CARRIER VOICE NETWORK MANAGEMENT

Elvis N. Ngah

Supervised by:

Dr. Sandjai Bhulai
Department of Mathematics
Vrije Universiteit Amsterdam
The Netherlands

Deryck Cole
Network Operations Center
Telesonique Global Telecom eXchange
Zurich, Switzerland

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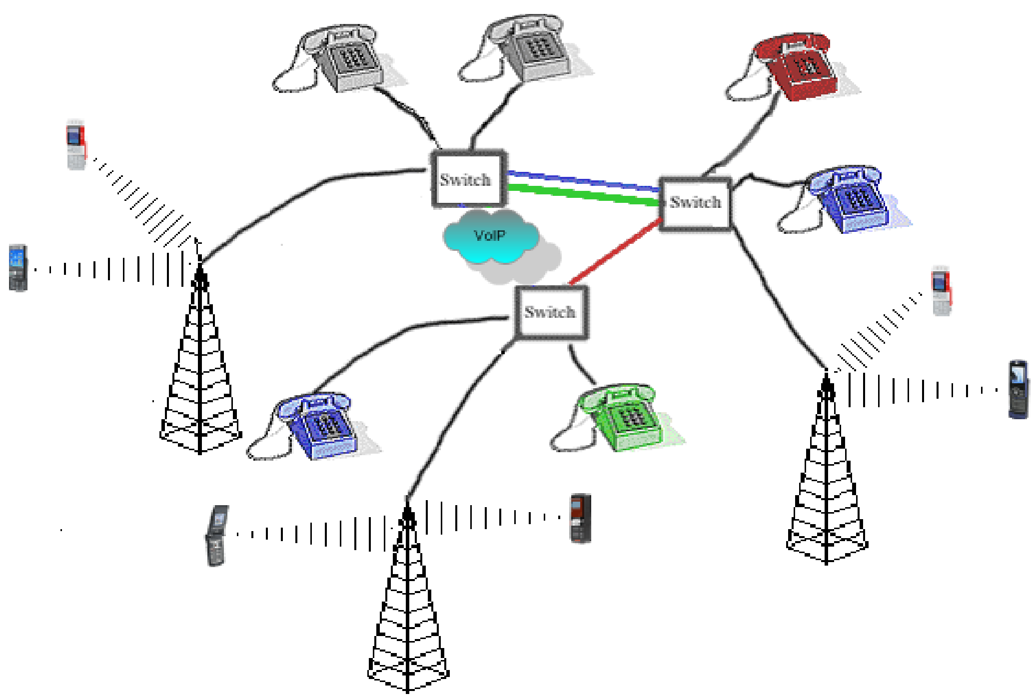
Business Mathematics and Informatics

Vrije Universiteit Amsterdam
Depts. of Maths. and Comp. Science
Faculty of Sciences
De Boelelaan 1081a
1081 HV Amsterdam
The Netherlands



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Preface and Acknowledgements

The project documented in this report was done as the final unit of the MSc programme in Business Mathematics and Informatics of the Vrije Universiteit Amsterdam, the Netherlands. It was carried out in Zurich for a duration of 7 months at the Network Operations Center of the Swiss telecom operator, Telesonique GTeX where I worked on Carrier Voice Network Management with a focus on Routing and Network Trouble-shooting. Carrier voice routing is also a function of various costs. So, although I was a member of the technical team, on the one hand, I had to rely on the commercial department for price and revenue details, and on the other hand, they had to rely on the results of my route performance analyses in order to make price offers to other carrier customers.

Just one person never completes a project. In this respect, I would like to thank a number of people who gave me their helping hands in one way or the other. Beginning with the company, I would like to give thanks to the CEO, Mr. Adel Labib, for giving me the privilege to carry out this project within the company. Next, is my supervisor and chief Network Systems Engineer at the company, Mr. Deryck Cole. I am grateful for the on-hand practical technical switching experience that he has given me and more especially, the confidence in letting me handle equipments all on my own. I would also like to say thank you to the Product Manager, Mr. Gunnar Berglund, for letting me know what the commercial side of carrier voice switching is like, more especially, customer billing and pricing. I am also grateful to Nasser Bessada and David Sgier not only for the ever open ears they gave to my endless commercial and customer related questions, but also for making me exploit some social aspects of Zurich.

At the university, I will always be grateful to my supervisor, Dr. Sandjai Bhulai, for the academic assistance he has offered to me especially during the last year of my study. His challenging suggestions, corrections, and comments form an integral part of this report. Next is Drs. Wemke van der Weij. Thanks for being my second reader.

Finally, thanks go to my mum, Osong Zipporah, for her encouragements; and to my indebted friend at the University of Brescia (Italy), Tomson Ngassa, for his documentation feedback.

Elvis Ndomon Ngah

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List of Acronyms

ACD	Average Call Duration
ACM	Address Complete Message
ADSL	Asymmetric Digital Subscriber Line
ANM	ANswer Message
ASR	Answer Seizure Ratio
BHCA	Busy Hour Call Attempts
CCS7	Common Channel Signaling 7 (same as SS7)
CDR	Call Detail Record
CLI	Calling Line Identification
CLR	CLeaR message
CTF	CircuiT Free message
DMS	Digital Multiplex System
DPC	Destination Point Code
GoS	Grade of Service
IFAM	Initial and Final Address Message
ITU	International Telecommunication Union
LCR	Least Cost Routing
NOC	Network Operations Center
OPC	Origination Point Code
PCM	Pulse Code Modulation
PD	Pricing Department
PDD	Post Dial Delay
PIN	Personal Identification Number
PSTN	Public Switched Telephone Network
QoS	Quality of Service
REL	RELease message
SLA	Service Level Agreement
SS7	Signaling System 7 (same as CCS7)
TDM	Time Division Multiplexing
TT	Trouble Ticket
VoIP	Voice over Internet Protocol

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Chapter 1

INTRODUCTION

1.1 About Telesonique GTeX

Telesonique Global Telecom eXchange[1] (GTeX) is a telecommunications provider in Switzerland. It has its establishments in Geneva (headquarters) and in Zurich, and provides services like Calling Cards, ADSL, Satellite Telephony, E-mail, Internet Telephony commonly called Voice over IP (VoIP), etc. Although the qualities of these services meet with the most recent industrial standards, there is still the need to optimize them.

In Zurich is housed the Network Operations Center (NOC) and the Pricing Department (PD). NOC is responsible for network operations like switching, routing decisions, capacity management, troubleshooting, etc., whereas PD deals with matters like customer billing, price negotiations, revenue management, etc. These two departments work hand in hand with each other especially in aspects like billing and making routing decisions.

Telesonique, just like any other international carrier, switches telephone traffic from one destination to another. In other words, it trades (buys and sells) telephone minutes with other carriers such as T-Systems, KPN, Verizon, Swisscom, Tele2, Vodafone, etc. by serving as a passageway for voice traffic.

1.2 Problem Definition

In the past, the goal of telecom engineers was to provide better services at whatever costs.

[1] This name will simply be abbreviated to Telesonique in the rest of this report.

The costs were then being levied on the customer. To this end, only the rich could afford these services. Over the years, there have been changes to this situation. The industry is driving to the positive direction where better services are being provided at very low charges to the customer. In addition, telecom companies have in recent years experienced a significant increase in number, which has led to a high level of competition amongst them. At the same time, the number of customers has also grown tremendously. Thus, there is the need for better management of resources such as optimization of the quality of the services they provide to these and other carrier customers. Trade-offs need to be made between costs, quality, and priorities.

A telephone call is between two parties - the calling party (or caller) and the called party (or callee) who are connected by one or more switches at various carrier companies' exchanges. These switches form an electrical connection between both end-users, and their setting is electronically determined by pulses or tones generated by the dialed number. When a connection is established, and caller and callee subsequently go in speech, their voices are transported as analogue and digital signals between the switches in the network. In order to succesfully realize this process, the telecom exchange companies are charged for this. Each time a number is dialed, each of these companies sees it as an attempt, which may either be successful or a failure. They make a very small profit margin for each successful call but rely on the minutes generated by the huge amounts of successful calls in order to make a noticeable profit.

Problem statement

With respect to the above two paragraphs, the problem faced by Telesonique that we need to solve is to maximize the success/attempt ratio of calls (i.e., voice and fax) subject to the following conditions:

1 Call resources are expensive to provide. For this reason, it is cost effective not to provide more resources than required.
2 Call arrivals at Telesonique's network are uncertain over time. Subsequently, a call may arrive when all resources are in use. Such a call is blocked. Each carrier customer wants the blocking of its traffic to be as low as possible. In this sense, very high blocking does not satisfy customer requirements, which may eventually lead to poor carrier-carrier relationships. On the other hand, when the blocking of calls is very low, it means that there is more provisioning of costly resources than needed.
3 Calls also fail at the level of an outgoing route[2] as a result of congestion. The trade-off here is that the chosen route should have minimal network congestion and at the same time offer minimal costs.
4 Even when a call is successful, the caller has to be satisfied with the voice quality. In the carrier business, there is the tendency that callers stay longer in speech when the call quality is good. An increase in expected call duration means the sales of more telephone minutes, implying an increase in revenue for the business.

[2] A route is the next available carrier to which a call is switched and not the complete path taken by the call from the caller to the callee.

1.3 Study Objectives

The constraints outlined above have three basic themes, which are costs, carrier relationships, and quality. To this end, we map the underlying problem by addressing the following research questions:

Q1: How do costs and network performance influence Telesonique's relationship with other carrier customers and suppliers?
Q2: What are the resources needed by callers and how do they lead to carrier-carrier relationships?
Q3: What are the performance metrics in question and how do we improve them?
Q4: How do we guarantee some better traffic quality to carrier customers?
Q5: Which route (supplier) is optimal, i.e., renders the best price-quality option for traffic to a particular destination?

To solve the stated problem, we need to answer these questions in a cost effective manner. In principle, they should be answered in such a way that the benefits obtained from them outweigh both the costs of answering them and the costs of the system [1]. Subsequently, we follow the steps outlined below, each in a restricted time frame:

1. Gather relevant information and data concerning the problem,
2. Formulate a model with sub-components that represent the problem,
3. Use a mathematics and computer-based approach to solve the model, and
4. Validate the results of the model.

The details of these steps are the remaining content of this document.

1.4 Organization of this Report

The rest of this report is organized as follows: the routing and performance related activities of Telesonique's PD are treated under Carrier Services in Chapter 2. More generally, this chapter elaborates on how routing costs and route quality lead to, and influence the relationship between carriers thereby answering the first research question, Q1. In Chapter 3, we study the activities of the NOC. The aim of this chapter is to bring out the resources needed by callers and how they lead to carrier-carrier relationships. Thus, we answer Q2. Here, we also resolve Q3 as we identify the network performance metrics, and how they can be improved. We then treat Q4 and Q5 as Performance Analysis in Chapter 4. The results of the analysis are validated in Chapter 5. Finally, some conclusions and suggestions for future research are presented in Chapter 6.

Chapter 2

CARRIER SERVICES

2.1 Area Code Management

2.1.1 Area Codes and Pricing

When a caller in a country makes a phone call to a person in another country, it is possible that the caller and the callee are subscribers of different network providers. Even if they are both in the same country, they could still belong to different network providers. Because of this, Telesonique's customers are mostly carriers that trade on an international scale. They buy and sell traffic that are destined for various countries. Different carriers have their own pricing schemes for different destinations. To this end, Telesonique determines the price it charges for incoming traffic. Since the carriers of this traffic have to pay money to Telesonique, this traffic is referred to as *sold traffic*. At the same time, other carriers supply Telesonique with their pricelists in case Telesonique has to send *purchased traffic* to them.

A major factor that determines the price is the destination (not the source) of the calls. Each area code is charged a different price and each carrier's switching equipment uses area codes as well as prices in order to route traffic. As days go by, new mobile and fixed network operators come into business and are given unique operator numbers by the concerned governing telecommunications authorities. More so, as a country's population increases, new area codes are introduced as well as old ones disappeared. To this end, each carrier regularly updates its frequently changing area code list in order to make optimal routing decisions. Telesonique is no exception. NOC together with the PD handle this issue. While the latter uses it for better revenue management policies, NOC on the other hand, uses it as a criterion for making optimal routing decisions.

