$

$$29.2 \text{ to } 29.325 \text{ GHz} = 150 \text{ MHz}$$

31 to 31.3 GHz = 300 MHz

The first two chunks and 150 MHz of the third chunk(31 to 31.075 GHz and 31.225 to 31.3 GHz) which add up to 1.15 GHz make up the block A of the spectrum. They have been designated for use on a primary operator basis. For this part, LECs and Cable companies were not allowed to bid. The remaining 150 MHz called the block B, is to be used on a secondary operator basis, and there were no restrictions on bidders.

Such a large chunk of the spectrum has many advantages with respect to the bit rates it is capable of providing. The number of channels a license holder for the A block, can provide, gives an idea of its potential.

| Service     | Video | Voice |
|-------------|-------|-------|
| All Video   | 331   | -     |
| All Voice   | -     | 21160 |
| Average Mix | 179   | 8040  |

Table 1.1: Service Capabilities [3]

Here an average mix represents an average Basic Trading Area(BTA) where he will provide voice as well as video services.

Since it is protocol independent, LMDS can support all transmission standards for voice, video and data i.e. ATM, TCP/IP, MPEG-2 etc.

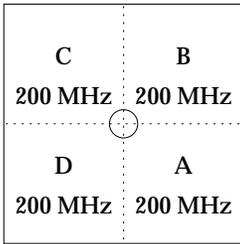
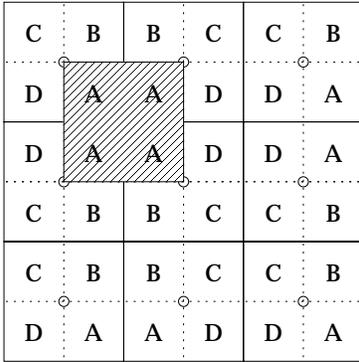
**Shadow regions:** The waves at these frequencies are millimetric waves, and have special characteristics. They cannot penetrate walls and hills, as they get reflected. The signals thus need a line-of-sight from the transmitter tower to the subscriber's antenna. The shadow areas need to have active repeaters to amplify and redirect the signal. Passive repeaters like buildings or other obstructions can also be used, though their range is much smaller.

**Weather interference:** The waves at these frequencies are absorbed by water. Water in tree leaves and in rainfall causes signals to deteriorate. Depending on the severity of the rainfall (tropical regions) and distance travelled, a LMDS system can compensate by providing a large signal-to-noise ratio margin. Rain detection devices included in the transmitter can automatically boost the transmit power when it rains. Areas with dense foliage will also need closer cell locations. Since foliage varies with the season, that effect will also need to be considered when determining cell size.

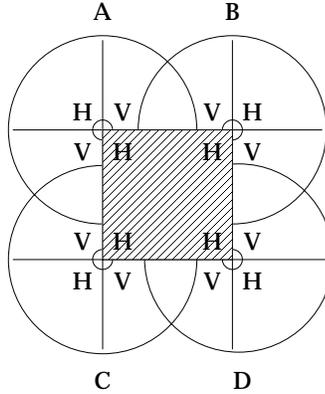
Due to these factors, transmitters can provide a signal range up to 3 miles, depending on the weather conditions, vegetation and built up area. This is a very small cell size, and for any BTA of average size, the number of cells needed will be a few hundreds.

### 1.4.3 Cell Layout

1. Cell layout suggested by HP.



2. Cell layout suggested by TI.



V: Vertical Polarization

H: Horizontal Polarization

Figure 1.3: Cell layouts suggested by Hewlett Packard and Texas Instruments

Figure 1.3 shows the cell layout suggested by HP and TI, on the basis of the experiments they conducted in Palo Alto and Atlanta markets.

**Cell layout suggested by HP:** The layout suggested by HP divides each cell into 4 sectors, and assigns a different frequency to each. This helps in each sector getting transmissions on the same frequency (A in Figure 1.3) from 4 adjacent hubs, and reduces to a minimum the chances of the subscriber being in a shadow area from the transmitter. Subscribers getting weak signals from one hub may get a stronger signal from an adjacent one. In addition, this layout achieves a frequency reuse of one.

**Cell layout suggested by TI:** Layout used by TI utilizes the entire 1 GHz band for transmission, in each sector. Each adjacent sector has opposite polarizations, while, as with HP, each sector gets same signal from 4 adjacent hubs, reducing shadow areas. However, spacing between a potential interfering transmitter is not as high as in the layout suggested by HP.

#### 1.4.4 Service provision

A bidder who gets 1.15 GHz on a primary operator basis is capable of providing services like:

- Medium - large to large corporations, Universities are the ideal sized organizations for being provided services by a few LMDS cells. Two - way voice, video and data communications between the central office and outskirts of the company territory like security clearance and warehouses can be provided.
- In protected areas, where boundaries are under surveillance, infrared night vision cameras do not need to be connected to the surveillance towers via give away cables. Wireless links reduce the time needed for setting up the system, and keep the setup inconspicuous.

A service provider who has rights to use the spectrum meant for LMDS needs to install the infrastructure, before he can start providing services. This will involve the following expenses:

- @ Head end costs consisting of the costs of the central office, head end equipment, engineering and network planning.
- @ Backbone costs which include the fiber, optical transducers.
- @ Hub costs which include the transreceivers, the antenna and mast, installation costs and costs of site acquisition.

Once these costs have been met, no further investment is required till the households passed actually become subscribers. At this stage, the service provider has to invest in and install the customer premises equipment. This is in contrast with a wireline system, in which, entire service area needs to be wired as if everyone is a subscriber, requiring a larger investment before any returns can start flowing. LMDS is extremely profitable at low take rates. Due to various options for these services in the market today, it is not likely to make everyone a subscriber to your service. Each technology can have only a section of the market, making this a big advantage to consider using LMDS.

#### 1.4.5 Advantages

In the beginning of the chapter, we listed a few factors which need to be available to take us into the future. LMDS has the bandwidth capability to provide us with bandwidth on demand. It is capable of being used for two way transmission, and will bring us real - time

interactive applications. It has low fixed costs, and the time to market is that needed to set up the transmitters. It is indeed the shortest path to deployment of broadband services.

### 1.4.6 Disadvantages

LMDS is capable of providing true multimedia services at very feasible rates, but its main drawback is that receiver must be stationary. It is not a technology for mobile applications.

A new technique, it has not been deployed on a major scale anywhere as of yet. However, the U.S. license auction was completed recently and many companies are proceeding with installations. Already, there are several systems operating abroad.

## 1.5 Comparison

Comparing these technologies with respect to the key features we enlisted for future broadband service provision, we can tabulate the results as follows [4].

| Service              | Service Technology |                |                               |                        |                      |                 |
|----------------------|--------------------|----------------|-------------------------------|------------------------|----------------------|-----------------|
|                      | MMDS               | DBS Satellite  | LEO Networks                  | ADSL & VDSL            | Fiber Optic Networks | LMDS            |
| Wideband Channels    | No                 | No             | Yes                           | Yes                    | Yes                  | Yes             |
| Classical POTS/ISDN  | No                 | No             | No                            | Yes                    | Yes                  | Yes             |
| National Programming | Yes                | Yes            | No                            | Yes                    | Yes                  | Yes             |
| Local Programming    | Yes                | No             | Yes                           | Yes                    | Yes                  | Yes             |
| Mobility             | No                 | No             | Yes                           | No                     | No                   | No              |
| Main Advantage       | Large cells        | Large coverage | Independent of infrastructure | Technology in place    | Huge bandwidth       | All services    |
| Main Disadvantage    | Low Bandwidth      | Broadcast only | Large cells                   | Hardware not developed | High Fixed costs     | Signal strength |

Table 1.2: Comparison of promising technologies

Though mobility is not a feature it can boast of, LMDS definitely seems to be a very promising technology for future services.

In chapters to follow, we make a detailed analysis of LMDS with respect to its economic feasibility, which presents a clear and more interesting picture of its potential and promise.

## Chapter 2

# Network Planning Tool

Local Multipoint Distribution Service is a new technology with great potential. However, it has not yet been deployed for high - technology applications. Recent spectrum auctions show that ventures planning to use this resource are all new firms. To provide profitable services using the best possible network, they need to carefully evaluate the cost versus performance trade-offs. Design of the network is a crucial part of deciding on whether it must be a homogeneous or a hybrid network, and recovering investments. In this lies the significance of the proposed Network Planning Tool.

### 2.1 Important aspects of LMDS

The present and the future sees high data rate applications as most profitable. Providing applications with such characteristics is the forte of LMDS. New service providers will use this opportunity to make the best out of it.

The spectrum auction was done on the basis of Basic Trading Areas (BTAs). These are regions made up of one or more counties joined together. Each BTA has its own characteristics. These are the

- Number of business customers.
- Number of residential users.
- Median Income of residents.
- Area of BTA
- Services already being provided to the market by other service providers

These factors affect the QoS that can be provided, demands that can be satisfied and feasibility of providing the required services to this BTA.

Thus an aspirant service provider must evaluate the profile of the market for which he is going to bid in the auction. He must consider

1. Which services can he provide?
  2. Which services will such a market demand?
  3. What returns can he get?
  4. What is the time period over which he will get returns?
- and,
5. Which is the best technology for meeting demand criteria?
  6. Should it be a homogeneous network or a hybrid, consisting of an appropriate inter-connection of more than one technologies?

The analyst will make decisions on some of the above criteria, and the tool will use default values for remaining parameters.

A detailed study of these topics will inform the service provider how much investment one can afford to make in this market, and what is the network one must build. This involves repeatedly performing a lot of calculations, checking the satisfaction of many constraints. Next, one needs to vary parameters like penetration of services for different technologies. One must observe the variation of **Returns On Investment** for various combinations of these parameters. Then one can make a decision with some degree of accuracy regarding chances of recovering investments and providing services with the desired QoS to the subscribers.

## 2.2 Parameters of optimization

Optimization involves a detailed demand analysis, in which the service provider will gather relevant data about the market. These data will be used to perform calculations that will return numbers giving a measure of the feasibility of that market.

**Type of Services:** One must decide which are the services one wants to provide to a market of this profile. For example, in areas with a large number of businesses, there is a good market for providing high data rate Internet services or video-conferencing. For example, Manhattan. On the other hand if one is providing services to a rural area with

very few high end users, one need not make a lot of investments in setting up high QoS networks, and number of cells that will be needed to cover the same area will be much smaller.

**Optimacy criterion** The service provider must study other technologies and the way they can provide the same services. Each technology has its own strengths and it may be easier and more efficient to provide the same services using some other technology or a combination of two or more techniques.

For example, in an area with a large number of high data rate Internet users, it will be a better idea to use MMDS to broadcast all TV channels it can. This will make more bandwidth available to provide services to more Internet users in each LMDS cell. This is due to the large cell size of MMDS cells. The area it covers with one cell requires many LMDS cells to cover. LMDS would have to broadcast same video signals in all these cells. This takes up 300 Mbps of the capacity of each LMDS cell. To provide same services requires only one MMDS cell. MMDS could thus save 300 Mbps in each cell.

MMDS has a very large cell size, so the bandwidth lost in broadcasting TV signals in a relatively large number of LMDS cells which lie inside the MMDS cell can be put to better use.

The Network Planning Tool is designed to perform such a demand analysis. A system analyst will decide the BTA he wants to analyze (See Figure 2.1 for block diagram). The tool will retrieve a profile associated with each market. This will contain information like size of market in terms of population, number of business establishments, number of households, and median income of residents. Next, the analyst will give the details about the services he expects his system to provide like:

Nature of service

Data rates of service

Time for network deployment

Penetration of services desired

The tool will incorporate these parameters into algorithms. These algorithms will be executed for 3 technologies namely LMDS, broadband LEO networks and fiber optic networks. The objective is to calculate values of parameters like

- What are the returns and what is the QoS obtained by using each of these 3 technologies to provide services?

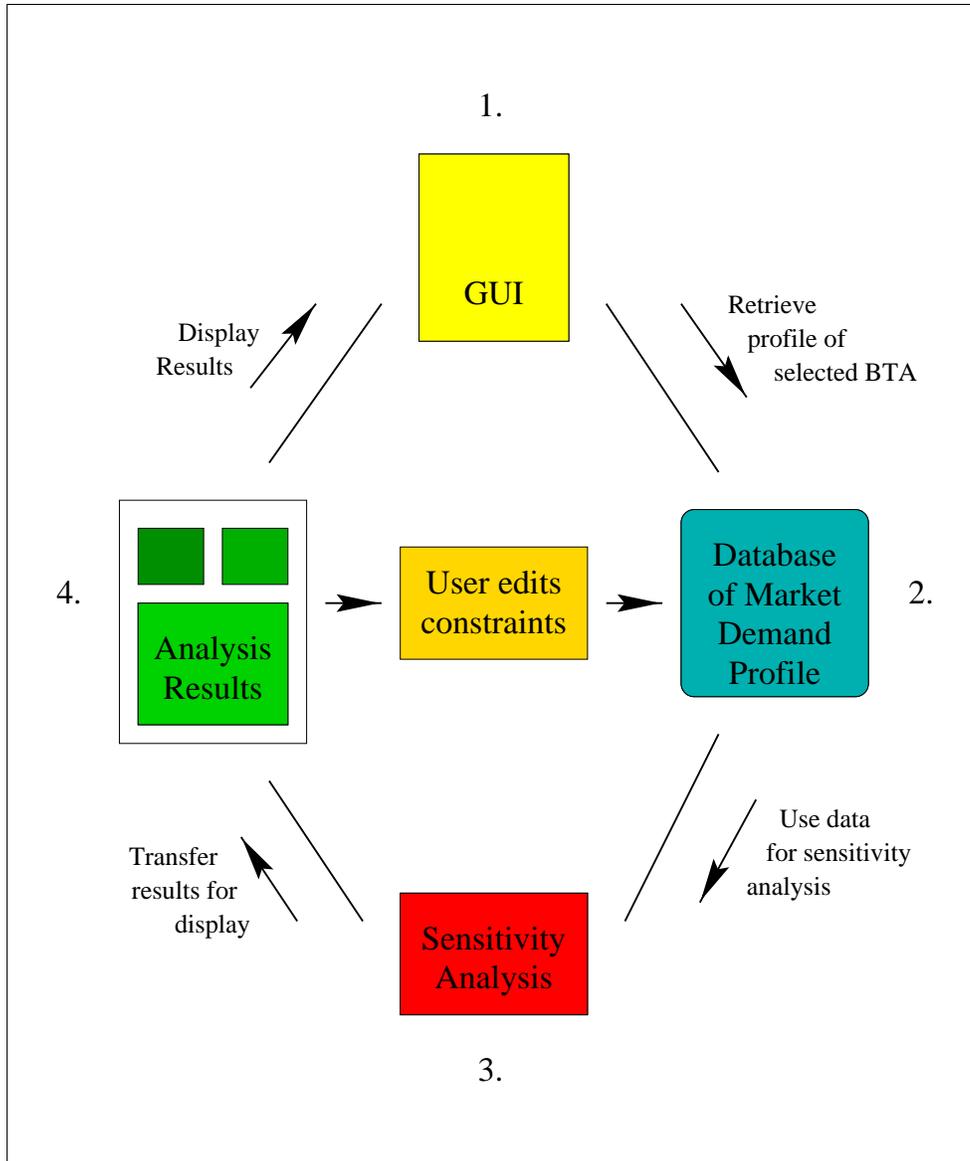


Figure 2.1: Block diagram of the Optimization Tool

- What is the pricing structure that needs to be practiced to get optimum returns on investment for each technology?
- What is the variation of returns with the variation in the time required for network deployment?