In general, for a particular country, traffic destined for mobile phones are more expensive than those for fixed phones. In this respect, it is necessary to ask the following questions:

- Would other carriers be willing to send us fixed phone traffic when we charge them the higher amounts meant for cellular phone traffic?
- Would we generate higher revenue and eventually be in business when we provide our services on a negative margin by charging mobile phone traffic with the low amounts meant for fixed phone traffic?

These questions leave Telesonique with the need to avoid simple but fatal coding errors of mistaking mobile numbers for fixed numbers and vice-versa. Area code management is done on average once every month or immediately when there is an alert.

2.1.2 ITU-T E.164 Standard

The management of the international codes for every country is in the auspices of the ITU-T[3]. In the ITU-T recommendation E.164, each country code is preceded by the + sign (meaning a preceding 00). The smallest international code is +1. The codes are grouped into 9 zones as shown in Table 1.

Zone nr	First digit of country code	Nr of digits in country code	Geographical Region
1	+1	1 or 4	North America and the Caribbean Islands
2	+2	2 or 3	Africa, Aruba, Greenland and the Faroe Islands
3	+3	2 or 3	Europe
4	+4	2 or 3	Europe
5	+5	2 or 3	South/Latin America
6	+6	2 or 3	South Pacific (Oceania)
7	+7	1	Russia and Kazakhstan
8	+8	2 or 3	East Asia and Special Services
9	+9	2 or 3	West Asia, South-East Asia, and Middle East

Table 1: ITU zone division and country code allocation.[4]

The ITU, however, does not govern the way in which each country does its national numbering plan. The telecommunications authorities of the respective countries handle this. The ITU has a database portal on its website [6] that contains all these details. It therefore urges each national authority to immediately inform ITU with the updated list. On this website, there is free subscription for an alert in case an update is made. Telesonique and other carriers count on these updates as their main source of area code management information.

[3] ITU-T is the sector of the International Telecommunication Union (ITU) responsible for telephony and data communications.
[4] For a detailed list of country codes, consult [6].

2.1.3 Routing Number Formats

In international voice switching, carriers adopt a destination number system that ensures switching efficiency. This number has as few digits as possible after the country code [3]. The most commonly used format is +CC ABC XXX where

CC = destination country code,
ABC = unique code specifying service provider and service type, and
XXX = customer number.

Let us take for example the Netherlands where we can identify the routing number format +31 624. Here, CC = 31 and ABC = 624 which is reserved for the cellular network provider T-Mobile. Thus, all calls switched by Telesonique to the destination numbers +31 624 849912 and +31 624 531345 will be routed to the same carrier since they have the same routing number format 31 624. A call for the T-mobile number +31 641 134526 might be routed to a different carrier because this destination has a different routing number format, +31 641, hence a difference in tariff. More about tariffs is explained in Section 2.4.2. Each routing number is interpreted as a destination.

2.2 Product Management

2.2.1 Service Differentiation

Telesonique renders two different kinds of services. These are retail and wholesale services. Retail services include Calling Cards, E-mail provisioning, ADSL, etc. The wholesale service it provides is switching voice traffic from one telecom carrier to another. Since the scope of this project is switching voice traffic, we limit ourselves to the retail Calling Card and wholesale voice services.

The Calling Card service works as follows. A customer has a pre-paid Telesonique calling card that contains a toll-free access number and a PIN[5]. To make a call, the following steps as shown in Figure 2.1 apply:

1 Caller dials toll-free access number on card using a Swisscom fixed phone.
2 Digitalk requests for PIN of calling card.
3 Caller inserts PIN.
4 Digitalk checks if PIN is valid.
5 If so, Digitalk requests for destination number. If not, caller is informed and call is terminated.
6 Caller inserts destination number.
7 A Digital Multiplex System (DMS) switches the call to another carrier depending on the given destination.

[5] Personal Identification Number.

All requests and responses are switched by the DMS.

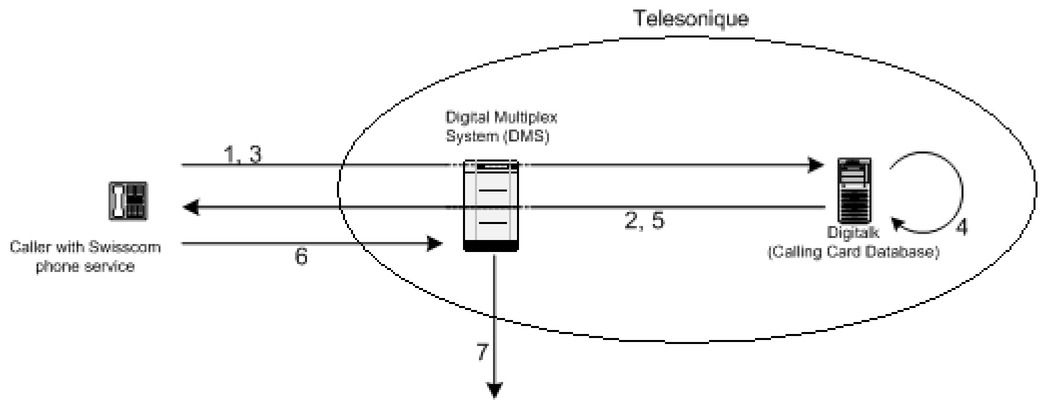


Figure 2.1: Functioning of Telesonique Calling Card

2.2.2 Number Differentiation

In both the retail and wholesale voice services, different pricing schemes are attributed to the different destination numbers that are switched. It is therefore worthwhile to know the different number categories. These are:

- *Fixed (local) numbers*: These are numbers attributed to local telephony where the network provider renders services within a limited geographical region. The telephone calls terminate at a telephone exchange. When a call is made for a far destination, the branch exchange switches the call to the respective long-distance network. Calls to local numbers are generally cheap.
- *Cellular numbers*: These are numbers attributed to subscribers by operators whose radio networks consist of cells, each being served by a base station in the cell. The base stations are connected to cellular telephone switches, which in turn connect to a Public Switched Telephone Network (PSTN). When a user moves from one cell to another, the switch automatically commands the cellular phone to the new cell frequency. Switching calls destined for mobile numbers is generally more expensive than switching those for fixed phones.
- *Toll-free numbers*: These are numbers that can be called for free. The called party, usually a business unit, pays the costs for these calls. Costs are usually a function of the usage of the phone number and the costs of the trunk lines being used. The called party usually makes sales in which case it recovers the incurred costs. Different countries use different prefixes to denote toll-free services for their national networks. Switzerland and the Netherlands adopt 0800 whereas the USA adopts 800.
- *Value added service numbers*: These are also termed *premium rate numbers*. They are usually called for services like weather forecasts, diplomatic services, TV gambling, adult entertainment, etc. The caller normally pays higher charges to the network provider. Some service providers attribute these numbers as a means of

reducing call volume as well as call length for technical support. In some situations, the revenue obtained is shared both by the network provider and the owner of the number, in which case it is termed a *shared revenue number*. Some countries refer to these numbers as the 09 numbers because of the 090X prefix.

2.3 Carrier Sales

2.3.1 Traffic Hubbing

Hubbing is the phenomenon whereby traffic is switched from one carrier, *A*, to another carrier, *B*, via an intermediary carrier, *C*. This is done because of the bilateral agreements between *A* and *C* and between *C* and *B* [3]. *C* aggregates and manages traffic from various carriers and then terminates them to various destinations. When *B* observes that traffic switched by *C* is coming from *A*, the situation is called a *transit* [4]. On the other hand, when *B* knows nothing about *A* and sees the traffic as originating from *C*, then it is called a *re-file*. Telesonique plays the role of origin, destination, re-file, or transit carrier depending on the circumstance. We now consider the traffic transit and re-file steps.

Traffic transit

Transit involves direct agreements and negotiations between all parties involved. As shown in Figure 2.2, *A* and *B* may use the same transit point *C* as in (a), or two different

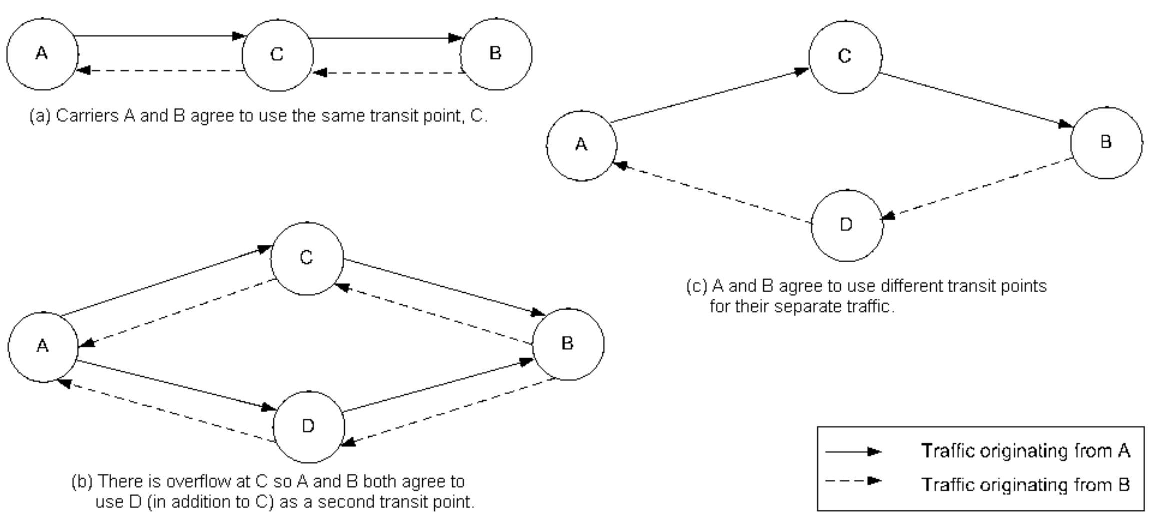


Figure 2.2: Different transit scenarios.

transit points as in (c). In the situation where two different transit points are used, calls from *A* to *B* might transit via *C*, while calls from *B* to *A* might transit via *D*. The destination carrier pays the transit fee and therefore chooses the transit carrier. This is subject to negotiations between *A* and *B*, for example, to check if the originator is able to send calls via the desired transit carrier.

The originator provides the necessary details (such as the routing number formats) to the transit carrier. Each carrier implements the necessary routing requirements in its network, e.g., by opening the required routing codes in their switches. Carriers sometimes agree to both use two transit routes as shown in Figure 2.2(b) so as to take care of situations like overflow routing.

Traffic re-file

In a re-file, there are separate arrangements between the originator of the traffic and the re-filer, and between the re-filer and the destination carrier. The re-filer replaces the Calling Line Identification (CLI)[6] with a new one thereby making the destination carrier see the calls as coming from the re-filer. The idea behind re-filing is that the originator ends up paying less if the calls come from the country indicated by the new CLI rather than from the original country.

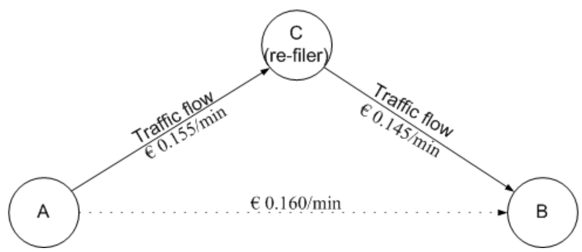


Figure 2.3: Traffic re-file.

To illustrate this, some arbitrary values have been included in Figure 2.3. If A would send directly to B, it would pay, say, €0.160/min. Sending via the re-filer C, A pays just €0.155/min to C who pays € 0.145/min to send to B. The benefits are calculated as follows:

A saves: 0.160 – 0.155 = €0.005/min.
C gains: 0.155 – 0.145 = €0.010/min.

2.3.2 Switchless Reselling

Selling traffic could also involve another small telecom company called a switchless reseller. Such a company has no switches or network facilities. It buys the switched facilities from long-distance carriers for resale to customers. It signs contracts with large carriers specifying per-minute rates and then resells the traffic to other companies and residences for profits.

Some customers need personal services like billing, as well as network functions, which can be very costly. Dealing with these customers by using switchless resellers can be very cost effective. The switchless reseller handles the responsibility of handling the customer service functions.

[6] This is the same as the Caller ID.