These results will be in the form of graphs, showing variation in the form of plots like returns versus tariff, returns versus penetration into the market and returns versus the bandwidth of applications needed.

## 2.3 Structure of the tool

Brief discussion on the design of the tool is provided in what follows.

### 2.3.1 Graphical User Interface

The Graphical User Interface (GUI) will display the markets and the results of optimizations. ArcView and ArcInfo are used for this purpose. ArcView is a Geographical Information System (GIS) and ArcInfo holds the data associated with ArcView, which enables the user to add themes, tables, charts and layouts to the display. A description of these features follows.

ArcView is a very flexible software consisting of multiple windows, used to view a map of a region. The window displaying the map is called a **View** (Figure 2.2). ArcInfo comes with ArcView and contains data used to display in Views. A **Theme** is data about the geographical region being displayed, which can be represented in the View. For example, ArcView can display the map of North America in a View. We can add a theme to it, called U.S. States (Figure 2.2) or U.S. counties, which will show those regions in the country.

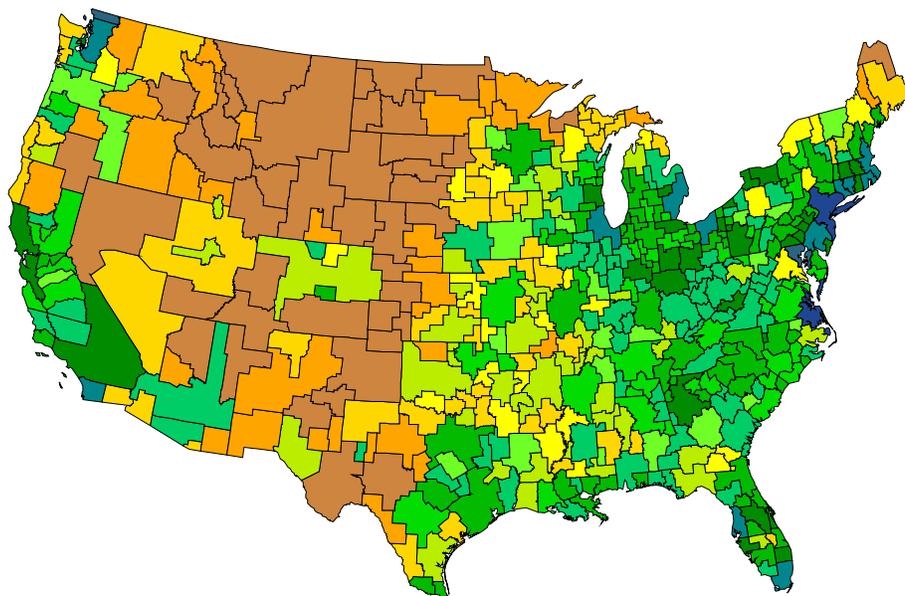


Figure 2.2: A **Theme** of U.S. states in a **View** of North America

Similarly, it has themes which can show rivers, lakes, roads etc. in the entire nation. Associated with each theme is a table. This contains the data associated with the theme. A table consists of a series of records. For example, the table associated with the theme of the US States, has a series of 50 records, one for each state (Figure 2.3).

| Area | Pop1996 | For_join | Path2      |
|------|---------|----------|------------|
| 5925 | 4410587 | 461      | /test_pro/ |
| 9204 | 1181975 | 374      | /test_pro/ |
| 2907 | 209777  | 75       | /test_pro/ |
| 1370 | 159999  | 266      | /test_pro/ |
| 1916 | 165311  | 479      | /test_pro/ |
| 1883 | 130605  | 183      | /test_pro/ |
| 1422 | 108236  | 430      | /test_pro/ |
| 2540 | 161387  | 100      | /test_pro/ |
| 1017 | 108763  | 306      | /test_pro/ |
| 3801 | 195998  | 82       | /test_pro/ |
| 8028 | 632760  | 73       | /test_pro/ |

| Name              | State_name           | Area      | Pop1996 | Median Inco | Household | Z_links bt |
|-------------------|----------------------|-----------|---------|-------------|-----------|------------|
| Washington        | District of Columbia | 68.3417   | 550076  | 31529       | 249634    | 461        |
| Prince William    | Virginia             | 348.9972  | 247108  | 54827       | 69709     | 461        |
| Arlington         | Virginia             | 25.9704   | 176756  | 47700       | 78520     | 461        |
| Fairfax City      | Virginia             | 6.1636    | 20964   | 52628       | 7362      | 461        |
| Rappahannock      | Virginia             | 266.8342  | 7378    | 36271       | 2496      | 461        |
| Alexandria        | Virginia             | 15.3762   | 113367  | 45600       | 53280     | 461        |
| Manassas City     | Virginia             | 10.0345   | 33107   | 51200       | 9481      | 461        |
| Calvert           | Maryland             | 220.3898  | 65473   | 50754       | 16986     | 461        |
| Charles           | Maryland             | 469.1563  | 111491  | 49148       | 32950     | 461        |
| Culpeper          | Virginia             | 382.2809  | 30380   | 35556       | 9757      | 461        |
| Stafford          | Virginia             | 279.4615  | 80131   | 50794       | 19415     | 461        |
| St. Marys         | Maryland             | 363.9711  | 83327   | 40868       | 25500     | 461        |
| Lake of the Woods | Minnesota            | 1768.2797 | 4378    | 28473       | 1576      | 166        |
| Ferry             | Washington           | 2257.1818 | 7503    | 27203       | 2247      | 425        |
| Stevens           | Washington           | 2540.0978 | 39798   | 28371       | 11241     | 425        |
| Okanogan          | Washington           | 5314.2207 | 38135   | 23971       | 12654     | 468        |
| Boundary          | Idaho                | 1277.7427 | 9878    | 25146       | 2857      | 425        |

Figure 2.3: Table associated with U.S. States, with the records corresponding to Mid-Atlantic states highlighted

Each record has data like the Area, Population etc. stored in it. These data are stored in columns which are called **Fields**. The data available in these tables from ArcInfo is mostly demographic data, which gives statistics on average age, number of people of different races etc. The tables are stored in dBASE format. Additional data can be added to these tables, using two alternatives called **Join** and **Link**. They can be used when two tables have a common field. Records with same values in the selected field are joined or linked.

Join - for each value in any table, there is only one value similar to it in the other table.

Records with common values in the field selected are joined to form a single record.

Link - for each value in one table, there are more than one identical values in the other table. For example in tables, one giving data on U.S. States and the other on U.S. Counties, there are more than one counties with the same "State Abbreviation".

These tables are connected to the displayed View. Using the **Select** tool, one can select one or more regions from the View. The selected regions are highlighted in the View. The records in the Table associated to those regions are also highlighted simultaneously. For example, selecting the Mid-Atlantic states will highlight their records in the table(Figure

2.3). If the table is linked to another table, all the records in the linked table associated with the selected record get highlighted. The select tool works in the opposite direction as well. For example, if the user selects the record belonging to Massachusetts in the table, that region is highlighted in the View.

When one or more records are selected we can plot a **Chart** displaying values of a chosen field in the selected records. This gives an idea of the variation, and can be used to make comparisons. For example, if we select some Mid-Atlantic states and chart their median income, we will see the following display(Figure 2.4).

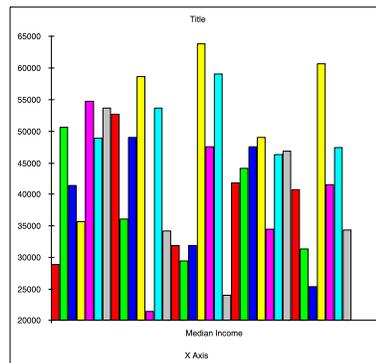


Figure 2.4: Chart showing Median Income of New York and Maryland residents

A user interested in knowing which BTAs have income higher than \$50,000, can get a good idea by this chart. Another useful function of ArcView is the **Layout**. Layout is used to display results of a project on a single sheet. It can contain Views, Tables and Charts (Figure 2.5). It can be used to display results as it conveys a lot of information at one time.

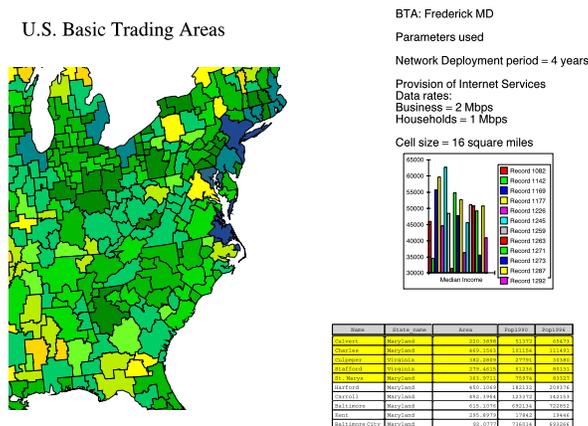


Figure 2.5: Layout showing a View, Chart and a Table

Layout has an updating feature. If any of the Charts, Views or Tables which is a part of the Layout is altered, then the change is immediately reflected in the Layout. An example is a Layout showing a View, a Chart and a Table. The View shows the U.S. BTAs. The selected BTA is Pittsburgh. The Median Income of residents of Pittsburgh has been displayed in the Chart. Now if another region is selected, that BTA will get highlighted in the View, and the Layout will show this change at once in the View it is displaying. The Table will highlight records corresponding to that region, and the table in the Layout will make this change too. As a Field is selected and a Chart plotted, the Chart in the Layout will get updated at once.

These features make ArcView a very flexible package to work with and customize. It has all features required for the tool. This package will be used as the GUI of the tool. When the analyst selects markets he is interested in evaluating, the data associated with those markets is exported for using in optimizations, to calculate performance measures. The optimizations give market analysis and help the analyst in planning an optimum network.

### 2.3.2 Optimization

Optimization algorithms are run by CPLEX. CPLEX is a mathematical programming software. It will be used for its Linear Programming capabilities. From the markets the analyst selects, data associated is exported to a file in text format. A program in C will read these values and write out the optimization problem in a file<sup>1</sup>. The parameters obtained are converted into coefficients of variables or are used as bounds on variable values or simply to determine other constants. For example, the values of Median Income obtained are used to approximate the penetration of a service in the market in the form of a percentage of the population. These values and population of markets give bounds on the values of the variables used. The variables formulate an objective, constraints and bounds.

**Objective:** This is a function of one or more variables. This is the first line of the algorithm and it is evaluated for every iteration. The algorithm may be written to either maximize or minimize the objective function. If it is a cost expression it will be minimized while if it is a returns expression, it will be maximized.

**Constraints:** These are constraints that restrain the variation of variable values. Any optimization solution must satisfy these constraints. For example, there will be a bandwidth constraint that will limit the values variables corresponding to the number of users per cell takes, as each additional user utilizes the bandwidth resource and spectrum available to each cell is limited.

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<sup>1</sup>Details of the optimization portion are covered in the next chapter

**Bounds:** These are lower and upper limits on the values of variables. Bounds are necessary to incorporate natural or artificial limits on the range of values which the variable can take. For example, the number of subscribers for home Internet services are limited to the number of households in that area.

For each of the three technologies: LMDS, Broadband LEO, and Fiber Optic networks, there are separate algorithms to be executed<sup>2</sup>. Solution of each optimization will be used to vary the values of relevant parameters and the optimization is repeated. Results will be written out in a file in a specific format. This will be presented by the GUI in the form of a graph. These graphs, along with the Views will be incorporated into a Layout for display to the analyst.

### 2.3.3 Results of optimization

The Layout will display the following results:

- Variation of returns with data rates, for each technology
- Variation of returns with penetration, for each technology
- Variation of returns with subscription charges, for each technology

The analyst can use the graphs and the values of parameters to alter their values and try to simulate better performance from his network. The tool is customized to ask the analyst if he wants to repeat the optimization for a new set of values. He is presented a window with choices from which he will choose the values he wants to try out for the new optimization. The simulation will be repeated till enough data has been obtained and a good estimate of the network design can be made.

We will now fit all these pieces together to form the tool.

### 2.3.4 Tailoring the pieces

The major advantage of using ArcView for the GUI is the ease of customizing it. ArcView has a user friendly script which can be written to execute any ArcView function. This script is called **Avenue**. Avenue can customize ArcView very easily to make it execute various actions.

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<sup>2</sup>Detailed description of algorithms used has been done in the next chapter.

A function called **Hotlink** is available to its themes. This will call on ArcView to do a specific task when it is used. This task is dictated by the customizer, in the form of an Avenue script. Hotlink is denoted by a unique icon. When a user clicks on a particular part of the theme, ArcView will execute the specified Avenue script. This is the option which will be used to perform the series of the actions required in our tool<sup>3</sup>.

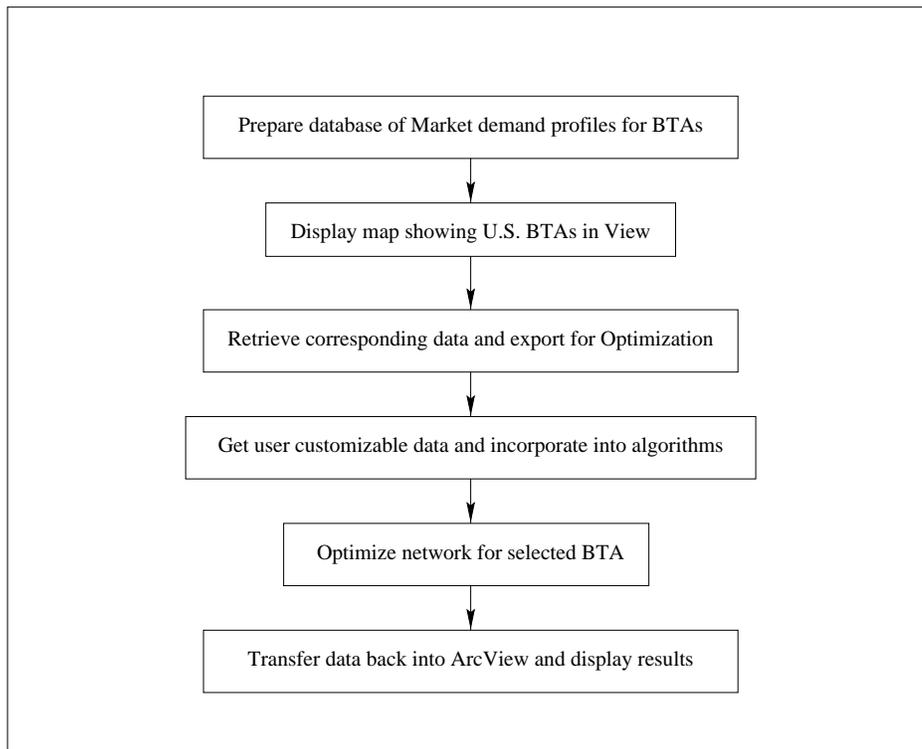


Figure 2.6: Functioning steps of the tool

The flow Chart (Figure 2.6) gives the outline which will be followed to build the tool. A description of the steps follows.

**Prepare database:** The Ka-band spectrum is auctioned by the FCC on the basis of BTAs. We need to have a database containing all the information related to the BTAs. ArcView has a theme on the basis of counties. The table associated with this theme was not very comprehensive. There was no theme on the basis of BTAs. However, there was another table called “Demographic data about US counties” which had detailed data about counties. This table was stored in ArcInfo, and had 28 Fields. Both these tables had a Field called “county geocodes” containing the serial number of every county in the country. There was a one to one relationship between these two tables via this field. This table

<sup>3</sup>The Avenue script which performs all these functions is given in Appendix A

was joined to the county data table. This gave a table with comprehensive statistics. This served as the database for county and BTA data. It is possible to unify shapes in ArcView using an option called “Union Features”. Union Features removes the boundaries between the adjacent areas and results in a continuous area. The respective records in the table get added up to give a single record corresponding to the new area. Using a View showing counties and the select tool, all the counties which constitute a BTA were selected. Choosing the “Union Features” menu option integrates all the counties into one area. Records of all the merged counties are replaced by a single record with values equal to the sum of the individual records. This record corresponds to the resultant BTA formed. This was done for all counties constituting the 486 BTAs. Thus a market demand database in the form of a table with all the detailed information about each BTA was obtained.

**Display map of North American BTAs:** The display should contain a View showing all the BTAs in North America, out of which the user will select the ones he is interested in evaluating. In the process of congregating the records of counties into those for BTAs as considered above, we get a View showing the counties merged to form BTAs. Thus a display of US BTAs is obtained.

**Retrieve data:** The database associated with the BTAs is in the form of a Table, in which each BTA has a record corresponding to it. This gets selected whenever a BTA is selected. ArcView has a function called “Export Table”. This will export data inside the table to a file in either “dBASE” or “delimited text” format. If a portion of the table has been selected, then only the selected portion is exported. We also designed and implemented the following algorithms,

1. For accuracy, we decided to use data on a county basis. For this implementation there needed to be a link between the tables of the counties and BTAs. However, there was no common field among these two tables. A new field called “BTA Index” was added. Each BTA was made up of multiple counties. Using the view which displayed the counties, the “BTA Index” field in each record was given the BTA number it belonged to. Records of each county had the number of the BTA it belonged to as the value in the “BTA index” field. The table associated with BTAs and that associated with counties had a common field with values the index number of the BTA. As for each entry in the Field (column) of the BTA table giving the BTA number, there were one or more than one entries in the county table with same values. Thus, this was a one to many relationship. The tables are linked, so that on selecting any BTA in the view, the records it is linked to in the county table are highlighted.

2. The data associated with the BTA chosen by the analyst need to be transferred to CPLEX. When the analyst chooses the BTA, records associated with it in both the tables get selected. "Export Table" discussed earlier, exports this selected record data to a file in the home directory.

This forms the first part of the Avenue script.

**User parameters:** In addition to the data which is attributed to the BTA, additional information is needed. This includes the types of service that the service provider wants to provide, the data rates which these services will have; this information will determine the demand segment he is targeting these services for. These values are obtained by a dialog box which will ask the analyst for all these values. The values the tool gets from the user are:

1. Nature of services. For example,
  - Video conferencing
  - Internet service for business users
  - Internet service for household users
  - Tele - medicine
  - Distance learning
2. Data rates of services
  - 50 Mbps
  - 2 Mbps
  - 1 Mbps
  - 64 Kbps
3. Time for network deployment desired
  - 10 years
  - 4 years
4. Cell size for a LMDS cell

On average, the area of a BTA is 3000 square miles. If the user does not give the value, a cell size of side length 2.5 miles is the default considered.

**Optimize for selected BTA:** The relevant data has now been exported to a text file in the home directory. This can be read and written as required using a C program. The program<sup>4</sup> substitutes the values of the BTA parameters into the algorithm, which is run by opening CPLEX and using CPLEX library functions to perform optimizations. The results it gets are written into a file in the form of a table. ArcView allows external commands to be executed via Avenue. To run this program, we will use the Avenue “SystemExecute” script.

**Display results:** We want to display the results of the optimization in the form of a chart. As discussed earlier, if the records which have been selected in that table are changed or other records are selected in their place, then the chart changes automatically. In the Avenue script used by the Hotlink, a script is written to plot a chart of the selected values. As the user selects his BTAs, the parameters are transferred to CPLEX and optimization is completed, and then the results are written over the same file whose values have been plotted in that chart. Next, using the Avenue “Table.Refresh” script, the table is updated, which brings the new values into the table. This immediately updates the chart in the Layout, and the new results are displayed.

The Layout displays the View of the BTAs and the charts displaying the results. The Layout also has the instantaneous update feature. Whenever the View in the View window is changed or the chart changes the values it is displaying, the respective Views and Charts in the Layout also get updated.

In addition to these features, the tool is left open for editing by the analyst. He can alter the package so that he is asked for the values of specific parameters for the optimization everytime, or so that he is never asked for the values of certain parameters. He can change the positioning of results on the layout, or add other options to the tool by introducing them in the form of button menus on the top bar.

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<sup>4</sup>Working of this program is described in detail in the next chapter and the code is in Appendix B

## Chapter 3

# Functioning of Tool

The data associated with the market selected by the analyst has been exported from the tool to a file in the home directory. This data now needs to be processed. This chapter will describe how it is used to configure the optimization problems and how the optimization is structured.

### 3.1 Optimization process

A block diagram of the optimization process is shown in Figure 3.1.

- When the analyst selects the market, two files are exported to the home directory. The analyst clicks on the BTA, and the first file exported contains details about this BTA. Counties making up the BTA have a detailed database. Data of these counties are written to the second file.
- These two files are read and selected values are used to determine parameters to be used in algorithms. They are used to calculate coefficients of variables, range of rates over which variables will vary and bounds on the values of variables.
- The values thus determined, are substituted into the optimization algorithm. The algorithm is to be optimized by using the CPLEX callable library functions. Separate algorithms for LMDS, LEO and HFC networks are prepared.
- First, the algorithm is optimized using the first values of the range over which the variation (in returns, penetration or data rates) is going to be measured. The solution is written into a file. The next value from the range is used and the algorithm is optimized again. This time the solution is written to another file. This process is repeated for the entire range.

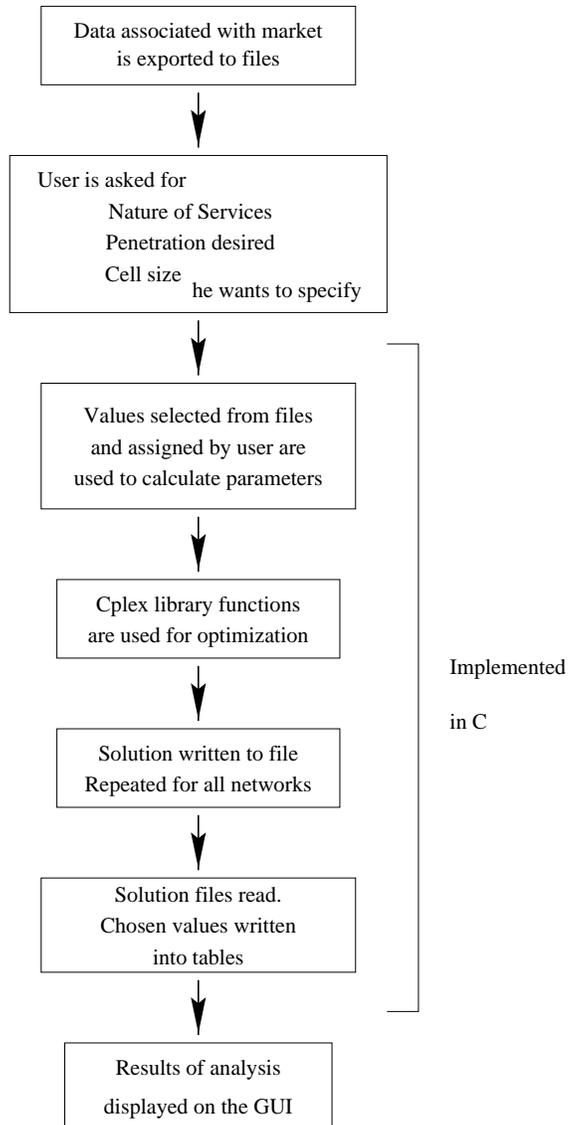


Figure 3.1: Block diagram of the Optimization process

- This process of varying values, optimizing and writing the solution is carried out for LMDS, LEO and HFC networks.
- The solution files are read. Selected parameters are used to plot a graphical display.
- These values are updated as new BTAs are analyzed. ArcView is instructed to update the Chart and the Layout (described in Chapter 2) so that the new results of the optimization can be observed by the analyst.

## 3.2 Optimization algorithms

From the file containing data about the BTA and the counties, we get the following information:

BTA    Points of presence  
       BTA Number

County    Area of Market  
          Total Number of businesses  
          Total Number of business employees  
          Total Number of households  
          Median income

The different variables we will use are as given in Table 3.1. Of these, we need to optimize some, and some are constraints or bounds.

| <u>Variable</u>   | <u>Value</u>  | <u>Processing Required</u>  |
|---|---|---|
| $R_i, r_i$  | Subscription rates for $i^{th}$ service                                     | Optimize rates to maximize penetration or returns on investment                           |
| $N_i$   | Number of subscribers for $i^{th}$ service                                  | Optimize number of subscribers to meet break-even constraints and bounds of penetration   |
| $\sum_i N_i$  | Total Number of subscribers   | Optimize subscribers per cell to meet bandwidth constraints and expenses over fixed costs |
| $\sum_i R_i \times N_i$                                       | Returns on Investment (Maximize)  | Maximize total monthly returns from charges to subscribers                                |
| $\frac{\sum_i N_i}{Population} \times \text{Number of Cells}$ | Penetration of services (Optimize)  | Optimize penetration such that returns are maximized                                      |
| Returns = $f(\mathcal{T})$                                    | Returns as a function of time period for Break-Even ( <u>Constraint 1</u> ) | Returns must meet depreciation as well as initial fixed costs                             |
| $\sum_i N_i \times BW_i$                                      | Bandwidth required for services in the market ( <u>Constraint 2</u> )       | Bandwidth available must be enough to provide the optimum mixture of services per cell    |

Table 3.1: Important parameters associated with the optimization

These variables will be used repeatedly to determine the following attributes for each technology in turn:

- Variation of returns from each technology, as a function of data rates provided to subscribers.
- Variation of returns from each technology, as a function of penetration.
- Variation of returns from each technology, as a function of subscription charges.

### 3.3 Optimizing for LMDS

The structure of the optimization problem designed for LMDS is:

#### Maximize Returns per month

$$\sum_{all\ services} \left( \text{Number of subscribers per service} \right) \times \left( \text{Subscription charges for each} \right)$$

#### Subject To Break-Even constraints

$$\sum_{all\ services} Returns(\mathcal{T}) - \sum_{all\ cells} \text{Transmitter Costs} - \sum_{all\ cells} \text{Depreciation}(\mathcal{T}) - \text{Fiber costs} \geq 0$$

#### Subject To Bandwidth constraints

$$\text{Bandwidth available} - \sum_{all\ services} \left( \text{Number of subscribers} \times \text{Bandwidth for each service} \right) \geq 0$$

#### Bounds

Subscribers of high end data rates

$$N \leq \sum \text{Employees in business establishments} \times \Phi \text{ (Median Income)}$$

Subscribers of medium end data rates

$$n \leq \sum \text{Number of households} \times \Psi \text{ (Median Income)}$$

Subscribers of broadcast services

$$V \leq \sum \text{Number of households} \times \Omega \text{ (Median Income)}$$

the variables used in the algorithms are:

- N, R: Number of high data rate subscribers, the rate they are charged
- n, r: Number of low data rate subscribers, the rate they are charged
- V, c: Number of broadcast video subscribers, the rate they are charged
- P: Optimum number of cells or fiber nodes required for LMDS and fiber optic networks respectively.

end

In Constraint 1, returns are taken as a function of time. This is to simulate the change in subscription in the market as a function of time. The number of subscribers for any service are assumed to increase in fixed amounts every year (Linear approximation), and reach the current subscription at the end of the break-even period. Thus for a break-even period of 4 years, the number of subscribers at the end of the first year is taken to be a quarter of the total number of subscribers to date. The number of subscribers at the end of the second year becomes two-quarters the total number of subscribers and so on [5].