Switchless reselling also has a drawback. Switchless resellers are usually characterized by managerial incompetence in which case dealing with them would mean first researching and studying the effectiveness of their management team [8]. This can be very costly.

2.3.3 Performance Contracting

Telesonique signs service contracts with other carriers. Each contract contains some performance related agreements. These are interconnection regulations and the quality standards each party has to adhere to.

Interconnection is the linking of different networks so that customers of the different networks may call one another. Parties agree on capacity as well as connection bandwidth. The aim to regulate interconnections is to handle competition amongst carriers. Consumers benefit from this in that the competition causes carriers to lower their prices and improve the quality of the services they provide.

For quality standards, each party accepts to render best effort quality. This Quality of Service (QoS) is based on present connection conditions and should be consistent with industry standards, government regulations and sound business practices. Service Level Agreements (SLAs) include acknowledgement, response, restoration, and closure times of a fault. Sometimes, there is a marketing motive attributed to the SLA such as "If you buy destination *Y* from me[7], I can terminate *X*% of the traffic providing an average call duration of *C* minutes charging you €*D*/min." Traffic is then sent where the sender is guaranteed a better quality-price offer. *How can Telesonique define a quality-price benchmark for a particular destination and then make SLAs to customers with some degree of certainty?* This issue is covered in Chapter 4.

2.4 Traffic Economics

2.4.1 Traffic Auditing

Auditing refers to the examination of records to check for accuracy. Traffic records that require auditing are billing records for each customer. These are determined from the customer's Call Detail Record (CDR). Billing comprises gathering and tracking of the network resource usage metric, i.e., the total call duration and reporting the costs of utilization to the customer.

The billing system has the capability of tracking high-cost services like international, long distance, and value-added-service-number calls. Reporting the usage and costs for a

[7] Same as "if you send destination Y to me".

particular customer is done across the entire network and is independent of the implementation [12]. Implementation here refers to the method in which traffic is switched. In order words, the billing system functions in such a way that for a particular customer, a single price is established for terminating calls to a particular destination irrespective of whether the calls are terminated via trunk lines or via an IP network.

2.4.2 Accounting Rate and Currency Impact

For each call, the originating carrier charges the caller a fee called *tariff*. The charge paid by the originating carrier to another carrier for terminating (switching) this call is known as the *accounting rate*. The accounting rate is negotiated between the originating and terminating carrier and is related to the carriers' end-to-end facility costs.

Week nr	B's price/min	C's price/min
1	€0.1049	$0.1401 (€0.1051)
2	€0.1049	$0.1401 (€0.1030)

Table 2: Carrier A's cost analysis.

The billing arrangements other carriers make with Telesonique is that of invoicing sold or bought traffic weekly, semi-monthly, or monthly. These arrangements define the currency of payment. Monetary terms are either in Euros, US Dollars, or Swiss Francs. The variations in exchange rates of these currencies greatly influence the direction and amount of traffic flow. As an example, let us consider Table 2 where *A* deals with *B* and *C* in Euros and US Dollars, respectively. *B* sends its price (€0.1049/min) to *A* for terminating traffic to a particular destination. *C* also sends its price ($0.1401/min) to *A* for the same destination. Suppose the price offers stay constant in weeks 1 and 2, but the Dollar has dropped in value by 2% with respect to the Euro. Everything (quality, taxes, etc.) being equal, *A* sends traffic to *B* in week 1 since it costs less. In week 2, the drop in value of the Dollar makes *A* change its routing and now sends traffic to *C*. Fluctuations in currency value affect routing decisions and eventually capacity management.

Chapter 3

NETWORK OPERATIONS

3.1 Troubleshooting

3.1.1 Monitoring Performance Measures

Telesonique has real-time traffic software that records traffic details. This is split into two for the two respective kinds of traffic i.e. incoming and outgoing traffic monitor. The incoming traffic monitor reflects the performance of Telesonique's network at given moments. On the other hand, the outgoing traffic monitor reflects the performance of outgoing routes. Figure 3.1 shows the monitor for incoming traffic. It contains details of the number of call attempts, the number of answered calls, and the total call duration for each incoming carrier. From these, the performance features of interest are monitored. They include the following:

1. *Answer Seizure Ratio (ASR)*: This is used as a measure of quality for incoming or outgoing traffic depending on the traffic monitor in question. It is defined as

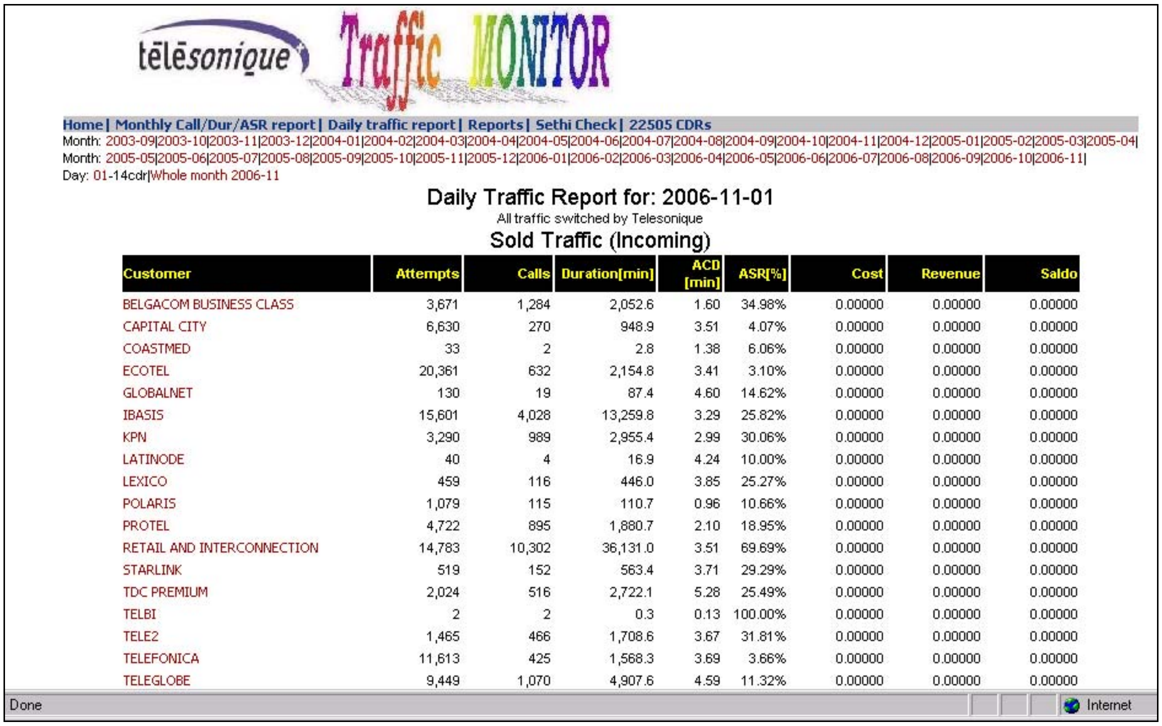
$$ASR = \frac{number\_of\_answered\_calls}{number\_of\_call\_attempts}. \tag{3.1}$$

   A low ASR implies that callers cannot get through to the other end, thus, signifying bad quality. Reasons for this are:

   i. *Congestion*: There is more traffic than the available capacity. Therefore, some calls are blocked.
   ii. Long *Post-Dial Delay (PDD)*: PDD is the time between dialing a number and hearing the dial tone or busy signal. In general, when the PDD is greater than

10 sec. [11] callers consider it to mean that there is no connection and therefore hang up. This is seen as an unsuccessful attempt.

iii. *Call Looping*: This is the situation where a call moves from one carrier to another and back over and over again. In most cases, the call does not reach its destination. Even if it does, a long PDD is experienced. The call is interpreted as an attempt each time it comes back to the switch. Call looping usually involves two or more carriers and is very undesirable. It is discussed in detail in Section 3.1.3.



Customer	Attempts	Calls	Duration[min]	ACD [min]	ASR[%]	Cost	Revenue	Saldo
BELGACOM BUSINESS CLASS	3,671	1,284	2,052.6	1.60	34.98%	0.00000	0.00000	0.00000
CAPITAL CITY	6,630	270	948.9	3.51	4.07%	0.00000	0.00000	0.00000
COASTMED	33	2	2.8	1.38	6.06%	0.00000	0.00000	0.00000
ECOTEL	20,361	632	2,154.8	3.41	3.10%	0.00000	0.00000	0.00000
GLOBALNET	130	19	87.4	4.60	14.62%	0.00000	0.00000	0.00000
IBASIS	15,601	4,028	13,259.8	3.29	25.82%	0.00000	0.00000	0.00000
KPN	3,290	989	2,955.4	2.99	30.06%	0.00000	0.00000	0.00000
LATINODE	40	4	16.9	4.24	10.00%	0.00000	0.00000	0.00000
LEXICO	459	116	446.0	3.85	25.27%	0.00000	0.00000	0.00000
POLARIS	1,079	115	110.7	0.96	10.66%	0.00000	0.00000	0.00000
PROTEL	4,722	895	1,880.7	2.10	18.95%	0.00000	0.00000	0.00000
RETAIL AND INTERCONNECTION	14,783	10,302	36,131.0	3.51	69.69%	0.00000	0.00000	0.00000
STARLINK	519	152	563.4	3.71	29.29%	0.00000	0.00000	0.00000
TDC PREMIUM	2,024	516	2,722.1	5.28	25.49%	0.00000	0.00000	0.00000
TELBI	2	2	0.3	0.13	100.00%	0.00000	0.00000	0.00000
TELE2	1,465	466	1,708.6	3.67	31.81%	0.00000	0.00000	0.00000
TELEFONICA	11,613	425	1,568.3	3.69	3.66%	0.00000	0.00000	0.00000
TELEGLOBE	9,449	1,070	4,907.6	4.59	11.32%	0.00000	0.00000	0.00000

Figure 3.1: Telesonique real-time traffic monitor

2. *Average Call Duration (ACD)*: This is the expected length of time in which a user is in speech. It is calculated as

$$ACD = \frac{total\_call\_duration}{number\_of\_answered\_calls} . \qquad (3.2)$$

When the ACD is low, it is interpreted to mean that callers do not complete their calls as desired but rather hang up as a result of bad quality. For wholesale, this implies a loss in revenue minutes. In a retail service like Calling Cards, it is a very important issue since people would not like to purchase, for a second time, a calling card that gives a low ACD.

3.1.2 Trouble-Ticketing

A *Trouble Ticket (TT)*, shown in Figure 3.2, is an electronic ticket that is opened (made) and stored each time there is a performance problem in the network, which cannot be solved immediately. Some of these problems (e.g., congestion, long PDD, and looping) have already been explained in Section 3.1.1 above. Other faults include:

iv. *Dead air*: Here, a call is being billed when no one is responding at the other end. This is very undesirable to the caller because he/she pays for a service he has not used.

v. *Call breaking*: Caller and/or callee get intermittent sound breaks. This is caused by impairments in the electronic equipments or packet loss in case of VoIP.

vi. *Echo*: This is the phenomenon whereby during a call, one repeatedly hears his/her own voice. In most cases, only one person hears an echo, which means his/her voice is reflected near to the other end-user. This occurs in VoIP.

vii. *Fax failing*: Fax which is data traffic, is transmitted using voice channels. It is described as failing when the receiver misses part or all of the transmitted data.

Figure 3.2: A trouble ticket

When a TT is opened for a performance problem, the TT includes the following main contents:

- Trouble Ticket number, e.g., TSQ 1456.
- Problem to be fixed, e.g., 0% ASR.
- Destination, e.g., France Mobile 68 (routing number format +33 68).
- At least 2 test numbers.
- Outgoing carrier.
- Incoming carrier.