The same procedure is followed for calculating depreciation. A depreciation amount per month per transmitter is used to calculate depreciation. The number of transmitters also increases linearly as a function of time, in tune with the increase in the number of subscribers.

### 3.3.1 Calculating values

We will develop an algorithm for optimizing a LMDS system for being set up in Pittsburgh.

Data exported by the Tool on selecting this BTA:

BTA Points of presence = 2,507,839

BTA Number = 350

County Area of Market = 5,921 square miles

Total Number of businesses = 179,048

Total Number of business employees = 2,946,155

Total Number of households = 990,181

Median Income: \$27,900

## Maximize Returns

$$\sum_{\text{all services}} \left( \text{Number of subscribers per service} \right) \times \left( \text{Subscription charges for each} \right)$$

$$N \times R + n \times r + V \times c$$

## Subject To Break-Even constraint

- \* Break-Even period = 4 years.
- \* Engineering costs per cell = \$650,000
- \* Rental costs per cell site = \$1,000
- \* Customer service costs = \$9.5 per year per customer
- \* Depreciation costs per transmitter, per month = \$14,000
- \* Expenses involved in installing fiber were obtained from the University of Maryland Telecommunications Department. A rough estimate is as follows:

- For a path for the fiber to follow,
  - Trenching costs = \$5 per foot
  - Directional boring (Typically used in cities) = \$10 per foot
- The price for pulling and terminating single mode fiber
  - 12 strands = \$2 per foot
  - 48 strands = \$5.50 per foot

This makes the cost of laying fiber \$ 17 per foot. 20% of all cells are assumed to be interconnected by fibers.

- \* An optimum side length of the cell, of 2.5 miles is chosen.

Therefore,

$$\sum_{\text{all services}} \text{Returns}(\mathcal{T}) - \sum_{\text{all cells}} \text{Transmitter Costs}$$

$$- \sum_{\text{all subscribers}} \text{Customer service costs} - \sum_{\text{all cells}} \text{Depreciation}(\mathcal{T}) - \text{Fiber costs} \geq 0$$

becomes:

$$\sum_1^4 \frac{i}{4} \left( R \times N + r \times n + V \times c \right) \times 12 - \left( 650000 \times P + \sum_1^4 \frac{i}{4} \times 1000 \times 12 \times P \right)$$

$$- 38 \times N - 38 \times n - \sum_1^4 \frac{i}{4} \times 14000 \times 12 - 17000 \times 2.5 \times 0.2 \times \geq 0$$

## Subject To Bandwidth constraint

- \* High data rate service (N; R): 2 Mbps. Actual data exchange at any time: 40% of demand.
- \* Medium data rate service (n; r): 1 Mbps. Actual data exchange at any time: 10% of demand.
- \* 50 Video channels at 6 Mbps for each (V; c).
- \* 5 % of video subscribers occupy separate pay per view channel of 6 Mbps each.
- \* With 1x frequency reuse, data rate capability of the LMDS band is 1.77 Gbps.

Therefore,

$$\text{Bandwidth available} - \sum_{\text{all services}} \text{Number of subscribers} \times \text{Bandwidth for each service} \geq 0$$

becomes:

$$1770 - 2 \times 0.4 \times N - 1 \times 0.1 \times n - 300 - 0.3 \times V \geq 0$$

## Bounds

Median Income of the area being considered is \$27,900. This lies in the \$15,000 and \$30,000 range. This decides the penetration of each service:

- High speed data(N): 9 % of total number of businesses.
- Medium speed data(n): 13 % of total number of households.
- Broadcast Video(V): 20 % of total number of households.
- Number of cells(P):  $\frac{BTAArea}{6.25}$

$$N \leq 265,154$$

$$n \leq 128,723$$

$$V \leq 198,036$$

$$P = 947$$

**end**

To calculate the variation in returns as a function of penetration, we assume subscription rates of:

- High speed data(N): \$160
- Medium speed data(n): \$80
- Broadcast Video(V): \$40

**Maximize**

$$160N + 80n + 40V$$

**Subject To**

$$4,800N + 2,400n + 1,200V - 650,000P - 30,000P - 38N - 38n - 420,000P - 8,500P \geq 0$$

$$1770 - 0.8N - 0.1n - 300 - 0.3V \geq 0$$

**Bounds**

$$N \leq 265,154$$

$$n \leq 128,723$$

$$V \leq 198,036$$

$$P = 947$$

This is the algorithm which was optimized. Following two sections will cover development of algorithms for LEO and fiber optic networks. Results obtained in the form of case studies of three BTAs are displayed in Chapter 4.

In the Objective of the maximization algorithm, we have two variables in each term. This will require quadratic optimization. To solve this problem using Linear Programming, we will have to assume the value of one of the variable pairs, say R, and calculate the value of the other, N. This is what has been done in the program shown. Then by varying the required value (for example the parameters selected as data rates), the variation in the objective can be measured. The value of the Objective above gives the Returns per month.

- To get the variation in returns as a function of data rates provided to subscribers, fix the value of R and vary the values of the data rates in the bandwidth constraint.
- To get the variation in rates required as a function of penetration, vary the upper limit set on the number of subscribers for each type of service.
- To get the variation in returns as a function of rates charged to subscribers, fix the value of N and vary R.

### 3.4 Optimizing for Broadband LEO Networks

Broadband LEO Networks have some very different aspects compared to LMDS.

- Number of satellites in the constellation always remains fixed. It is not possible to increase the bandwidth capacity of the network by launching new satellites, as in terrestrial systems, where capacity can be enhanced by installing more towers.
- Market covered by each transmitter is very large and available bandwidth needs to be shared by the entire market. This makes lower rates available to all.
- As the satellite is shared by a number of cells, the fixed costs of each satellite are also split up between the subscribers of those cells. This makes necessary lower fixed costs per cell to break even with.
- The network provides global coverage, which is a premium service. Its rates can therefore be comparatively higher.

We want to compare and contrast the performance of LMDS networks with other homogeneous networks. Since LMDS networks are operated on the basis of BTAs, we will study LEO networks on that scale too. The following steps will enable us to analyze this global service system at the scale of a BTA.

- Each LEO satellite has a large footprint. We divide fixed costs of each satellite, in the ratio of the area of the BTA with that of the supercell. This will give the fixed cost of the satellite per BTA.

- The data rate available to each cell is known. Multiplying this by the ratio of area of the BTA and that of the cells, we get capacity available to provide services to the BTA.

The variables associated with these networks are the same as in LMDS. Also, depreciation of the satellites is calculated in the same way as a linear function of time.

### 3.4.1 Calculating values

Broadband LEO requires a large number of satellites. Using the Teledesic plan as reference, the surface of the earth is divided into 20,000 supercells. Each supercell consists of 9 cells of size 33 km by 33 km. Each satellite covers 64 supercells = 576 cells in its footprint. It uses a 1 GHz band for downstream and a different 1 GHz band for upstream transmission. It has capacity to provide 56.8 Gbps per cell. Mass production of satellites has currently brought their price down to \$12 million. Constellations needing them in hundreds will be able to manufacture them at \$6 million each.

We now have all the values to substitute into the algorithm. Considering the same BTA (Pittsburgh; as in the earlier example), we can write the optimization algorithm as a function of its attributes.

## Maximize Returns

$$\sum_{all\ services} \left( \text{Number of subscribers per service} \right) \times \left( \text{Subscription charges for each} \right)$$

$$N \times R + n \times r$$

## Subject To Break-Even constraint

\* Break-Even period = 4 years

\*  $\frac{\text{System Cost}}{\text{Total Number of Cells}}$  gives the fixed cost per cell, and

$\left( \frac{\text{BTAArea}}{33 \times 33} \times \text{fixed cost per cell} \right)$  gives the fixed cost for the BTA under consideration to break-even.

Fixed cost for selected BTA =

$$\$ \frac{10,000,000,000}{180,000} \times \frac{5921}{1097} = \$333,000$$

\* Depreciation is calculated as a linear function of time. Using a satellite life expectancy of 8 years and a linear variation, depreciation for one satellite per year comes out to \$187,500. Thus for the first year the depreciation cost is \$187,500. For the second year, it is  $2 \times \$187,500$ . For the third year, it is  $3 \times \$187,500$ , and so on. Using a break - even period of 4 years as in LMDS,

$$\text{Depreciation costs} = \sum_{t=1}^4 187,500 \times t = 1875,000$$

Fraction that this BTA needs to break - even with =

$$\frac{\frac{5,921}{1,097}}{64} \times 1875,000 = 175,000$$

Therefore,

$$\sum_{all\ services}^{all\ cells} \text{Returns}(\mathcal{T}) - \sum_{all\ cells} \text{Satellite Fixed Costs}$$

$$- \sum_{all\ subscribers} \text{Customer service costs} - \sum_{all\ cells} \text{Depreciation}(\mathcal{T}) \geq 0$$

becomes:

$$\sum_1^4 \frac{i}{4} \times 12 \times \left( R \times N + r \times n \right) - 333,000 - 38 \times N - 38 \times n - 175,000 \geq 0$$

## Subject To Bandwidth constraint

- \* Cell area =  $33.125 \times 33.125 = 1,097$  square miles. This cell gets a data rate of 56.8 Mbps.  $56.8 \times \frac{BTA\ Area}{1,097}$  will give the data capacity that the satellite can provide to the BTA under consideration.

Bandwidth available =

$$56.8 \times \frac{5,921}{1,097} = 342Mbps.$$

- \* High data rate: 2 Mbps. Actual data exchange at any time: 40% of demand.
- \* Medium data rate: 1 Mbps. Actual data exchange at any time: 10% of demand.

Therefore,

$$\text{Bandwidth available} - \sum_{\text{all services}} \text{Number of subscribers} \times \text{Bandwidth for each service} \geq 0$$

becomes:

$$342 - 2 \times 0.4 \times N - 1 \times 0.1 \times n \geq 0$$

## Bounds

Median Income = \$27,900. Same penetration levels as in the earlier case are used.

- High speed data(N): 9 % of total number of businesses.
- Medium speed data(n): 13 % of total number of households.

$$N \leq 265,154$$

$$n \leq 128,723$$

As in the example of the linear program given for LMDS, to calculate the variation in returns as a function of penetration, we assume subscription rates of:

- High speed data(N): \$160
- Medium speed data(n): \$80

**Maximize**

$$160N + 80n$$

**Subject To**

$$4,800N + 2,400n - 333,000 - 38N - 38n - 175,000 \geq 0$$

$$342 - 0.8N - 0.1n \geq 0$$

**Bounds**

$$N \leq 265,154$$

$$n \leq 128,723$$

It can be noted that the second constraint in this case limits the bandwidth available to this market to only 342 Mbps. This is the bandwidth bottleneck which is responsible for lower returns for these networks as compared to LMDS and fiber optic networks.

## 3.5 Optimization for Fiber Optic Networks

Some features about Fiber Optic networks are

- Networks have very high fixed costs. These networks are ideal for markets which need very high data rates. This is because incremental costs for laying fiber are lower compared to the increase in data rates obtained. Thus very high data rates can be provided with fiber optic networks.
- Expenses involved in setting up a fiber optic network are made up of the head end costs, Fiber node, Fiber feeder and the Coax distribution.
- Returns in HFC networks are highly dependent on the penetration. They can provide high data rates even for very high percentages of penetration. In fact it is at high levels of penetration that fiber optic networks are most profitable.

### 3.5.1 Calculating values

- Expense involved in laying coaxial cable till the users is \$250<sup>1</sup> per household or business establishment in the BTA i.e. this number is independent of number of subscribers the network has.

Thus the optimization algorithm becomes

---

<sup>1</sup>From Application Note 1296 by Hewlett Packard on LMDS

## Maximize Returns

$$\sum_{\text{all services}} \left( \text{Number of subscribers per service} \right) \times \left( \text{Subscription charges for each} \right)$$

$$N \times R + n \times r$$

## Subject To Break-Even constraint

To analyze Break-Even of these networks, we need to consider the fixed costs associated with their installation. An estimate of the relation of these costs to the number of nodes needed can be computed using linear approximation of numbers from the Hewlett Packard Application Notes 1296.

- \* Head End costs are independent of the number of nodes required, and are a function of the population of the area.

$$\text{Head end costs} = \$12 \times ( \sum \text{Households} + \sum \text{Businesses} )$$

Fiber Node costs and Fiber Feeder costs are independent of the number of subscribers. They depend on the total number of residences and businesses as the network needs to be set up everywhere.

- \* Fiber Node costs =

$$0.1 \times (\text{Number of Nodes}) \times ( \sum \text{Households} + \sum \text{Businesses} ) - 317,440$$

- \* Fiber Feeder costs =

$$0.35 \times (\text{Number of Nodes}) \times ( \sum \text{Households} + \sum \text{Businesses} ) + 11,048,960$$

Therefore,

$$\sum_{\text{all services}}^{\text{all cells}} \text{Returns}(\mathcal{T}) - \sum_{\text{all cells}} \text{Head End Costs} - \sum_{\text{all cells}} \text{Fiber Node Costs}$$

$$- \sum_{\text{all cells}} \text{Fiber Feeder Costs} - \sum_{\text{all subscribers}} \text{Customer service costs} \geq 0$$

becomes:

$$\sum_1^4 \frac{i}{4} \times 12 \times \left( R \times N + r \times n \right) - 12 \times \left( 990,181 + 179,048 \right)$$

$$- 0.1 \times \left( 990,181 + 179,048 \right) + 317,440 - 0.35 \times \left( 990,181 + 179,048 \right)$$

$$- 11,048,960 - 38 \times N - 38 \times n \geq 0$$

## Subject To Bandwidth constraint

- \* The cost figures available above are for a fiber cable assumed to consist of 4 strands of fiber. At a data rate of 2.5 Gbps available per strand, the total demand that can be met per node is 10 Gbps.
- \* High data rate: 2 Mbps. Actual data exchange at any time: 40% of demand.
- \* Medium data rate: 1 Mbps. Actual data exchange at any time: 10% of demand.