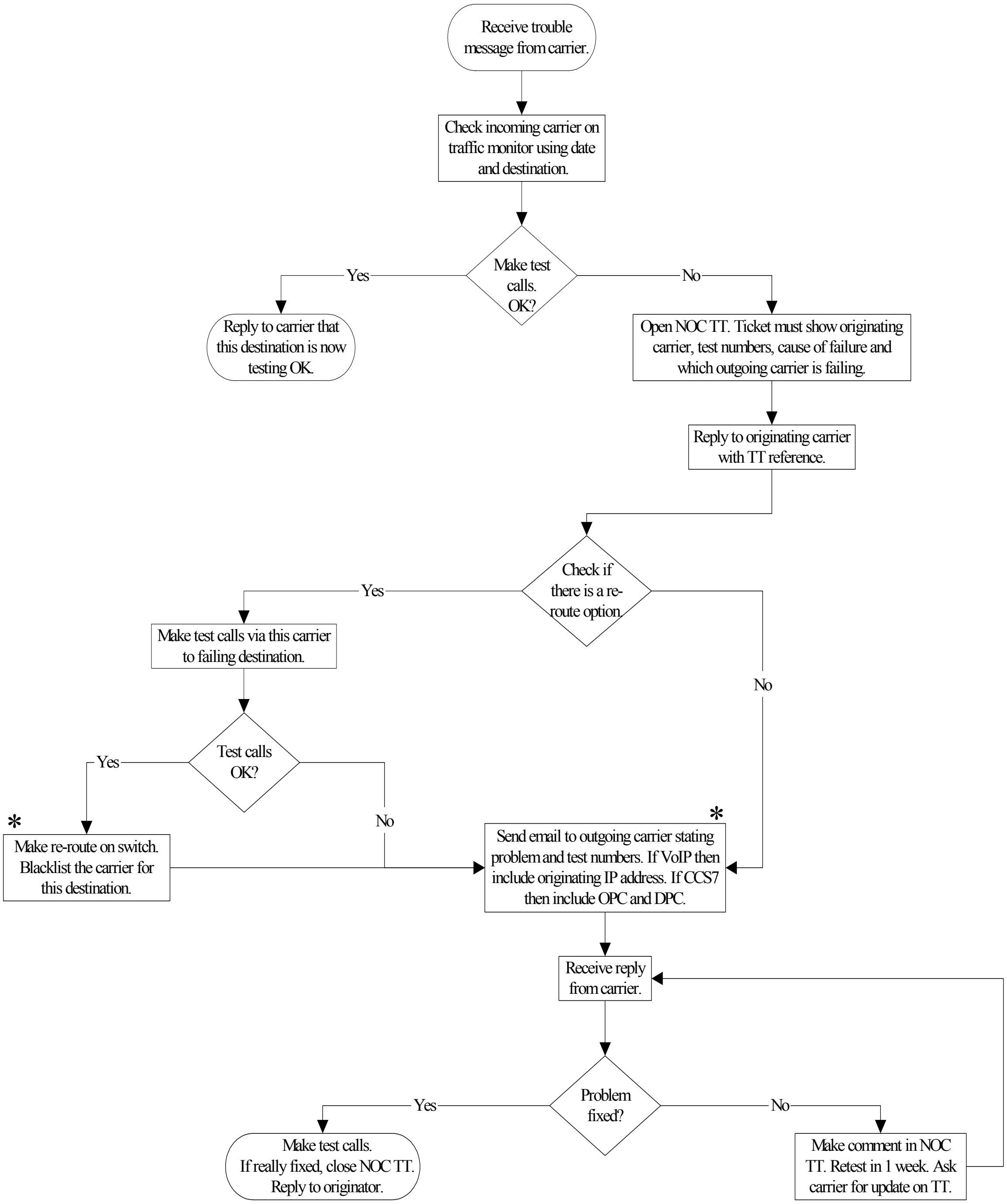


Figure 3.3: Trouble Ticket handling procedure.

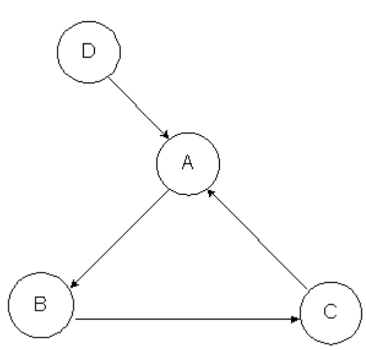
What is a TT used for?

There is always the need to have easy and better communication between carriers in order to maintain a good QoS. For example, let us consider the situation where carrier *A* sends the destination Brazil to Telesonique, which sends to carrier *B*. Suppose there is congestion at carrier *B*'s network where all channels are occupied and these calls are eventually dropped. *A* sees it as if it is Telesonique dropping these calls and therefore makes an inquiry (usually in the form of an E-mail to Telesonique). Telesonique must try to solve this problem. At least two (test) numbers are chosen at random and then called via *B*. If they are still dropped, Telesonique opens a TT for this problem and communicates the TT number as well as the solution status to *A*. The TT number is necessary for future reference to the problem. At the same time, Telesonique informs *B* of the problem stating the time of the problem and the test numbers. If there is another possible route *C*, to Brazil, Telesonique then makes a re-route via *C* and informs *A* of the solution. To better understand how handling trouble tickets works, it is good to take a look at Figure 3.3, which summarizes the process.

In the processes, the terms and abbreviations that have not been explained yet are marked by a (*), e.g., Origination Point Code (OPC) and Destination Point Code (DPC). Just like an IP address (for Internet), a point code is simply an SS7 network address (in the form xxx.xx.xx) that identifies an SS7 network node such as a switch. The remainder of the terminologies is explained under Switching and Routing in Sections 3.2 and 3.3, respectively.

3.1.3 Call Loop Detection

In international voice telecommunication, two carriers do not buy the same destination from each other. Let us say carrier *A* buys the destination, Brazil, from carrier *B* who in turn buys from *A*. In such a case one call goes from *A* to *B* and back to *A*. The call never leaves the system but keeps consuming the circuit. This situation is called *call looping*. In the situation where three or more carriers are involved as shown in Figure 3.4(a), it is very rare to notice whether a loop occurs because carrier *A* buys from *B* who buys from a different carrier, *C*. *C* in turn buys from *A* without knowledge of the destination's previous route. So the call just keeps moving between the three without termination. Within each carrier, the call is considered as an attempt each time it reaches the carrier's switch. This is seen as an unsuccessful call attempt.As an example a CDR extracted from the traffic monitor is shown in Figure 3.4(b). A call reaches Telesonique from the carrier



(a) A call that arrives at carrier A keeps moving round the loop ABC without reaching its destination.

CDRDetails for: TELEFONICA, Prefix: 683, day: 2006-12-08

StartDate	StartTime	Dur[s]	A num	B num	OutpNum	TTON	TrunkIN	TrunkOUT
2006-12-08	02:27:14	0	00	68335576618	68335576618	4	729	514
2006-12-08	02:27:19	0	00	68335576618	68335576618	4	735	514
2006-12-08	02:27:25	0	00	68335576618	68335576618	4	733	514
2006-12-08	02:27:31	0	00	68335576618	68335576618	4	731	514
2006-12-08	02:27:36	0	00	68335576618	68335576618	4	729	514
2006-12-08	02:27:42	0	00	68335576618	68335576618	4	731	514
2006-12-08	02:27:47	0	00	68335576618	68335576618	4	733	514
2006-12-08	02:27:53	0	00	68335576618	68335576618	4	729	514
2006-12-08	02:27:58	0	00	68335576618	68335576618	4	729	514
2006-12-08	02:28:04	0	00	68335576618	68335576618	4	733	514
2006-12-08	02:28:10	0	00	68335576618	68335576618	4	733	514
2006-12-08	02:28:15	0	00	68335576618	68335576618	4	735	514
2006-12-08	02:28:21	0	00	68335576618	68335576618	4	735	514
2006-12-08	02:28:26	0	00	68335576618	68335576618	4	729	514
2006-12-08	02:28:32	0	00	68335576618	68335576618	4	731	514

(b) CDR for the incoming carrier Telefonica for the destination +683 showing how one call to the number +68335576618 loops between Telefonica (TrunkIN), Telesonique and Capital City (TrunkOut).

Figure 3.4: Call looping

Telefonica (trunk codes 729, 735, etc.). Telesonique switches this call to iBasis (trunk code 514). From the *StartTime* field, we notice that this call comes back to the switch after every 5 to 6 secs. This is seen as a loop because the caller stays on the line for 1 minute and 18 seconds with a call duration *Dur(s)* of 0 sec.

Looping is very undesirable. For the caller, it is experienced as a PDD or dead air with false billing. For the carrier, it decreases the ASR and carriers keep billing each other over and over at the expense of the caller. This situation continues until either the caller hangs up or one of the carriers discovers it and makes a re-route or blocks it. Telesonique has a tool that determines suspected loops. This tool is explained in Appendix A. Figure 3.5 graphically illustrates the effect of looping on the ASR as discovered from outgoing traffic from the DMS to the IP gateway via SS7 trunk line channels[8]. Connected channels are channels in which users are actually in speech while used channels are the total number of channels occupied by looped calls and calls in speech.

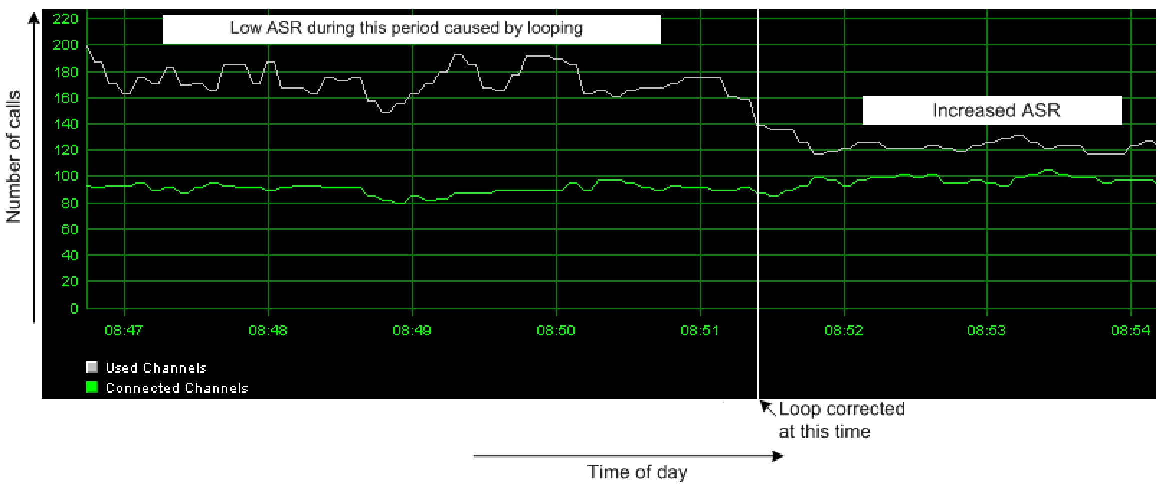


Figure 3.5: Graphical display of the effect of looping on the ASR.

3.2 Switching

3.2.1 Connection Set-up and Teardown

Call establishment and termination involves a series of electronic communications between the switching networks, *A* and *B*, of the caller and the callee, respectively. When the caller begins a call, an *Initial and Final Address Message (IFAM)*[9] is sent from switch *A* to switch *B*. When *B* receives the IFAM, it immediately sends an *Address Complete Message (ACM)* to *A* to indicate that it has received sufficient digits and routes the call to

[8] See Figure 3.8.
[9] IFAM = IAM + FAM. IAM indicates that the circuit in use has been seized for this call while FAM indicates that sufficient digits have been received to initiate routing.

the callee. The callee's phone starts ringing. Immediately the callee picks up the phone, *B* sends an *ANswer Message (ANM)* to *A* which immediately commences billing. Caller and callee go in speech. See Figure 3.6.

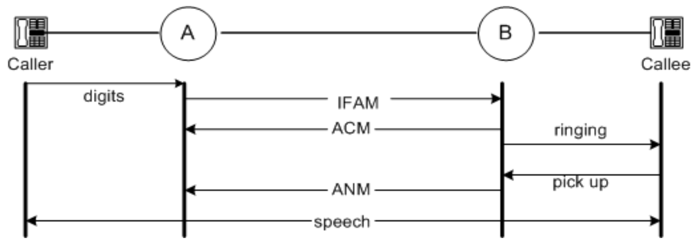
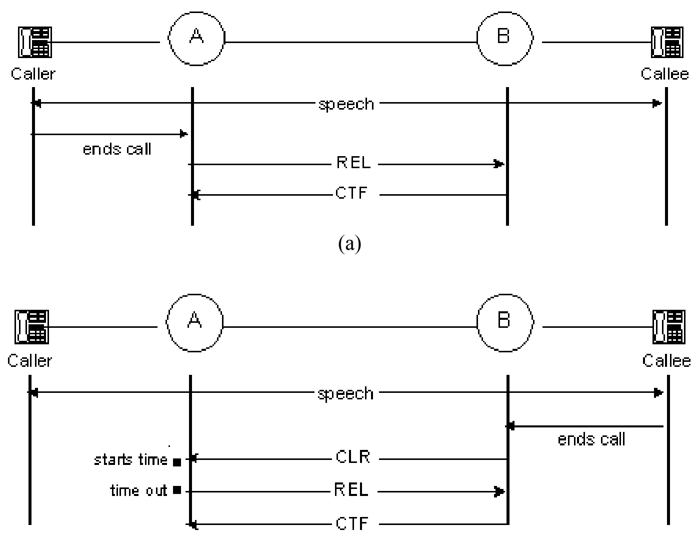


Figure 3.6: Connection set-up

Any of the two parties can terminate the call (Figure 3.7). When the call is ended by the caller, *A* sends a *RELease message (REL)* with reason to *B* which then releases the call and sends a *CircuiT Free message (CTF)*. If it is the callee who terminates the call, the situation looks a bit different. This is because termination signals become triggered at switch *B* rather than at switch *A*. *B* sends a *CLearR message (CLR)* to *A*. Upon receiving this message, *A* starts a timer. When the timer expires, the call ceases from the caller and *A* sends a REL message to *B* which then sends a CTF to indicate that the circuit is now free.



(b)

Figure 3.7: Connection teardown (a) by caller, (b) by callee.

Traffic reaches Telesonique's switching network via trunklines (SS7[10] signaling) or via an IP network (such as VoIP), and leaves the network in the same fashion. It should be noted that incoming SS7 traffic may as well leave as VoIP and vice versa (see Figure 3.8).

[10] SS7 = Signaling System 7. It is also known as CCS7 (Common Channel Signaling 7) or C7 for short.

3.2.2 SS7 Signaling

The switching system used is SS7 where a single circuit is dedicated for both voice and data at a constant bandwidth. This technique offers signaling for multiple circuit connections, error detection and correction, and the capability to launch query and response messages to databases. Connection links are called E1s. An E1 uses *Time Division Multiplexing (TDM)* where multiple analogue voice signals are combined into a single digital trunk. This TDM mechanism works as follows.

The switching system has a codec that digitizes each voice analogue signal by producing 8-bit streams 8,000 times per sec. This is called *Pulse Code Modulation (PCM)*. Each stream represents a time slot of constant bandwidth of 64 Kbps used by 1 voice call. This makes a time slot a voice channel. Consequently, the full duplex trunk bandwidth of 2,048 Mbps is split into 32 time slots or channels (of 8 bits each)[11]. The channels are numbered 0 to 31. Channels 0 and 16 are used for common channel signaling as well as signaling for the set-up and teardown of calls [10, 11]. The remaining 30 channels are used for the actual voice traffic. These channels in the SS7 switching network are basically the resources needed by callers. Each E1 can therefore handle a maximum of 30 simultaneous voice calls.

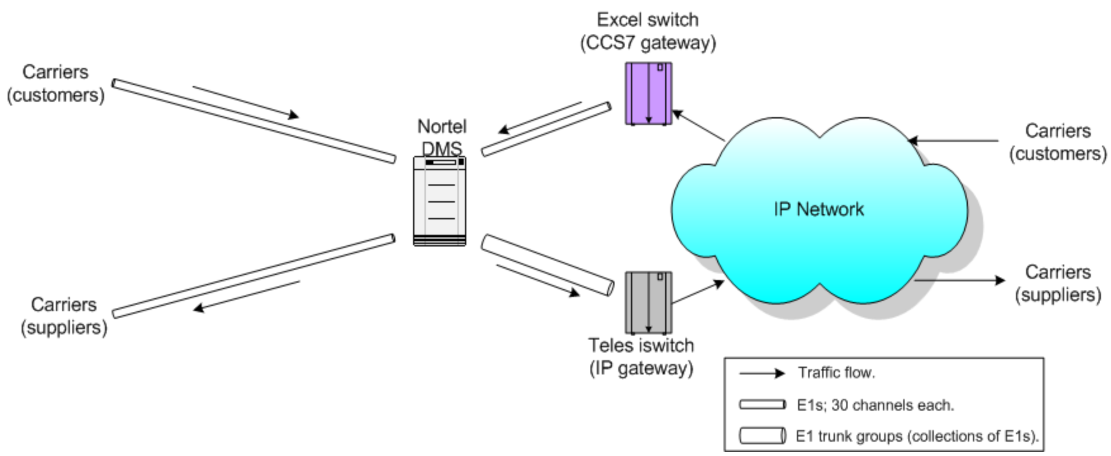


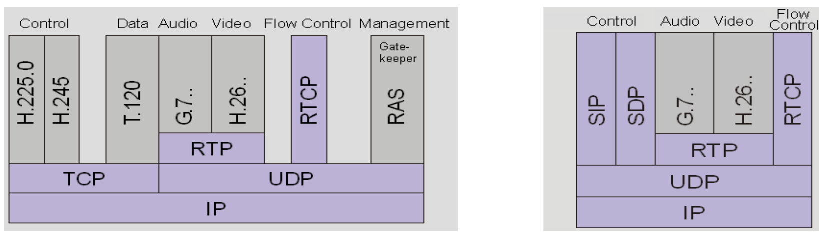
Figure 3.8: Telesonique's switching system.

Traffic that reaches the network as VoIP is converted from IP packets and decoded to 8-bit streams by a gateway called the Excel switch, and is then sent to the DMS via E1s. The DMS aggregates this traffic together with other incoming SS7 traffic and routes part to other carriers via SS7 trunk lines (E1s) and the other part as VoIP. In case all outgoing lines are in use, the DMS drops any incoming traffic. When the decision is to route as VoIP, the DMS sends the traffic via E1 trunk groups to a second gateway called Teles.iSwitch, which codes the 8-bit streams to IP packets, which are then transmitted via an IP network.

[11] 32 X 8 bits X 8,000 per sec = 2,048,000 bps = 2,048 Mbps

3.2.3 Voice over IP

The connection between the switching network and the IP network is through two gateways as was already seen in Figure 3.8. These gateways speak the H.323 protocol and SIP on the Internet side and PSTN protocols on the SS7 side. For the SS7 side, PCM has already been explained under SS7 signaling. For the IP network side, a description of the H.323 and SIP protocol stacks is given in Figure 3.9. More details on these protocols can be found in, e.g., Tanenbaum [11]. Unlike SIP which is a single module used for communication control, H.323 is a complete protocol stack with well-defined telephone industry standards. One of such standards is that all H.323 systems must support G.711, which does PCM. For this reason, H.323 is widely deployed.



(a) H.323 protocol stack (b) SIP protocol stack

TCP	Transmission Control Protocol - transmits signaling and provides network management.
UDP	User Datagram Protocol - attaches source and destination port number fields for (de)multiplexing for audio transmission.
H.225.0	Provides connection setup and teardown.
H.245	Negotiates channel usage and the compression procedure.
T.120	Provides application sharing etc. (not required for VoIP).
RTP	Real-time Transport Protocol – transports real-time data over the Internet
RTCP	Real-time Transport Control Protocol – provides, e.g., information on throughput and packet loss.
RAS	Registration, Admission and Status – defines communication between the gatekeeper and the gateway/terminal.
G.7XX	Standards for voice compression (G.711, G.723, etc.).
H.26X	Standards for video compression (not required for VoIP).
SIP	Session Initiation Protocol – creates, modifies and terminates sessions with one or more participants.
SDP	Session Description Protocol – describes purpose, codec format, timing, transport information, etc., for session to occur.

Figure 3.9: Description of H.323 and SIP protocol stacks

IP voice packets reach the switching network via the Excel switch. These packets arrive in disorder. This variation in delay (travel time of the packets) or *jitter* is eliminated with the help of a jitter buffer (Figure 3.10 (a)), after which the packets are converted to 8-bit streams necessary for SS7 signaling.

On the other hand, when the decision at the DMS of the SS7 network is to route traffic as VoIP, the 8-bit streams are sent to the IP gateway (Teles iSwitch), which converts them to packets (Figure 3.10 (b)). Each packet has a header that contains the IP address of the destination carrier. More details on (de)packetization are given in Tanenbaum [11], and van der Mei [2].

The codec for VoIP is negotiated between carriers. This means the same codec has to be supported by both the originating and destination carrier. G.7XX codecs are used for voice while T.XXX are used for data. Each codec offers a different bandwidth and payload size. Appendix B gives details on these codecs, and their respective bandwidths, payload sizes, etc.

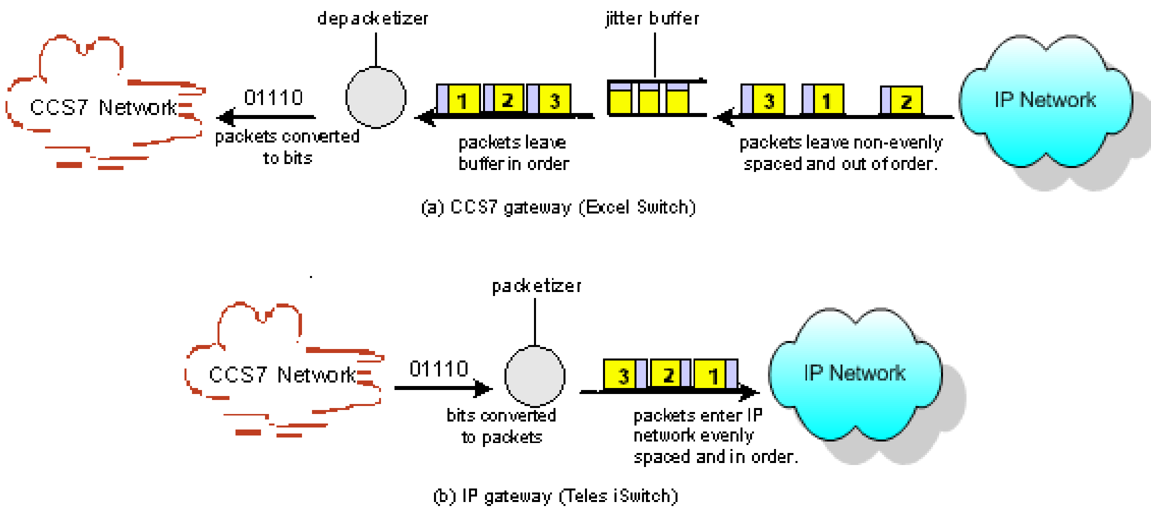


Figure 3.10: Telesonique's gateways.

3.3 Routing

3.3.1 Least Cost Routing

The routing metric used by Telesonique and other carriers is communication costs (in terms of money) giving rise to the name Least Cost Routing (LCR). Each carrier sends to every other carrier it trades with, individual pricelists for all the destinations it switches (terminates) traffic. Connection agreements include price notification details. The industry standard for an increase is a notification period of seven days while a decrease could take effect on the day of notification. This gives rise to the need for making routing changes everyday. Since LCR is cost based, some carriers define peak periods as being a period of high costs and off-peak periods, a period of low costs. These periods differ from carrier to carrier. Telesonique's peak period is the interval 8:00am – 7:00pm and its off-peak period is the interval 7:00pm – 8:00am.

LCR is therefore done twice per day – one for peak periods and the other for off-peak periods. Both follow the same scheme. Each carrier j indicates its price P_j to terminate traffic to destination c. There are over 3500 destinations. For each c let $\{P_j\}$ denote the sequence whose elements are the prices P_j. The following steps are implemented in software:

1 Sort $\{P_j\}$ to obtain $\{P_i\}$, $i = 1, 2, 3, \ldots$, such that $P_1 = \min_j P_j$.

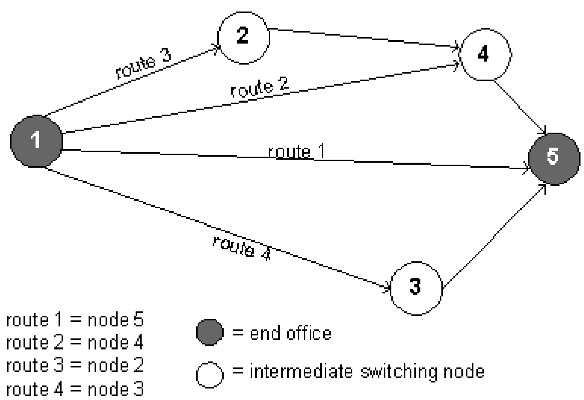
2 Calculate % margin as $g_i = \dfrac{P_i - P_1}{P_1} \times 100\%$.