Therefore,

$$\text{Bandwidth available} - \sum_{\text{all services}} \text{Number of subscribers} \times \text{Bandwidth for each service} \geq 0$$

$$10,000 - 0.8 \times N + 0.1 \times n \geq 0$$

## Bounds

Same penetration levels as in the earlier case are used.

- High speed data(N): 9 % of total number of businesses.
- Medium speed data(n): 13 % of total number of households.

$$N \leq 265,154$$

$$n \leq 128,723$$

**end**

As in the example for LMDS and LEO, we calculate the variation in returns as a function of penetration. Subscription rates assumed are:

- High speed data(N): \$160
- Medium speed data(n): \$80

**Maximize**

$$160N + 80n$$

**Subject To**

$$4,800N + 2,400n - 14,030,748 - 116,923P + 317,440 - 409,230P - 11,048,960 - 38N - 38n \geq 0$$

$$10,000P - 0.8N - 0.1n \geq 0$$

**Bounds**

$$N \leq 265,154$$

$$n \leq 128,723$$

### 3.5.2 Next

These are the three algorithms which will be optimized to evaluate cost versus performance attributes of each technology, for the selected market. Values given by the user will be kept fixed. Other values will be varied and returns plotted as a function of these values. There are three parameters which most strongly affect the comparative performance of these technologies. These are:

- Data rate of services provided. As the data rate increases, beyond a certain point, high bandwidth technologies like fiber optics will be able to better meet demands due to their potential of satisfying higher penetration levels. They will be a better alternative.
- Penetration of services. As penetration increases, high capacity systems like fiber optic networks give better service quality and returns on investment. Such levels of penetration are difficult, and up to the lower and more practical levels, systems with lower fixed costs are preferred.
- Rates charged for services. They affect the penetration of services being provided in the market, investments needed, and scale of returns. Low fixed cost systems are more profitable and have faster break-even periods.

Examples of these variations are given in the next chapter. Optimizations for the above three cases are performed over three BTAs. Their results give us an idea of the sensitivity cost versus performance trade offs have with respect to the features of the market being considered.

## Chapter 4

# Case Studies

In this chapter we present examples of the application of the algorithms developed in chapter 3. These were not implemented using the planning tool. They were solved independently, by keeping ranges narrower than would be possible when using the network planning tool.

Three examples have been considered. They demonstrate how

- Data rates of services provided affects feasibility. Rates up to certain levels can profitably be provided using LMDS. Beyond those levels, using fiber networks becomes more profitable.
- The size or area of BTA affects feasibility. The second example considered, of Nevada, has a very large area. Density of households and business establishments per square mile makes it formidably expensive to set up LMDS or fiber optic networks. Here LEO networks are most efficient in providing services.

## 4.1 Case study for Pittsburgh

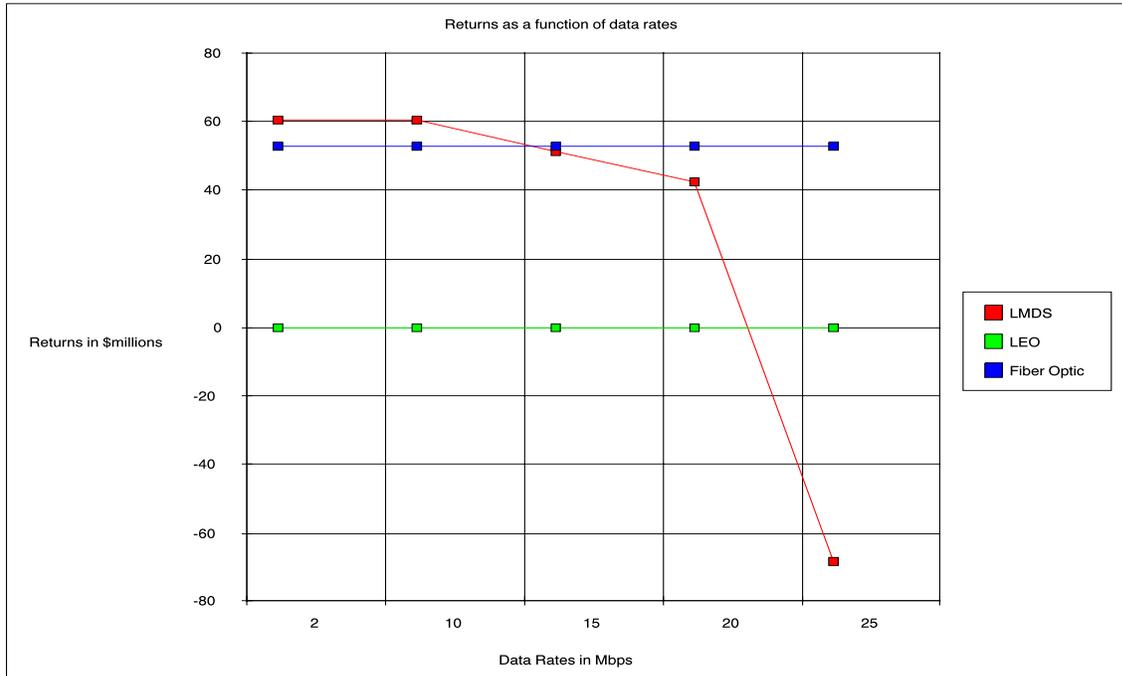


Figure 4.1: Returns for Pittsburgh as a function of data rates

| Data rates in Mbps | LMDS  | LEO   | Optic Fiber |
|--------------------|-------|-------|-------------|
| 2                  | 60.65 | 0.054 | 52.7        |
| 10                 | 60.65 | 0.054 | 52.7        |
| 15                 | 51.19 | 0.036 | 52.7        |
| 20                 | 42.3  | 0.027 | 52.7        |
| 25                 | -68   | 0.018 | 52.7        |

Table 4.1: Returns for Pittsburgh as a function of data rates

Pittsburgh is a good example of an average American market. This was the BTA for which the algorithms were designed in Chapter 3. We observe that:

- Up to low data rates of the order 13 Mbps, LMDS is ideal for providing services. Beyond these, it cannot sustain provision of very high data rates, and will go into losses.
- Returns from LEO networks are very low due to its low bandwidth capacity.
- Due to high capacity, fiber optic networks can sustain very high data rates without affecting subscriber level or returns.

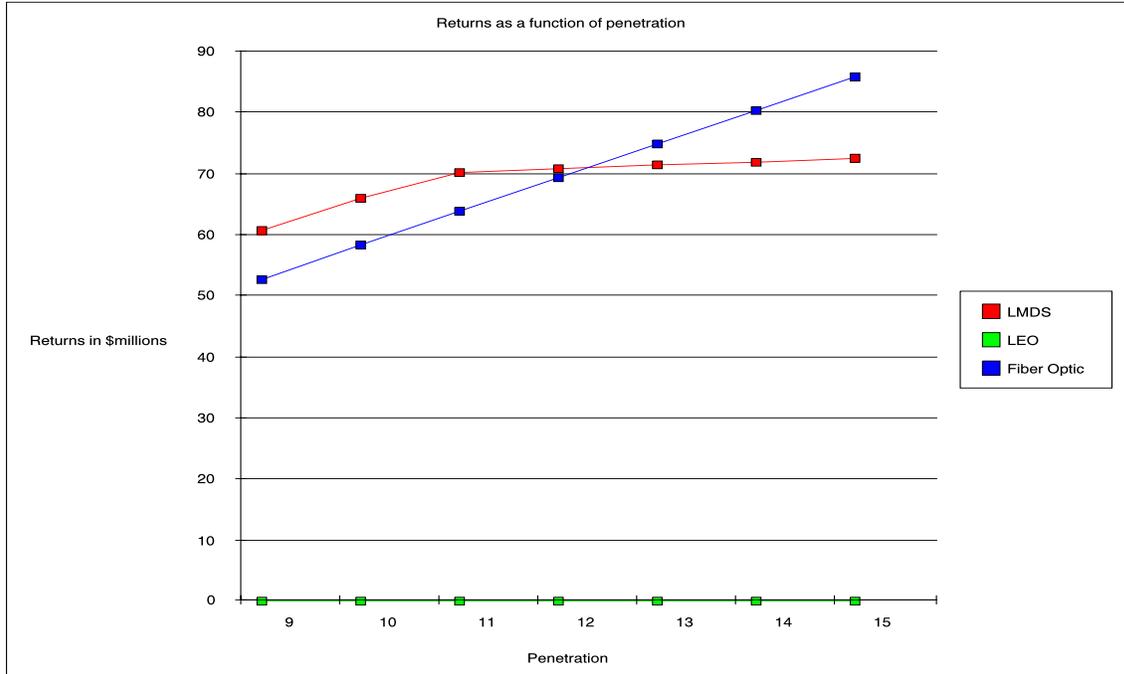


Figure 4.2: Returns for Pittsburgh as a function of penetration

| Penetration (%) | LMDS  | LEO   | Optic Fiber |
|-----------------|-------|-------|-------------|
| 9               | 60.65 | 0.054 | 52.7        |
| 10              | 66    | 0.054 | 58.22       |
| 11              | 70.15 | 0.054 | 63.73       |
| 12              | 70.74 | 0.054 | 69.24       |
| 13              | 71.33 | 0.054 | 74.74       |
| 14              | 71.93 | 0.054 | 80.24       |
| 15              | 72.52 | 0.054 | 85.74       |

Table 4.2: Returns for Pittsburgh as a function of penetration

For Pittsburgh, an increase in penetration of services is simulated.

- LMDS is more profitable for low orders of penetration. With increase in penetration, capacity becomes a bottleneck and fiber optic networks become more profitable.
- Returns of LEO networks are restricted by their data capacity per cell and inability to enhance network for higher data rates. They cannot achieve the penetration levels possible with terrestrial networks.

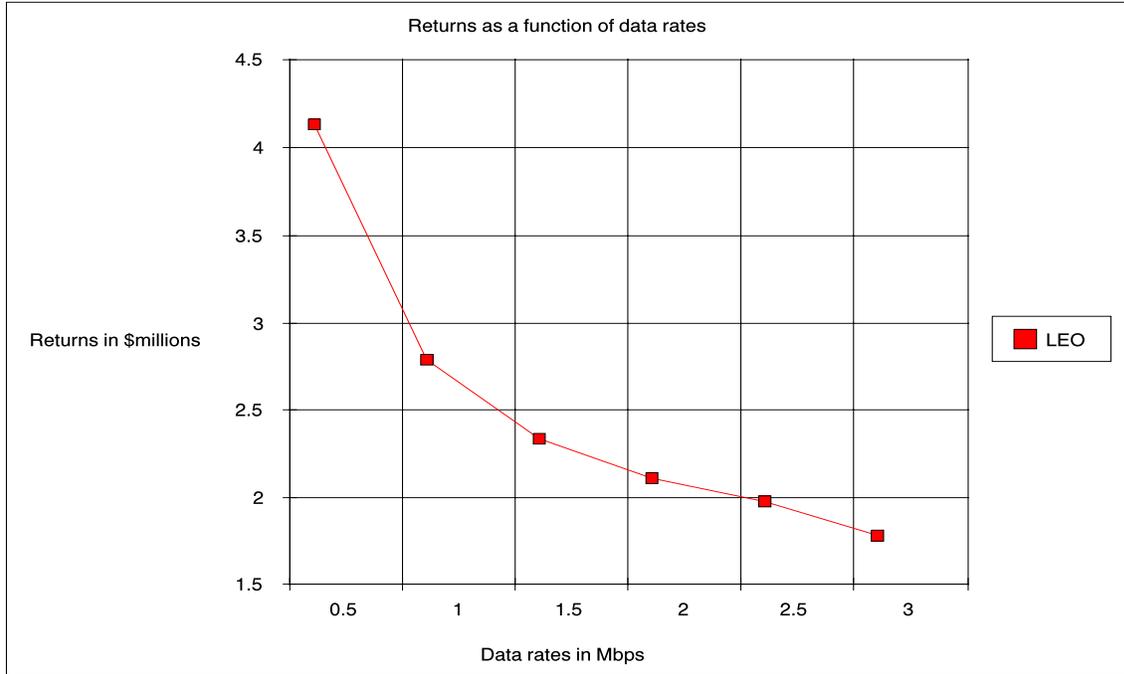


Figure 4.3: Returns for Nevada as a function of data rates

| Data rates in Mbps | LMDS         | LEO  | Optic Fiber  |
|--------------------|--------------|------|--------------|
| 0.5                | Not Feasible | 4.13 | Not Feasible |
| 1                  |              | 2.79 |              |
| 1.5                |              | 2.34 |              |
| 2                  |              | 2.11 |              |
| 2.5                |              | 1.98 |              |
| 3                  |              | 1.79 |              |

Table 4.3: Returns for Nevada as a function of data rates

## 4.2 Case study for Nevada

Nevada is a good example of central American markets. Characteristics are very large size and low population densities. In such markets:

- The major costs involved are installation of optic fibers for fiber networks, or the infrastructure of LMDS networks.
- LEO networks are the only feasible networks for data rates and take rates practically possible, and are sensitive to the data rate of services being provided.

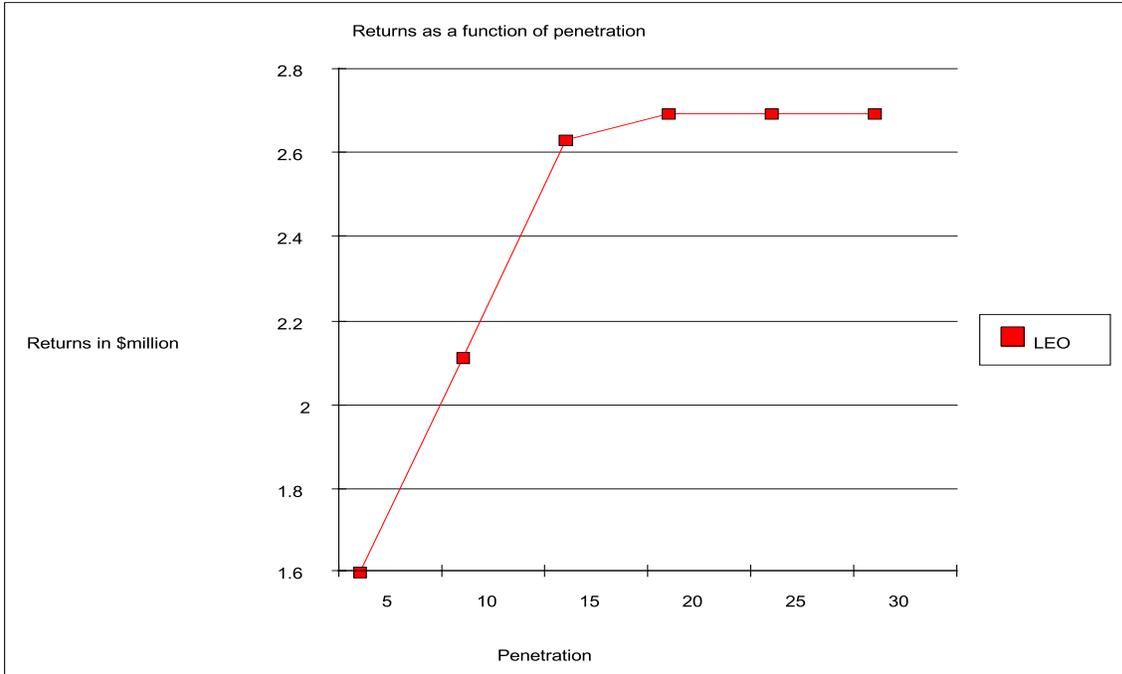


Figure 4.4: Returns for Nevada as a function of penetration

| Penetration (%) | LMDS         | LEO  | Optic Fiber  |
|-----------------|--------------|------|--------------|
| 5               | Not Feasible | 1.6  | Not Feasible |
| 10              |              | 2.11 |              |
| 15              |              | 2.63 |              |
| 20              |              | 2.69 |              |
| 25              |              | 2.69 |              |
| 30              |              | 2.69 |              |

Table 4.4: Returns for Nevada as a function of penetration

Since LEO networks are the only feasible networks, as long as fraction of subscribers is lesser than 12.5%, there is demand which can be met with the available resources. Beyond this, capacity becomes a bottleneck.

We must adjust pricing to keep penetration levels at this number. This gives optimum returns on investment and satisfies demand it produces.

This is congruent with markets for which LEO networks like Teledesic are being planned, for which they have been allotted this frequency band; for undeveloped markets with large areas.

### 4.3 Case study for Houston



Figure 4.5: Returns for Houston as a function of data rates

| Data rates in Mbps | LMDS | LEO          | Optic Fiber |
|--------------------|------|--------------|-------------|
| 14                 | 157  | Not Feasible | 148         |
| 15                 | 143  |              | 148         |
| 16                 | 136  |              | 148         |
| 17                 | 129  |              | 148         |
| 18                 | -163 |              | 148         |

Table 4.5: Returns for Houston as a function of data rates

BTA: Houston, Texas

- For given households and businesses, LMDS is more profitable for data rates up to 14 Mbps.
- For higher data rates, fiber optic networks make better investments.

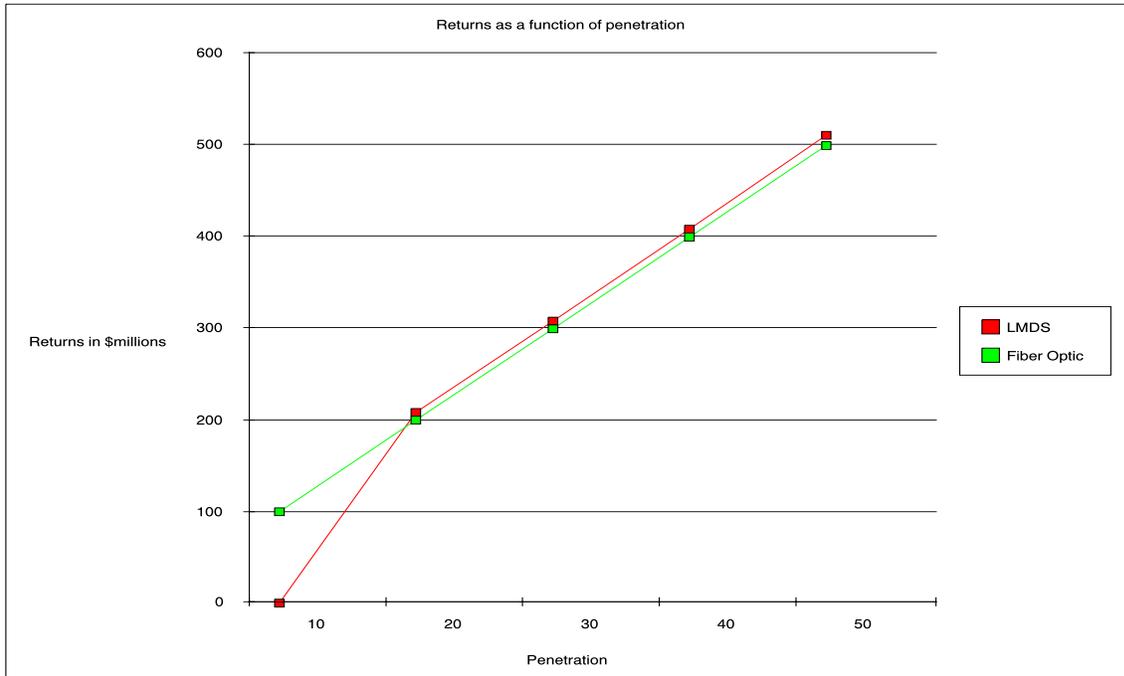


Figure 4.6: Returns for Houston as a function of penetration

| Penetration (%) | LMDS | LEO          | Optic Fiber |
|-----------------|------|--------------|-------------|
| 10              | 0    | Not Feasible | 99.8        |
| 20              | 208  |              | 199         |
| 30              | 308  |              | 299         |
| 40              | 408  |              | 399         |
| 50              | 510  |              | 499         |

Table 4.6: Returns for Houston as a function of penetration

LMDS can meet the demands of the market in step with fiber networks. Its extra revenues compared to fiber optic networks are due to the additional broadcast video services it provides.

## Chapter 5

# Horizons

A lot of work can be done on this Tool with respect to current capabilities and possible improvements. Its potential lies in being used in research and commercial environments.

1. Algorithms designed use currently available data. All technologies considered are relatively undeveloped, and numbers used are expected values taken from system plans. As systems are commercially deployed, more realistic information will be available. With foresight, the tool and scripts used are open for customization by the analyst. Systems Engineers can alter optimization algorithms using results of research experiments or figures from the industry to improve accuracy.
2. The tool does not have the capability of using rates of services charged to subscribers to extrapolate possible levels of penetration. This will need a relation between the median income levels and resulting demand of service. Level of penetration dictates supply capacities required from the network. If this relation can be calculated, it will no longer be necessary to assume values for either variables, and better accuracy in results can be obtained.
3. Penetration of services in any market depends on the already existing infrastructure and its subscriber base. For example a market already having many competitive high data rate service providers and a large proportion of the market as a subscriber base will yield low penetration levels to upstart firms unless they practise very competitive pricing procedures. To use this information to plan networks, we require market data about each service stored in the form of a database. If it is made available, this will be retrieved by the tool and used to customize algorithms.
4. Information on existing services can be used to modify the services the service provider can offer. Interconnecting with existing networks will enhance service capabilities

for such hybrid networks. Lower investments will be required. A technology which otherwise would not be ideal, can be designed to be the most favorable.

5. The tool optimizes only three technologies. Other high data rate technologies like ADSL and VDSL, MVDS (Multipoint Video Distribution System; which uses the 40 GHz channel) are equally promising. They will be more feasible in markets with suitable characteristics. Incorporating them in the tool will enhance its utility.

Additionally, MVDS is used in European countries. Once the tool has the capability of analyzing markets for these networks, the tool can be used for comparing performance of networks in European countries too. This will require data associated with those markets. If global data is available, the tool can optimize networks for any technology, in any part of the world.

# Bibliography

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- [2] “LMDS - The Wireless Interactive Broadband Access Service”, HP Application Note 1296, December 1996.
- [3] “LMDS and Broadband Local Networks for Asia”, Ken Zita, New York, New York USA, April 1997.
- [4] “Wireless: Part of the Broadband Future”, R. J. Nowak. Bell Northern Research, Ontario, Canada, February 1996.
- [5] 1996 Annual Report, CellularVision USA, Inc.

# Appendix A

## Avenue script for customizing ArcView

This is the Avenue script used to customize functions of ArcView and perform the desired processes. It has been divided into following parts:

1. Select BTA.
2. Export data associated with it to files in home directory.
3. Run C program in home directory to optimize for this BTA.  
This will write out results of optimization into a file
4. Open file of results in Table form
5. Plot chart to display results to analyst
6. Incorporate the View and 2 charts in a Layout

```
'*****
```

```
'This apostrophe is used for inserting comments
```

```
'Resize window
```

```
av.ReSize(1000,1000)
```

```
1.
```

```
'*****
```

```
'VIEW.SELECTPOINT selects the BTA analyst clicks on
```

```

theView = av.GetActiveDoc
r = theView.ReturnUserRect
theThemes = theView.GetActiveThemes
if (r.IsNull) then
  p = theView.GetDisplay.ReturnUserPoint
  if (System.IsShiftKeyDown) then
    op = #VTAB_SELTYPE_XOR
  else
    op = #VTAB_SELTYPE_NEW
  end
  for each t in theThemes
    if (t.CanSelect) then
      t.SelectByPoint(p, op)
    end
  end
else
  if (System.IsShiftKeyDown) then
    op = #VTAB_SELTYPE_OR
  else
    op = #VTAB_SELTYPE_NEW
  end
  for each t in theThemes
    if (t.CanSelect) then
      t.SelectByRect(r, op)
    end
  end
end
av.GetProject.SetModified(true)

```

'VIEW.SHOWTABLE displays table showing data associated with selected BTA

```

theView = av.GetActiveDoc
for each t in theView.GetActiveThemes
  if (t.HasTable) then
    t.EditTable
  end
end

```

```

    end
end

'MOVE DOCWIN moves this table to the upper left corner

aWindow = av.GetActiveDoc.GetWin
aWindow.Moveto(0, 0)

'RESIZE DOCWIN resizes table

aWindow = av.GetActiveDoc.GetWin
aWindow.ReSize(250,250)

'TABLE.PROMOTE highlights and brings data of selected market at top of table

theTable = av.GetActiveDoc
theTable.PromoteSelection

2.
'*****

'TABLE.EXPORT exports this data to the file - bresults in txt format

theTable = av.GetActiveDoc

theClass = DTXT
    theFilter = "*.txt"
    theExt = ".txt"

theVTab = theTable.GetVTab

if (theVTab.GetSelection.Count=0) then

    theVTab.Export("c:\esri\esridata\test_pro\bresults.txt".asFileName,

```

```

DTXT, FALSE)
    av.ShowMsg("All records written to bresults.txt")

else

    theVTab.Export("c:\esri\esridata\test_pro\bresults.txt".asFileName,
DTXT, TRUE)
    av.ShowMsg("Selected records written to bresults.txt")
end

'WINDOW.ACTIVATE to activate the counties View

'find the document in the project
theDoc = av.GetProject.FindDoc("BTAs for LMDS")
'bring the doc to the front
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
    theDoc.GetWin.Open
end

'SETTING THE SCALE OF THE VIEW Set scale so entire USA map is visible

MyView = av.FindDoc("BTAs for LMDS")
MyView.GetDisplay.ZoomToScale(36023026)

'LAYOUT.PAN Close up on BTA

theLayout = av.GetActiveDoc
theLayout.GetDisplay.Pan

'TO DEACTIVATE BTAs AND ACTIVATE COUNTIES make View of BTAs inactive and
'View of counties active

```

```

theView = av.GetActiveDoc
For each t in theView.GetThemes
    t.SetActive( FALSE )
end
'av.GetProject.SetModified(true)
myView = av.GetActiveDoc
myTheme = myView.GetThemes.Get(0)
    myTheme.SetVisible(TRUE)
    myTheme.SetActive(TRUE)

'MOVE DOCWIN move this window to the bottom part

aWindow = av.GetActiveDoc.GetWin
aWindow.Moveto(250, 0)

'RESIZE DOCWIN resize View to fill GUI

aWindow = av.GetActiveDoc.GetWin
aWindow.ReSize(540,500)

'ZOOMTOSELECTED Zoom in on selected BTA

theView = av.GetActiveDoc
r = Rect.MakeEmpty
for each t in theView.GetActiveThemes
    if (t.CanSelect) then
        r = r.UnionWith(t.GetSelectedExtent)
    end
end
if (r.IsEmpty) then
    return nil
elseif ( r.ReturnSize = (0@0) ) then
    theView.GetDisplay.PanTo(r.ReturnOrigin)

```

```
else
  theView.GetDisplay.SetExtent(r.Scale(1.1))
end
```

'VIEW.SHOWTABLE show data associated with counties in tabular form

```
theView = av.GetActiveDoc
for each t in theView.GetActiveThemes
  if (t.HasTable) then
    t.EditTable
  end
end
```

'MOVE DOCWIN move table beside that of BTAs

```
aWindow = av.GetActiveDoc.GetWin
aWindow.Moveto(0, 250)
```

'RESIZE DOCWIN resize the table of county data

```
aWindow = av.GetActiveDoc.GetWin
aWindow.ReSize(250,250)
```