3 Drop all P_i having $g_i > a$. Usually, $a = 3\%$.

4 In the worst case, only P_1 is left. If more P_i are left, select three more to obtain at least four routing choices.

The routes are: Route 1 = carrier with price P_1,
Route i = carrier with price P_i (if it exists), i = 2, 3, and 4.

The method of *alternate routing* is used. Any incoming traffic for destination *c* is sent to Route 1, which is most often, considered to be the direct route. If there is congestion, the DMS automatically routes it to Route 2. This process continues in this fashion right upto the last available route. If this route is congested, then the DMS drops the call. This is also seen as *overflow routing* and it works only in the case of congestion. The network topology and routing table are shown in Figure 3.11. The DMS has details of only the next hub (hub 1) to the destination and knows nothing about subsequent hubs.



(a) Network topology

	Hub 1 to destination *c*'s end office (node 5)			
Period	**Route 1**	**Route 2**	**Route 3**	**Route 4**
Off-peak	1 → 5	1 → 4	1 → 2	1 → 3
Peak	1 → 2	1 → 5	1 → 3	

(b) Routing table

Figure 3.11: Connection between X and Y: (a) Network topology[12], (b) Routing table.

3.3.2 Carrier Blocking

Blacklisting

Telesonique maintains a *black list* that contains mainly premium service numbers. These are numbers that are terminated at extraordinary high costs and their termination yields a negative profit margin. Blacklisting involves blocking calls with a given routing number format at the switch. When these calls reach the DMS, it immediately drops them. The black list is independent of the carrier.

Blocking carrier for destination

Some carriers send traffic that can effectively be terminated. However, because the LCR is done on daily basis coupled with the fact that the weekly issuing of pricelists does not take place the same day for all carriers connected, some traffic termination present a

[12] Figure is adapted from Krings, A.W. [16].

negative margin, i.e., the traffic is terminated at a loss. For this reason, such an incoming carrier is temporarily blocked for such a destination if the margin is that big. This reason is termed commercial. The carrier is unblocked again only when a new LCR has been done and indicates a positive margin for this destination. Carriers could also be blocked for some destinations for reasons of looping and traffic overload. All carriers blocked for particular destinations are kept in a *carriers' black list.*

As shown in Figure 3.12, when a call arrives at the DMS, the DMS checks if the routing number format of the call is in the black list. If it is found, the call is immediately dropped. If it is not found, the DMS proceeds to the carriers' black list to check if the incoming carrier has been blocked for this destination. If that is not found, then the normal alternate routing procedure takes place.

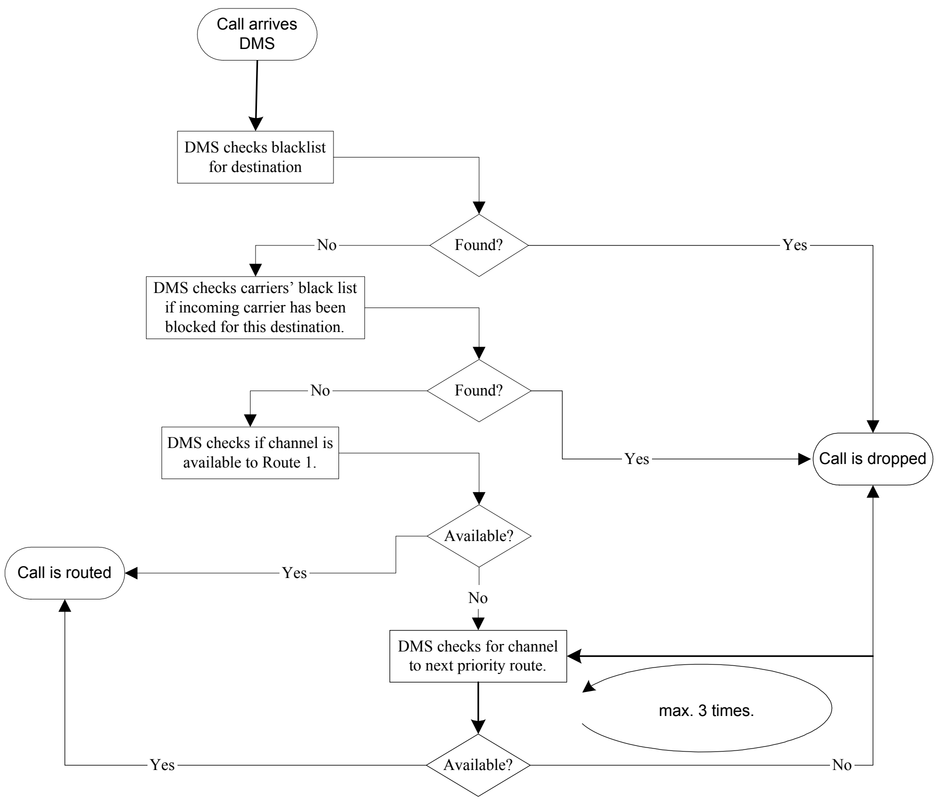


Figure 3.12: DMS switching process.

3.3.3 Route Configuration

In this section we explain how and where a call should be routed when the decision at the DMS is to route the call as VoIP. For the call to use an outgoing route, *routeA*, there are some route elements that need to be configured. We explain this using some functions: `dno()`, `share()`, and `route()`, which are implemented in Unix.

We set up the entry end of the E1 (or DNO), which the call has to use from the DMS to the IP gateway by using the following function

```
dno(from_routeA_DMS) {
  dno = "r/1,2,4,5/";
}
```

The call uses either trunk 1, 2, 4, or 5. This is for H.323. For SIP signaling, we proceed each trunk by an “S” e.g., `dno = "r/S1,S2,S4,S5/"`.

Next, we give a function that sets up the exit end of the DNO. As this is outgoing VoIP, we include the IP address (xx.xxx.xxx.xx) of *routeA*. We also add a prefix to the outgoing number, if needed[13].

```
share(to_routeA) {
  subst() {
        dno = "r/97-112,120-128/";
        dad = "s/ii/ii00/";
        vad = "exx.xxx.xxx.xx";
        dads = "eout_xx.xxx.xxx.xx";
        caps = "g729a";
  }
}
```

`dad` adds the prefix 00 to the outgoing number. Other prefixes could be used depending on the desire of the carrier customer.
`vad` assigns the IP address of *routeA*.
`caps` defines the compression codec used, e.g., g729a, t38, g729r8, etc.

We then match up the entry and the exit ends.

```
route(from_DMS_to_routeA){
  match() {
        paras(cdr_all);
        dno(from_routeA_DMS);
        dad = "^ii.*";
  }
  share(to_routeA);
}
```

Finally, we apply the routing to the IP gateway.

```
route(from_DMS_to_routeA);
```

[13] The reason is given under Re-file in Subsection 2.3.1.

Chapter 4

PERFORMANCE ANALYSIS

4.1 Metric for Routing

4.1.1 Understanding Grade of Service

In teletraffic engineering, the quality of voice service is determined by two parameters, which are the *Quality of Service (QoS)* and the *Grade of Service (GoS)*. The QoS is related to the design of a single circuit and is attributed to voice grade, which is influenced by factors such as equalization of the amplitude over a specific range of frequencies, the VoIP codec scheme, the packet loss in an already accepted call, etc. To this end, a premium service (like retail) would require a better connection quality as opposed to a standard service (like wholesale). Since switched traffic is predominantly VoIP, QoS at the moment mainly depends on the codec scheme used, which renders just best effort quality. Within each class of service, routing decisions have to be made. Although on the one hand these decisions are based on costs, on the other hand they are also based on the number of successful calls and not on the QoS of a successful call. This brings us to the quality criterion necessary for making routing decisions, which is GoS.

In a loss system where the capacity of each carrier's switch is known, GoS is the fraction of lost calls in the system. This can be determined for individual switches in the whole network [21]. It is calculated as

$$GoS = \frac{\left(\rho^n / n!\right)}{\sum_{k=0}^{n} \left(\rho^k / k!\right)}, \qquad (4.1)$$

where n is the number of channels for the switch, k is the number of occupied channels, and ρ is the capacity utilization or load on the switch. Equation 4.1 represents nothing but the Erlang loss model or *M/G/n/n* queue[14]. A single entity in a carrier network, however, does not have adequate knowledge of all other carriers' individual capacities. In this situation, the GoS is defined as

$$GoS = \frac{number\_of\_failed\_calls}{number\_of\_call\_attempts}, \tag{4.2}$$

which is the probability that a switched call is unsuccessful.

4.1.2 From Cost to Cost-Quality

The task of each carrier is that of effectively managing capacity at the level of its switch, as well as routing outgoing traffic to carriers such that call failures are minimized. Models that are used in managing capacity at the level of the switch have already been designed. The standard Erlang loss model is one-dimensional as it assumes a single type of arrivals. As an extension of this model, each incoming destination is assumed to have its own interarrival time and average call duration and the system is thus modeled as a multi-dimensional Erlang loss model where each destination is simply a single type of traffic. This brings us to the problem of capacity management with multiple types of arrivals, which has long been studied. See for example [26, 27]. Even the problem of capacity management in the situation where fax (data) traffic shares E1 capacity with voice traffic has been modeled as multiple bit rate traffic and solved by the Kaufman-Roberts recursion. See for example [22, 23, 25]. These two models are standard solutions used to manage E1 trunk capacity between the SS7 gateway and the DMS and between the DMS and the IP gateway shown in Figure 3.8.

What needs to be improved?

Since the goal of this project is to design a new innovative solution that should competently solve the problem defined in Section 1.2, we divert our interest to routing with the intention of minimizing call failures. The problem to consider here is that the universally adopted LCR focuses only on costs but not quality. This means that traffic is always sent to the cheapest route since it has the highest routing priority. This has a major setback in the sense that for some destinations (where there is more than one routing choice), a low priority route may offer a better performance than a high priority one. However, because the LCR implementation is static with respect to costs, the failing high priority route keeps running with very poor performance. This leads us to the task of designing a model that should not consider only costs as the criterion for routing but both costs and quality. *How therefore do we make optimal routing decisions to fairly balance costs and quality?*

[14] It is assumed that Queueing Theory is not new to carrier companies. Hence, the meaning of parameters like inter arrival times, etc., will not be elaborated on.

To answer this question, we first need to consider the metric that is universally used by carriers to measure route quality. This is the ASR defined in Equation 3.1, which is the probability that a switched call is successful[15]. Considering Equations 3.1 and 4.2, we notice that

$$ASR = 1 - GoS\,. \tag{4.3}$$

Since $ASR \geq 0$, and $GoS \geq 0$, Equation 4.3 clearly indicates that minimizing the GoS is directly interpreted as maximizing the ASR. We therefore need to design a model that maximizes the ASR as well as minimizes costs.

4.2 Routing Decision Analysis

4.2.1 Peer-to-Peer Model Description

In recent years, researchers have been working on the economics of peer-to-peer (P2P) communication systems. See for example Bhulai et al. [8] on Content Delivery Networks. The similarity of our communication network to theirs makes us use a P2P approach. Carriers are suppliers (servers) and customers (clients) to one another, i.e., there are no centralized nodes in the network. Thus, our routing problem can be redefined as an optimization problem in a P2P communication system where the objective of each node is to route traffic to an immediate node in such a way that it receives maximum quality as well as maximum net profit. We use *Mixed Integer Programming (MIP)* to solve the model.

The nodes form a mesh network topology in which pricing is both destination and node dependent. The information node *i* knows about node *j* are the destinations the latter can terminate, and the price and quality it offers per destination. For terminating traffic to a particular destination, a node charges every other node a different amount. Node *i* pays node *j* a per-minute amount for each destination that it sends to node *j* and continuously monitors the quality. If the quality drops beyond a certain level, it stops sending this destination to *j* and uses the next available route with a better price-quality option. It informs *j* of the situation. The connection for this destination is established again with *j* only when *j* starts offering the previous quality.