'TABLE.PROMOTE highlights and brings data of selected market at top of table

```
theTable = av.GetActiveDoc
theTable.PromoteSelection
```

'TABLE.EXPORT exports this data to the file - cresults in txt format

```
theTable = av.GetActiveDoc
```

```

theClass = DBASE
theFilter = "*.dbf"
theExt = ".dbf"

theVTab = theTable.GetVTab

if (theVTab.GetSelection.Count=0) then

    theVTab.Export("c:\esri\esridata\test_pro\cresults.txt".asFileName,
DTXT, FALSE)
    av.ShowMsg("All records written to counties.txt")

else

    theVTab.Export("c:\esri\esridata\test_pro\cresults.txt".asFileName,
DTXT, TRUE)
    av.ShowMsg("Selected records written to counties.txt")
end

3.
'*****

'SYSTEM EXECUTE to compile and run the C program "optimize.c", which will
'optimize for the selected BTA

System.Execute{"gcc optimize.c"}
System.Execute{"a.out"}

'WINDOW.ACTIVATE Find the BTAs for LMDS View which shows all the BTAs
' to the analyst
'This is an unnecessary step and was introduced to give some time to the tool

theDoc = av.GetProject.FindDoc("BTAs for LMDS")

```

```
'bring the doc to the front
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
    theDoc.GetWin.Open
end
```

```
'To deactivate BTAs and activate counties
```

```
myView = av.GetActiveDoc
myTheme = myView.GetThemes.Get(1)
    myTheme.SetVisible(TRUE)
    myTheme.SetActive(TRUE)
myView = av.GetActiveDoc
myTheme = myView.GetThemes.Get(0)
    myTheme.SetVisible( FALSE )
    myTheme.SetActive( FALSE )
```

4.

```
'*****
```

```
'WINDOW.ACTIVATE Displays the table having results of the optimization
' executed by the System Execute command. These are measures of
'variation of returns as a function of DATA RATES
```

```
'find the document in the project
theDoc = av.GetProject.FindDoc("Data Rates Table")
```

```
'bring the doc to the front
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
    theDoc.GetWin.Open
end
```

```
'TABLE.REFRESH to update the table to the new values for the BTA selected
```

```
theTable = av.GetActiveDoc
theTable.GetVTab.Refresh
```

```
'WINDOW.ACTIVATE Updates the chart showing Variation of returns as a
' function of data rates
```

```
'find the document in the project
theDoc = av.GetProject.FindDoc("Data Rates Chart")
```

```
'bring the doc to the front
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
    theDoc.GetWin.Open
end
```

```
'MOVE RESIZE DOCWIN makes the chart of the right size so that it can be
' viewed in the Layout
```

```
aWindow = av.GetActiveDoc.GetWin
aWindow.ReSize(250,250)
aWindow.Moveto( 500, 0)
```

5.

```
'*****
```

```
'WINDOW.ACTIVATE brings Layout in View and updates chart
```

```
'find the document in the project
theDoc = av.GetProject.FindDoc("Layout")
```

```
'bring the doc to the front
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
```

```
theDoc.GetWin.Open
end
```

```
'MOVE RESIZE DOCWIN brins Layout to right size if it is not
```

```
aWindow = av.GetActiveDoc.GetWin
aWindow.ReSize( 400, 500)
aWindow.Moveto( 600, 250)
```

```
'WINDOW.ACTIVATE Updates the table having results of the optimization
' executed by the System Execute command. These are measures of
'variation of returns as a function of PENETRATION
```

```
'find the document in the project
```

```
theDoc = av.GetProject.FindDoc("Penetration Table")
```

```
'bring the doc to the front
```

```
if (theDoc = nil) then
```

```
    av.GetProject.GetWin.Open
```

```
elseif (theDoc.GetWin.IsOpen) then
```

```
    theDoc.GetWin.Open
```

```
end
```

```
'TABLE.REFRESH to update the table to the new values for the BTA selected
```

```
theTable = av.GetActiveDoc
```

```
theTable.GetVTab.Refresh
```

```
'WINDOW.ACTIVATE Updates the chart showing variation of returns as a function
'of penetration
```

```
theDoc = av.GetProject.FindDoc("Penetration Chart")
```

```
'bring the doc to the front
```

```
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
    theDoc.GetWin.Open
end

'MOVE DOCWIN moves it beside the earlier chart
```

```
aWindow = av.GetActiveDoc.GetWin
aWindow.ReSize( 250, 250)
aWindow.Moveto( 750, 0)
```

```
'WINDOW.ACTIVATE brings Layout in View and updates chart
```

```
theDoc = av.GetProject.FindDoc("Layout")
'bring the doc to the front
if (theDoc = nil) then
    av.GetProject.GetWin.Open
elseif (theDoc.GetWin.IsOpen) then
    theDoc.GetWin.Open
end
av.ReSize(1000, 890)
```

## Appendix B

# Optimizing script

This is the C code which will integrate ArcView and Cplex. Its functions are:

1. Read files to get data associated with the BTA.
2. Calculate values of coefficients and bounds for optimization algorithms
3. Use Cplex library functions to perform optimizations and write results in a file
4. Read results and write values of objective to files for plotting charts

```
*****
/*this file reads from cresults and calculates values of Income, ... for
the BTA selected. Calls lmds, leo and optic functions and optimizes over
a range of bandwidth and penetration parameters. Returns are measured and
written to files. These files will be opened in ArcView and plotted in
the form of charts*/

#include <stdio.h>
#include <fcntl.h>
#include <ctype.h>
#include "sys/syscall.h"

int even(int years);/*function to calculate break-even factor*/

int lmds(int speed, int even, int rate, int cells, int HH, int Empl, int
D, int d ); /*function to use cplex and optimize for lmds*/
```

```

int leo( speed, even_factor, rate, bw_leo, fixed_cost, dep_leo, HH, Empl,
D, d); /*function to use cplex and optimize for leo*/

int optic( speed, even_factor, rate, fixed_optic, HH, Empl, D, d);
/*function to use cplex and optimize for optic*/

main(char cresults[], char format[], char chart1.txt[], char
chart2.txt[])

{ struct record{ int *Ar; int *Med_inc; int *Households; int *Ttl_Empl;
int *Ttl_Estab;} *records;

/* Range of data rates to measure variation in returns*/

struct Speed {int speed;} spd[] = { 2, 10, 20 ,30, 40, 50};

/* Range of penetration of services to measure variation in returns*/
struct Penetration {int penetration;} pntrnN[] = { 10, 15, 20, 25, 30};
struct Penetration pntrnm[] = { 14, 20, 26, 32, 38};

/* structures to hold results of optimization*/
struct Return {int return;} *lmds, *leo, *optic, *lmds_p, *leo_p, *optic_p;

int d, m, l, *Median, *Area, *HH, *Empl, *Estab, cells, income, years ;

FILE *f1, *f2, *f3, *f4;

f1 = fopen("cresults","r");
f2 = fopen("format","w");

1.
*****

fscanf( f1, "%*s");

```

```

while (( d = getc(f1)) != EOF)
{
    if (d == ',' || d == '.' )
        {putc ('\n', f2); }    else if ( d == '\n') { putc ('\n', f2); l++; }

else if (d == ' ')
putc ('_', f2);

    else putc(d, f2);

}

fclose(f2);

printf("%d", l);

/* put a loop to assign to the record structure */

f4 = fopen("format","r");

fscanf( f4, "%*s");

for( m = 0; m < l; m++, records++){

    /* The following scan statement will read only the important values*/

fscanf( f4, " %s %s %d %*d %*d %*d %*d %d %*d %d %*d %*d %*d %*d %d %*d
%d %*d %*d", &records->Ar, &records->Med_inc, &records->Households,
&records->Ttl_Empl, &records->Ttl_Estab );

Median = Median + records->Med_inc;
Area = Area + records->Ar;
HH = HH + records->Households;
Empl = Empl + records->Ttl_Empl;
Estab = Estab + records->Ttl_Estab;

```

```
}  
fclose(f4);
```

2.

```
*****
```

```
/* Now, we calculate the median income of the BTA, which will be used to  
determine the penetration or 'take' of services as a percentage of the  
population, using D for Business customers, d for household internet  
customers and vd for household video customers*/
```

```
income = Median/l;
```

```
if (15000 <= income <= 25000 ) { D = 0.06; d = 0.09; vd = 0.2 ;}  
else if ( 25000 <= income <= 40000 ) { D = 0.1; d = 0.14; vd = 0.3 ;}  
else if ( income >= 40000 ) { D = 0.15; d = 0.2; vd = 0.4 ;}  
else { D = 0.03; d = 0.06; vd = 0.15; } /* income is lesser than 15000*/
```

```
/*check if the analyst has given customized values for cell size, data  
rates to be provided, years for break-even, rates to be charged. For  
those that are not, assign default values*/
```

```
if (area == 0; area = 6.25; )  
if (speed == 0; speed = 2; )  
if (years == 0; years = 4; )  
if (rate == 0; rate = 160; )
```

```
even_factor = even( int years);
```

3.

```
*****
```

```
/* Optimizing for LMDS starts*/
```

```

cells = Area/area;

/* Vary data rates provided from 2 to 50 Mbps and calculate returns and
store in lmds[].return structure*/

    for ( a =0; a < 6; a++, spd[a].speed, lmds[a].return){

lmds[a].return = lmds( spd[a].speed, even_factor, rate, cells, HH, Empl,
D, d);

    }

/* Optimizing for LEO starts*/

cells_leo = Area/1097;
bw_leo = cells_leo*56.8;
fixed_cost = 55555.5*cells_leo;

dep_leo = cells_leo*187500*even(years)*12*years/64; /* Depreciation of
satellite as a function of the break even period*/

/* Vary data rates provided from 2 to 50 Mbps and calculate returns and
store in leo[].return structure*/

    for ( c =0; c < 6; c++, spd[c].speed, leo[c].return){

leo[c].return = leo( spd[c].speed, even_factor, rate, bw_leo, fixed_cost,
dep_leo, HH, Empl, D, d);

    }

/* Optimizing for Optic Fiber networks starts*/

fixed_optic = 12*( HH + Estab) - 317440 + 11048960;

```

```
/* Vary data rates provided from 2 to 50 Mbps and calculate returns and
store in leo[].return structure*/
```

```
for ( e =0; e < 6; e++, spd[e].speed, optic[e].return){
```

```
optic[e].return = optic( spd[e].speed, even_factor, rate, fixed_optic,
HH, Empl, D, d);
```

```
}
```

```
/*Vary penetration from 10 to 30% and calculate returns and store in
lmds_p[].return structure, for the lowest value of data rate(bw)*/
```

```
for ( b = 0; b < 5; b++, pntrnN[b].penetration, pntrnn[b].penetration,
lmds_p[b].return, ){
```

```
D = pntrnN[b].penetration;
```

```
d = pntrnn[b].penetration;
```

```
bw = spd[1].speed;
```

```
lmds_p[b].return = lmds( bw, even_factor, rate, cells, HH, Empl, D, d);
```

```
}
```

```
/*Vary penetration from 10 to 30% and calculate returns and store in
leo_p[].return structure, for the lowest value of data rate(bw)*/
```

```
for ( g = 0; g < 5; g++, pntrnN[g].penetration, pntrnn[g].penetration,
leo_p[g].return, ){
```

```
D = pntrnN[g].penetration;
```

```

d = pntrnn[g].penetration;
bw = spd[1].speed;

leo_p[g].return = leo( bw, even_factor, rate, bw_leo, fixed_cost,
dep_leo, HH, Empl, D, d);

}

/*Vary penetration from 10 to 30% and calculate returns and store in
optic_p[].return structure, for the lowest value of data rate(bw)*/

for ( f = 0; f < 5; f++, pntrnN[f].penetration, pntrnn[f].penetration,
optic_p[f].return, )

{

D = pntrnN[f].penetration;
d = pntrnn[f].penetration;
bw = spd[1].speed;

optic_p[f].return = optic( spd[f].speed, even_factor, rate, fixed_optic,
HH, Empl, D, d);

}

4.
*****

/* print out the values of the returns obtained by varying data rates of
service to a file, for being opened by ArcView*/

f5 = fopen("chart1.txt", "w");

```

```

fprintf( f5, " LMDS, LEO, Optic Fiber \n 2 %d %d %d \n 10 %d %d %d \n 20
%d %d %d \n 30 %d %d %d \n 40 %d %d %d \n 50 %d %d %d \n ",
lmds[1].return, leo[1].return, optic[1].return, lmds[2].return,
leo[2].return, optic[2].return, lmds[3].return, leo[3].return,
optic[3].return, lmds[4].return, leo[4].return, optic[ 4].return,
lmds[5].return, leo[5].return, optic[5].return, lmds[6].return,
leo[6].return, optic[6].return );

```

```

/* print out the values of the returns obtained by varying penetration of
service to a file, for being opened by ArcView*/

```

```

f6 = fopen("chart2.txt", "w");

```

```

fprintf( f6, " LMDS, LEO, Optic Fiber \n 10 %d %d %d \n 15 %d %d %d \n 20
%d %d %d \n 25 %d %d %d \n 30 %d %d %d \n ", lmds_p[1].return,
leo_p[1].return, optic_p[1].return, lmds_p[2].return, leo_p[2].return,
optic_p[2].return, lmds_p[3].return, leo_p[3].return, optic_p[3].return,
lmds_p[4].return, leo_p[4].return, optic_p[4].return, lmds_p[5].return,
leo_p[5].return, optic_p[5].return);

```

```

return 0;

```

```

}

```

```

*****

```

```

/* function to calculate the multiplication factor to multiply the
revenue and depreciation for lmds. This is a function of the number of
years, to incorporate the effect of change in its value, over time. For
leo, we will use the same factor, but since
we want depreciation in terms of years there, we will divide it by 12. */

```

```

int even( int years)

```

```

    { int i, t, value;

    for (i = 1; i <= years; i++){
t = t + i;
    }
value = t*12/years;

return value;

}

```

## B.1 Functions

These are the functions which will be called upon by the Main program to perform the optimization.