Let us consider Figure 4.1 where

$C = \{1,2,..., w\}$ is the set of all destinations to be switched,
$I_c = \{1,2,..., r_c\}$ is the set of all client nodes for destination $c \in C$, and
$J_c = \{1,2,..., s_c\}$ is the set of all supplier nodes for destination $c \in C$,

[15] A call is considered successful when end-to-end users go in speech.

with $w = |C|$, $r_c = |I_c|$, and $s_c = |J_c|$. Suppose node j charges node i a per-minute[16] price $p_{ij}^c > 0$ for switching a request to destination $c \in C$, and offers an ASR q_{ij}^c, where $0 \le q_{ij}^c \le 1$. If node i receives a request from node k and switches the request to node j, then the fractional profit margin obtained by node i is given by

$$m_{kij}^c = \frac{p_{ki}^c - p_{ij}^c}{p_{ij}^c}. \tag{4.4}$$

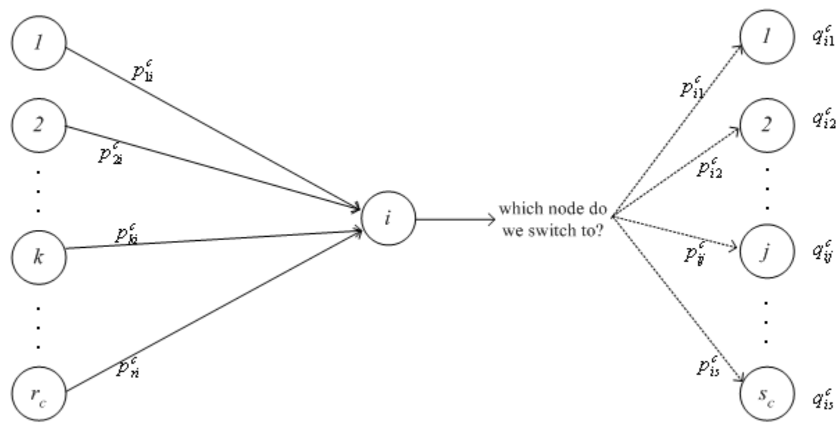


Figure 4.1: Switching of destination c by node i; cost-quality consideration.

Since node i aggregates traffic from all customers and decides on which outgoing route to use, the utility enjoyed by node i in switching destination c to node j is therefore given by

$$U_{ij}^c = q_{ij}^c + \sum_{k \in I_c} m_{kij}^c. \tag{4.5}$$

4.2.2 MIP Formulation

It is clear that if node i is a direct route to destination $c \in C$, then the call is immediately terminated to the end-user. On the other hand, if node i is not a direct route, then the decision has to be made on which outgoing node, j, to switch to. We therefore introduce a binary variable defined as

$$x_{ij}^c = \begin{cases} 1, & \text{if node i switches destination c directly to node j,} \\ 0, & \text{otherwise.} \end{cases}$$

[16] This is used for the problem in question. Generally speaking, we should talk of unit price rather than per-minute price.

Prices have an upper limit, which implies $\forall c \in C, \forall j \in J_c, \forall k \in I_c, \forall i \in I_c \cap J_c$, the fractional profit margin $m_{kij}^c \leq \beta$, $\beta \in IR_+$. Also, we consider that some customers are aggressive for certain destinations in that they force supplier nodes to sell to them at a loss, i.e., $m_{kij}^c < 0$. To this end, node i fixes a lower bound $\alpha \in IR$ i.e., $m_{kij}^c \geq \alpha$, where $\alpha < \beta$. On the overall, the supplier has to at least make some profit for this destination, i.e., $\sum_{k \in I_c} m_{kij}^c \geq M$, $M \in IR_+$. We also consider that for each destination, node i can switch traffic only to at most N other nodes.

Combinatorial formulation

The objective is to maximize the utility. The optimal solution for node i is obtained by solving the following optimization model

$$Max\left\{\sum_{c \in C} \sum_{j \in J_c} x_{ij}^c \left(q_{ij}^c + \sum_{k \in I_c} m_{kij}^c \right)\right\}$$

subject to

$$\begin{aligned}
&\sum_{j \in J_c} x_{ij}^c \leq N, && \forall c \in C, \forall i \in I_c \cap J_c, \\
&0 \leq q_{ij}^c \leq 1, && \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c, \\
&\alpha \leq m_{kij}^c \leq \beta, && \forall c \in C, \forall j \in J_c, \forall k \in I_c, \forall i \in I_c \cap J_c, \\
&\sum_{k \in I_c} m_{kij}^c \geq M, && \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c, \\
&x_{ij}^c \in \{0,1\} && \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c.
\end{aligned}$$

The decision variables are $x_{ij} \in \{0,1\}^w$, the routing strategy. This optimization model is non-linear because of the last constraint and is difficult to solve efficiently [7]. Considering the fact that w is of the order 10^3, this model cannot be practically used for computation. A linear model would do much better.

Linear formulation

To develop a linear model, we use the idea of *LP-relaxation* on the last constraint, i.e., we relax the constraint $x_{ij}^c \in \{0,1\}$ to $0 \leq x_{ij}^c \leq 1$, $\forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c$. The reason for doing this is that if an optimal solution exists (for the linear model), then at the point where it exists, $x_{ij}^c \in \{0,1\}$. The LP formulation is as follows

$$Max\left\{\sum_{c \in C} \sum_{j \in J_c} x_{ij}^c \left(q_{ij}^c + \sum_{k \in I_c} m_{kij}^c \right)\right\} \tag{4.6}$$

subject to

$$\sum_{j \in J_c} x_{ij}^c \le N, \qquad \forall c \in C, \forall i \in I_c \cap J_c, \tag{4.7}$$

$$q_{ij}^c \le 1, \qquad \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c, \tag{4.8}$$

$$q_{ij}^c \ge 0, \qquad \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c, \tag{4.9}$$

$$m_{kij}^c \le \beta, \qquad \forall c \in C, \forall j \in J_c, \forall k \in I_c, \forall i \in I_c \cap J_c, \tag{4.10}$$

$$m_{kij}^c \ge \alpha, \qquad \forall c \in C, \forall j \in J_c, \forall k \in I_c, \forall i \in I_c \cap J_c, \tag{4.11}$$

$$\sum_{k \in I_c} m_{kij}^c \ge M, \qquad \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c, \tag{4.12}$$

$$x_{ij}^c \le 1, \qquad \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c, \tag{4.13}$$

$$x_{ij}^c \ge 0, \qquad \forall c \in C, \forall j \in J_c, \forall i \in I_c \cap J_c. \tag{4.14}$$

The constraint in (4.7) indicates that node *i* can switch traffic for a given destination to at most *N* other nodes; (4.8) and (4.9) represent the constraint on the route quality (i.e., the ASR); (4.10) and (4.11) represent the constraint on the fractional profit margin; (4.12) represents the fact that node *i* must at least make some profit for each destination that is switched; (4.13) and (4.14) are relaxations on the binary variable.

4.3 Solving the Decision Model

4.3.1 Quality at the Busy Hour

We use the concept of *Busy Hour Call Attempts (BHCA)*, which is the number of telephone calls attempted at the busiest hour of the day. We split each day into 15-minute periods resulting in a total of 96 periods. The busy hour is the four consecutive periods whose total call attempts is the maximum for that day. The reason for doing this is that the throughput of a node is highest at the busy hour. It is assumed that the number of channels for the switch as well as the expected call duration for each destination stays unchanged. We therefore determined, for each node, the ASR obtained during the busy hour for each destination.

We discovered that most nodes establish prices on weekly basis and since this has an influence on the routing, we had to consider the average ASR for a complete month rather than for individual days of the month. Normally, we should consider the ASR during the busy hour of individual days of a complete year and then take the average of the top 30 days of the year [24]. However, due to data limitations, we decided to take the average of the busy hour for a complete month.

Let us consider a month where for destination *c*, node *j* offers a quality $(q_{ij}^c)_d$ to node *i* during the busy hour of day *d*. Actually, not all nodes had traffic record for all days of the month in question. So for each node, we determined the maximum number of days $d_{\max}$ that we had traffic recorded and then calculated the offered quality using the following formula

$$q_{ij}^c = \frac{1}{d_{\max}} \sum_{d=1}^{d_{\max}} (q_{ij}^c)_d \,, \qquad (4.15)$$

where $1 \le d_{\max} \le 31$.

4.3.2 Input Data

At the time when we ran the model, the network consisted of 22 peers. We indexed them as shown in Figure 4.2. We took node *i* to be peer 22, the decision making node. We used

Peer	Byiltel	Capital City	Coast Media	Ecotel	iBasis	IDT	KPN	Latinode	Lexico	Protel	Starlink	Swisscom	TDC	Tele2	Telekom Austria	Telefonica	TeliaSonera	T-Systems	TVI	Verizon	Wind	Telesonique
Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

Figure 4.2: Peers and their corresponding indices.

Matlab to solve the model and had our input data in the form of two matrices: *A* for suppliers, and *B* for customers where

$$A = \begin{pmatrix} 1 & 2 & 0.1570 & 1.00 \\ 1 & 3 & 0.1560 & 0.64 \\ 1 & 5 & 0.1575 & 0.00 \\ 1 & 17 & 0.1530 & 0.06 \\ 2 & 5 & 0.1523 & 0.41 \\ 2 & 6 & 0.1503 & 0.06 \\ 3 & 5 & 0.1523 & 0.00 \\ . & . & . & . \\ . & . & . & . \\ c & j & p_{22,j}^c & q_{22,j}^c \\ . & . & . & . \\ . & . & . & . \\ w & . & . & . \end{pmatrix}, \quad and \quad B = \begin{pmatrix} 1 & 14 & 0.1611 \\ 1 & 19 & 0.1608 \\ 1 & 21 & 0.1598 \\ 2 & 7 & 0.1580 \\ 2 & 19 & 0.1580 \\ . & . & . \\ . & . & . \\ c & k & p_{k,22}^c \\ . & . & . \\ . & . & . \\ w & . & . \end{pmatrix}.$$

Column 1 of matrix *A* represents the destination; column 2, the supplier peer; column 3, the quality offered; and column 4, the price charged in €/min. We notice that there are 4 suppliers for destination 1 (i.e., $s_1 = 4$), 2 suppliers for destination 2 (i.e., $s_2 = 2$), etc. Thus, *A* is a $\sum_{c=1}^{w} s_c$ X 4 matrix. So, row 2, for example, should be read as follows: for destination 1, peer 3 (Coast Media) charges €0.1560/min and offers an ASR of 0.64 (i.e., 64%). Similarly, *B* is a $\sum_{c=1}^{w} r_c$ X 3 matrix where column 1 represents the destinations; column 2, the customer peers; and column 3, the prices paid. Thus, row 5, for example, should be read as follows: for destination 2, peer 19 (TVI) pays €0.1580/min.

4.3.3 Parameter Setting

We ran the model for different values of α, β, *M*, and *N*. The results are explained in the next chapter.

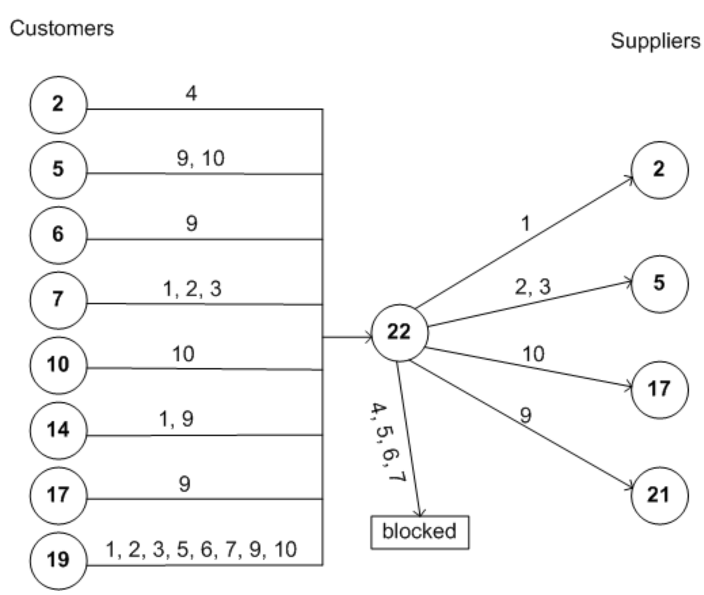
Chapter 5

RESULTS

One would normally expect that routes that sell so cheap or provide very high quality would be prioritized. However, when we ran the LP model, we noticed that this is not always the case. Our routing options are based on the settings of the parameters *α, β, M*, and *N*; and on the constraints in the LP model. For example, one would expect each destination to have at least one route. However, because some of the constraints are violated, some destinations are preferably blocked. While varying *α, β, M*, and *N*, we discovered that the degree of blocking changes as well as the routing decisions.