### B.1.1 LMDS

```

/* This is on the lines of lpex1.c from the CPLEX manual, to call Cplex
librarfunctions and optimize the lmds, leo and optic cases*/

#include "cplex.h"
#include <string.h>
#ifdef CPX_PROTOTYPE_ANSI

static void

lmds (int speed, int even_factor, int rate, int cells, int HH, int Empl,
int D, int d); optimize (char *probname, int *numcols_p, int *numrows_p,
int *objsen_p, double *obj, double *rhs, char *sense, int *matbeg, int
*matcnt, int *matind, double *matval, double *lb, double *ub);

#else

```

```

static void optimize();
#endif

#define COLSPACE 10
#define ROWSPACE 4
#define NZSPACE 23

#ifdef CPX_PROTOTYPE_ANSI
int main (void)
#else int main ()
#endif

{char probname[16];
int numcols;
int numrows;
int objsen;
double obj[COLSPACE];
double rhs[ROWSPACE];
char sense[ROWSPACE];
int matbeg[COLSPACE];
int matcnt[COLSPACE];
int matind[NZSPACE];
double matval[NZSPACE];
double lb[COLSPACE];
double ub[COLSPACE];

int solstat;
double objval;
double x[COLSPACE];
double pi[ROWSPACE];
double slack[ROWSPACE];
double dj[COLSPACE];

CPXENVptr env = NULL;
CPXLPptr lp = NULL;
int status;
int i, j;

```

```

int cur_numrows, cur_numcols;

env = CPXopenCPLEX (&status);
if (env == NULL){
char errmsg[1024];
fprintf (stderr, "Could not open CPLEX environment. \n");
CPXgeterrorstring (env, status, errmsg) ;
fprintf (stderr, "%s", errmsg);
goto TERMINATE;
}

status = CPXsetintparam (env, CPX_PARAM_SCRIND, CPX_ON);

optimize(probname, &numcols, &numrows, &objsen, obj, rhs, sense, matbeg,
matcnt, matind, matval, lb, ub);

lp = CPXloadlp(env, probname, numcols, numrows, objsen, obj, rhs, sense,
matbeg, matcnt, matind, matval, lb, ub, NULL, COLSPACE, ROWSPACE,
NZSPACE);

status = CPXoptimize (env, lp);

status = CPXsolution (env, lp, &solstat, &objval, x, pi, slack, dj);

cur_numrows = CPXgetnumrows (env, lp);
cur_numcols = CPXgetnumcols (env, lp);

return objval;

TERMINATE:

if (lp != NULL){
status = CPXfreeprob (env, &lp);
if (status){
fprintf (stderr, "CPXfreeprob failed, error code %d. \n", status);
}
}
}

```

```

if {env != NULL} {
status = CPXcloseCPLEX (&env);
if (status){
char errmsg[1024];
fprintf(stderr, "Could not close CPLEX environment. \n");
CPXgeterrorstring (env, status, errmsg);
fprintf(stderr, "%s", errmsg);
}
}

return(status);
}

```

```

#ifdef CPX_PROTOTYPE_ANSI static void optimize (char *probname, int
*numcols_p, int *numrows_p, int *objsen_p, double *obj, double *rhs, char
*sense, int *matbeg, int *matcnt, int *matind, double *matval, double
*lb, double *ub)

```

```

#else
static void optimize (probname, numcols_p, numrows_p, objsen_p, obj, rhs,
sense, matbeg, matcnt, matind, matval, lb, ub)

```

```

char *probname;
int *numcols_p;
int *numrows_p;
int *objsen_p;
double *obj;
double *rhs;
char *sense;
int *matbeg;
int *matcnt;
int *matind;
double *matval;
double *lb;

```

```

double *ub;
#endif

{
    strcpy (probname, "lmds");
*numcols_p = 9;
*numrows_p = 2;
*objsen_p = -1;

obj[0] = rate; obj[1] = rate*0.5; obj[2] = 40.05;

matbeg[0] = 0; matbeg[1] = 2; matbeg[2] = 4;
matcnt[0] = 2; matcnt[1] = 2; matcnt[2] = 2;

matind[0] = 0; matind[2] = 0; matind[4] = 0; sense[0] = 'G';

matval[0] = rate*even_factor; matval[2] = rate*even_factor*0.5; matval[4]
= 40.4*even_factor; matval[6] = -650000; matval[8] = -38; matval[10] =
-38; matval[12] = -1000*even_factor; matval[14] = -14000*even_factor;
matval[16] = -17000*0.2*cells; rhs[0] = 0.0;

matind[1] = 1; matind[3] = 1; matind[5] = 1; sense[1] = 'G';
matval[1] = 1470; matval[3] = -speed*0.4; matval[5] = -speed*0.5*0.1;
matval[5] = -0.3; rhs[1] = 0.0;

lb[0] = 0.0; lb[1] = 0.0; lb[2] = 0.0; lb[3] = cells;
ub[0] = Empl*D; ub[1] = HH*d; ub[2] = HH*vd; ub[3] = cells;

}

```

## B.1.2 Broadband LEO

```

/* This is on the lines of lpex1.c from the CPLEX manual, to call Cplex
librarfunctions and optimize the lmds, leo and optic cases*/

```

```

#include "cplex.h"
#include <string.h>
#ifdef CPX_PROTOTYPE_ANSI

static void

leo( speed, even_factor, rate, bw_leo, fixed_cost, dep_leo, HH, Empl, D,
d);

optimize (char *probname, int *numcols_p, int *numrows_p, int *objsen_p,
double *obj, double *rhs, char *sense, int *matbeg, int *matcnt, int
*matind, double *matval, double *lb, double *ub);

#else

static void optimize();
#endif

#define COLSPACE 10
#define ROWSPACE 4
#define NZSPACE 30

#ifdef CPX_PROTOTYPE_ANSI
int main (void)
#else int main ()
#endif

{char probname[16];
int numcols;
int numrows;
int objsen;
double obj[COLSPACE];
double rhs[ROWSPACE];
char sense[ROWSPACE];
int matbeg[COLSPACE];
int matcnt[COLSPACE];

```

```

int matind[NZSPACE];
double matval[NZSPACE];
double lb[COLSPACE];
double ub[COLSPACE];

int solstat;
double objval;
double x[COLSPACE];
double pi[ROWSPACE];
double slack[ROWSPACE];
double dj[COLSPACE];

CPXENVptr env = NULL;
CPXLPptr lp = NULL;
int status;
int i, j;
int cur_numrows, cur_numcols;

env = CPXopenCPLEX (&status);
if (env == NULL){
char errmsg[1024];
fprintf (stderr, "Could not open CPLEX environment. \n");
CPXgeterrorstring (env, status, errmsg) ;
fprintf (stderr, "%s", errmsg);
goto TERMINATE;
}

status = CPXsetintparam (env, CPX_PARAM_SCRIND, CPX_ON);

optimize(probname, &numcols, &numrows, &objsen, obj, rhs, sense, matbeg,
matcnt, matind, matval, lb, ub);

lp = CPXloadlp(env, probname, numcols, numrows, objsen, obj, rhs, sense,
matbeg, matcnt, matind, matval, lb, ub, NULL, COLSPACE, ROWSPACE,
NZSPACE);

status = CPXoptimize (env, lp);

```

```

status = CPXsolution (env, lp, &solstat, &objval, x, pi, slack, dj);

cur_numrows = CPXgetnumrows (env, lp);
cur_numcols = CPXgetnumcols (env, lp);

return objval;

TERMINATE:

if (lp != NULL){
status = CPXfreeprob (env, &lp);
if (status){
fprintf (stderr, "CPXfreeprob failed, error code %d. \n", status);
}
}

if {env != NULL} {
status = CPXcloseCPLEX (&env);
if (status){
char errmsg[1024];
fprintf(stderr, "Could not close CPLEX environment. \n");
CPXgeterrorstring (env, status, errmsg);
fprintf(stderr, "%s", errmsg);
}
}

return(status);
}

#ifdef CPX_PROTOTYPE_ANSI
static void
optimize (char *probname, int *numcols_p, int *numrows_p, int *objsen_p,
double *obj, double *rhs, char *sense, int *matbeg, int *matcnt, int

```

```

*matind, double *matval, double *lb, double *ub)

#else
static void

optimize (probname, numcols_p, numrows_p, objsen_p, obj, rhs, sense,
matbeg, matcnt, matind, matval, lb, ub)

char *probname;
int *numcols_p;
int *numrows_p;
int *objsen_p;
double *obj;
double *rhs;
char *sense;
int *matbeg;
int *matcnt;
int *matind;
double *matval;
double *lb;
double *ub;
#endif

{
    strcpy (probname, "leo");
*numcols_p = 7;
*numrows_p = 2;
*objsen_p = -1;

obj[0] = rate; obj[1] = rate*0.5;

matbeg[0] = 0; matbeg[1] = 2; matbeg[2] = 4;
matcnt[0] = 2; matcnt[1] = 2; matcnt[2] = 2;

matind[0] = 0; matind[2] = 0; matind[4] = 0; sense[0] = 'G';

matval[0] = rate*even_factor; matval[2] = rate*even_factor*0.5; matval[4]

```

```

= -fixed_cost; matval[6] = -38; matval[8] = -38; matval[10] = -dep_leo;
rhs[0] = 0.0;

matind[1] = 1; matind[3] = 1; matind[5] = 1; sense[1] = 'G';
matval[1] = bw_leo; matval[3] = -speed*0.4; matval[5] = -speed*0.5*0.1;
rhs[1] = 0.0;

lb[0] = 0.0; lb[1] = 0.0;
ub[0] = Empl*D; ub[1] = HH*d;

}

```

### B.1.3 Optic Fiber

```

/* This is on the lines of lpex1.c from the CPLEX manual, to call Cplex
librarfunctions and optimize the lmds, leo and optic cases*/

#include "cplex.h"
#include <string.h>
#ifdef CPX_PROTOTYPE_ANSI

static void
optic( speed, even_factor, rate, fixed_optic, HH, Empl, D, d);

optimize (char *probname, int *numcols_p, int *numrows_p, int *objsen_p,
double *obj, double *rhs, char *sense, int *matbeg, int *matcnt, int
*matind, double *matval, double *lb, double *ub);

#else

static void optimize();
#endif

```

```

#define COLSPACE 10
#define ROWSPACE 4
#define NZSPACE 30

#ifdef CPX_PROTOTYPE_ANSI
int main (void)
#else int main ()
#endif

{char probname[16];
int numcols;
int numrows;
int objsen;
double obj[COLSPACE];
double rhs[ROWSPACE];
char sense[ROWSPACE];
int matbeg[COLSPACE];
int matcnt[COLSPACE];
int matind[NZSPACE];
double matval[NZSPACE];
double lb[COLSPACE];
double ub[COLSPACE];

int solstat;
double objval;
double x[COLSPACE];
double pi[ROWSPACE];
double slack[ROWSPACE];
double dj[COLSPACE];

CPXENVptr env = NULL;
CPXLPptr lp = NULL;
int status;
int i, j;
int cur_numrows, cur_numcols;

env = CPXopenCPLEX (&status);

```

```

if (env == NULL){
char errmsg[1024];
fprintf (stderr, "Could not open CPLEX environment. \n");
CPXgeterrorstring (env, status, errmsg) ;
fprintf (stderr, "%s", errmsg);
goto TERMINATE;
}

status = CPXsetintparam (env, CPX_PARAM_SCRIND, CPX_ON);

optimize(probname, &numcols, &numrows, &objsen, obj, rhs, sense, matbeg,
matcnt, matind, matval, lb, ub);

lp = CPXloadlp(env, probname, numcols, numrows, objsen, obj, rhs, sense,
matbeg, matcnt, matind, matval, lb, ub, NULL, COLSPACE, ROWSPACE,
NZSPACE);

status = CPXoptimize (env, lp);

status = CPXsolution (env, lp, &solstat, &objval, x, pi, slack, dj);

cur_numrows = CPXgetnumrows (env, lp);
cur_numcols = CPXgetnumcols (env, lp);

return objval;

TERMINATE:

if (lp != NULL){
status = CPXfreeprob (env, &lp);
if (status){
fprintf (stderr, "CPXfreeprob failed, error code %d. \n", status);
}
}

if (env != NULL) {
status = CPXcloseCPLEX (&env);
}

```

```

if (status){
char errmsg[1024];
fprintf(stderr, "Could not close CPLEX environment. \n");
CPXgeterrorstring (env, status, errmsg);
fprintf(stderr, "%s", errmsg);
}
}

return(status);
}

#ifdef CPX_PROTOTYPE_ANSI
static void

optimize (char *probname, int *numcols_p, int *numrows_p, int *objsen_p,
double *obj, double *rhs, char *sense, int *matbeg, int *matcnt, int
*matind, double *matval, double *lb, double *ub)

#else
static void

optimize (probname, numcols_p, numrows_p, objsen_p, obj, rhs, sense,
matbeg, matcnt, matind, matval, lb, ub)

char *probname;
int *numcols_p;
int *numrows_p;
int *objsen_p;
double *obj;
double *rhs;
char *sense;
int *matbeg;
int *matcnt;
int *matind;
double *matval;

```

```

double *lb;
double *ub;
#endif

{
    strcpy (probname, "optic");
*numcols_p = 7;
*numrows_p = 2;
*objsen_p = -1;

obj[0] = rate; obj[1] = rate*0.5;

matbeg[0] = 0; matbeg[1] = 2; matbeg[2] = 4;
matcnt[0] = 2; matcnt[1] = 2; matcnt[2] = 2;

matind[0] = 0; matind[2] = 0; matind[4] = 0; sense[0] = 'G';

matval[0] = rate*even_factor; matval[2] = rate*even_factor*0.5; matval[4]
= -fixed_optic; matval[6] = -0.1; matval[8] = -0.35; matval[10] = -38;
matval[12] = -38; rhs[0] = 0.0;

matind[1] = 1; matind[3] = 1; matind[5] = 1; sense[1] = 'G';

matval[1] = 10000; matval[3] = -speed*0.4; matval[5] = -speed*0.5*0.1;
rhs[1] = 0.0;

lb[0] = 0.0; lb[1] = 0.0;
ub[0] = Empl*D; ub[1] = HH*d;

}

```