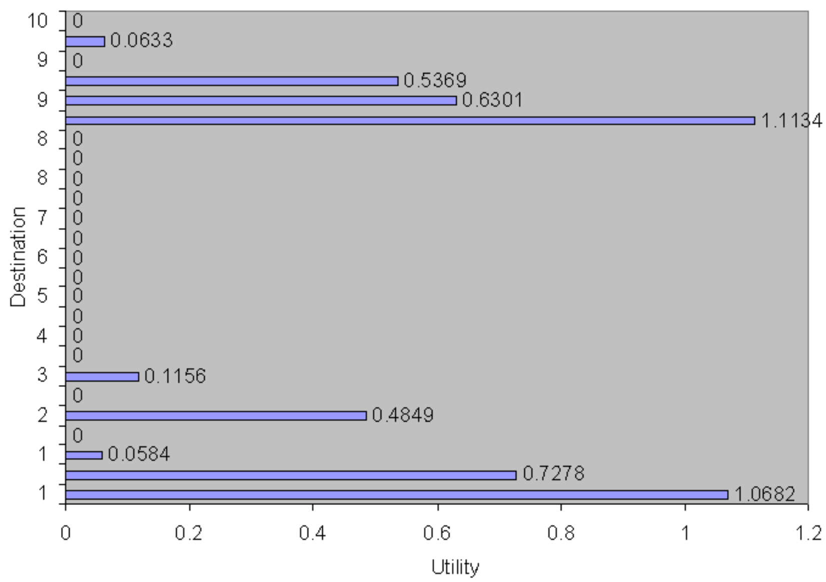
We now show some results for the first 10 destinations and for $N = 4$.

I: (α, β, M) = (-0.01, 0.05, 0.05)



In this network diagram we clearly see the customers and suppliers for the first ten destinations. Only the first route choices (suppliers) to destinations are shown. The links represent the switched destinations. For example node 5 buys destinations 9 and 10, which are switched by node 22 (the decision making node) to node 21 and node 17, respectively. Destination 8 has not been bought and as a result, no route has been chosen for it. This meets with our expectation. We notice that with the given values of the parameters α, β, M, and N, some destinations (4, 5, 6, and 7) are preferably blocked.

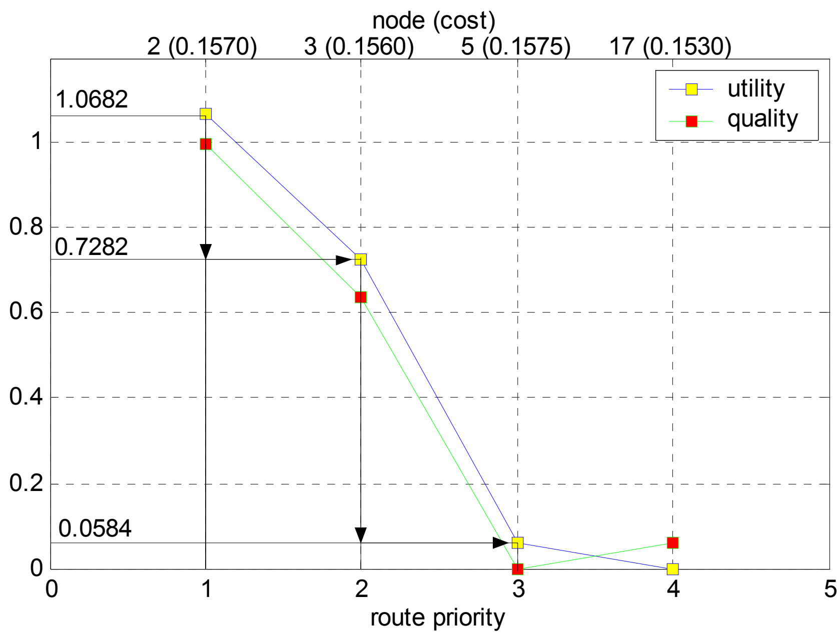
Next, we express the results in terms of utility for each destination. Bear in mind that the utility is a function of quality and net profit as expressed in Equation 4.5. Let us consider for example destination 1 where node 2 offers the greatest utility of 1.0682 and is thus the first routing choice for this destination. Consequently, the second choice is node 3, the third choice is node 5, and the last choice is node 17. We also notice that there are no routes to destinations 4 up to 8. As for destination 8, we did not expect any route for the reason that this destination has not been bought i.e. the utility offered by all routes is 0.



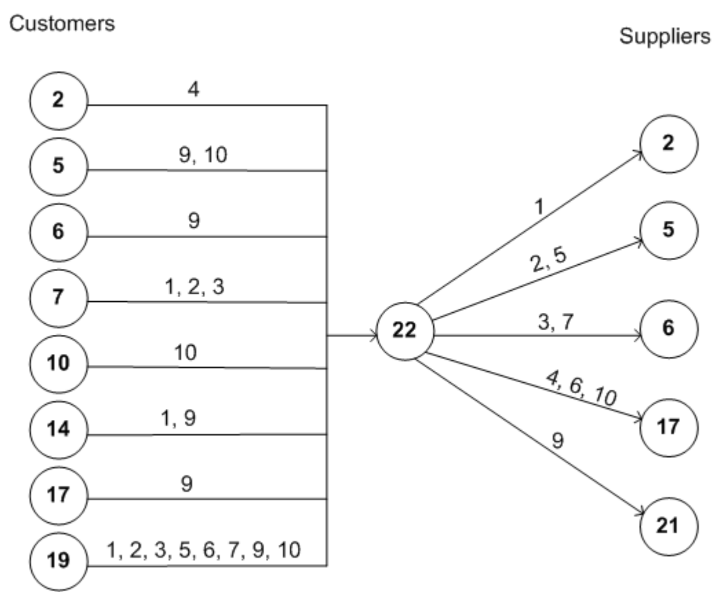
Destination	Route	Utility
1	2	1.0682
1	3	0.7278
1	5	0.0584
1	17	0
2	5	0.4849
2	6	0
3	5	0.1156
3	6	0
4	17	0
5	5	0
5	7	0
5	15	0
6	7	0
6	17	0
7	6	0
7	17	0
8	5	0
8	7	0
8	17	0
9	21	1.1134
9	18	0.6301
9	17	0.5369
9	6	0
10	17	0.0633
10	18	0

Routing Table

Taking a look back at destination 1, the routing management strategy is graphically explained in the following plot. This destination should be sent to node 2 for a cost of €0.1570/min where a utility of 1.0682 is obtained. If the utility drops to a threshold of 0.7282, we should stop sending this destination to node 2, but re-route the traffic to node 3 where it costs €0.1560/min. The connection should be re-established with node 2 for this destination only when it reassures a utility greater than 0.7278. This means that node 2 should either offer a decrease in price, or an increase in quality, or both. A similar procedure should be followed for nodes 3 and 5 if the utility drops to 0.0584. We notice a strange behavior between route 3 (i.e., node 5) and route 4 (i.e., node 17). Although node 17 is cheaper and offers a better quality than the more expensive node 5, node 5 is still prioritized over node 17. This is because, according to the chosen value of the parameter β, constraint 4.10 of the LP model is violated by node 17, hence its offered utility is 0. Thus, with the given values of parameters α, β, M, and N, this destination has just three routing choices, which in terms of decreasing priority are nodes 2, 3 and 5.

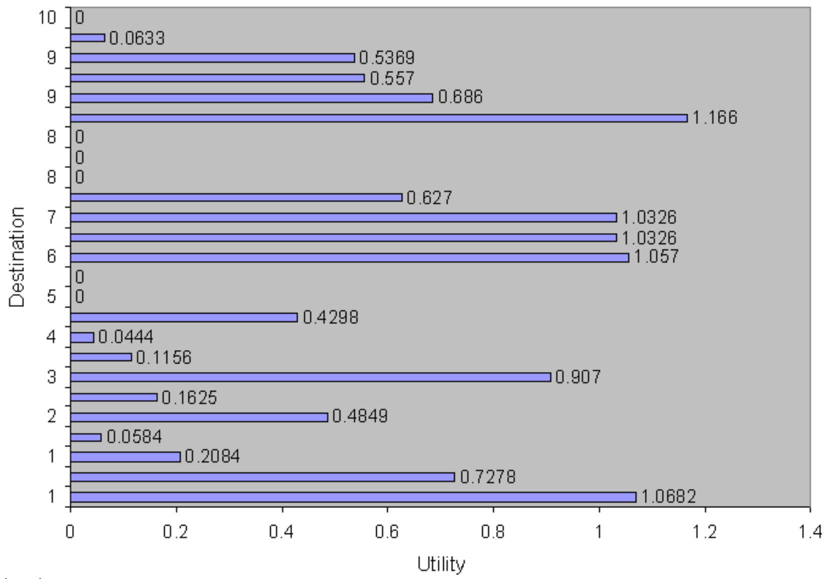


II: (α, β, M) = (0.00, 0.06, 0.03)



With these settings for α, β, M, and N, we notice in this network diagram that for the first 10 destinations, all sold destinations (by node 22) can effectively be switched to the appropriate routes.

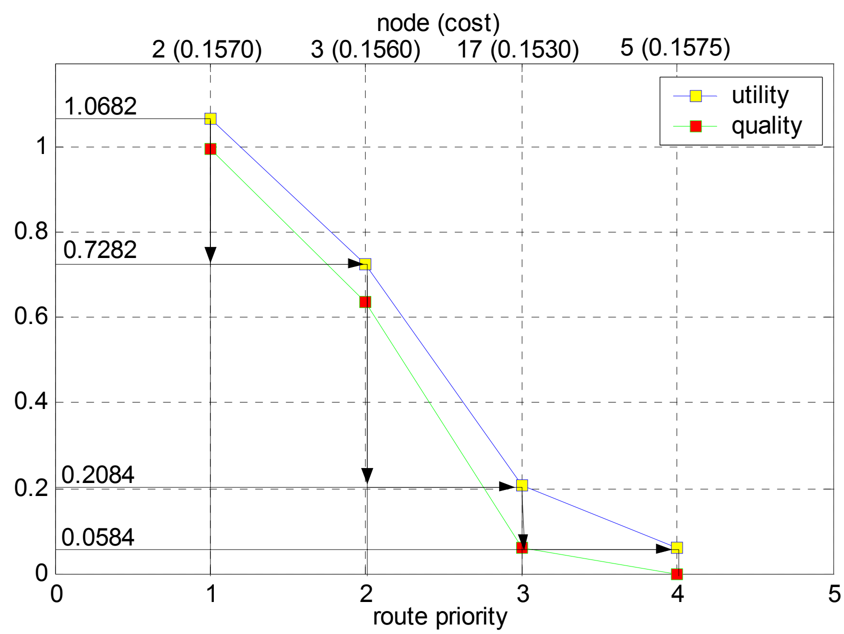
In the following utility diagram, looking at destination 1 as example, we notice that there are four routes. The utility offered by node 17 has also increased from 0 (in case I) to 0.2064 (in the present case) as shown in the routing tables.



Destination	Route	Utility
1	2	1.0682
1	3	0.7278
1	17	0.2084
1	5	0.0584
2	5	0.4849
2	6	0.1625
3	6	0.907
3	5	0.1156
4	17	0.0444
5	5	0.4298
5	7	0
5	15	0
6	17	1.057
6	7	1.0326
7	6	1.0326
7	17	0.627
8	5	0
8	7	0
8	17	0
9	21	1.166
9	18	0.686
9	6	0.557
9	17	0.5369
10	17	0.0633
10	18	0

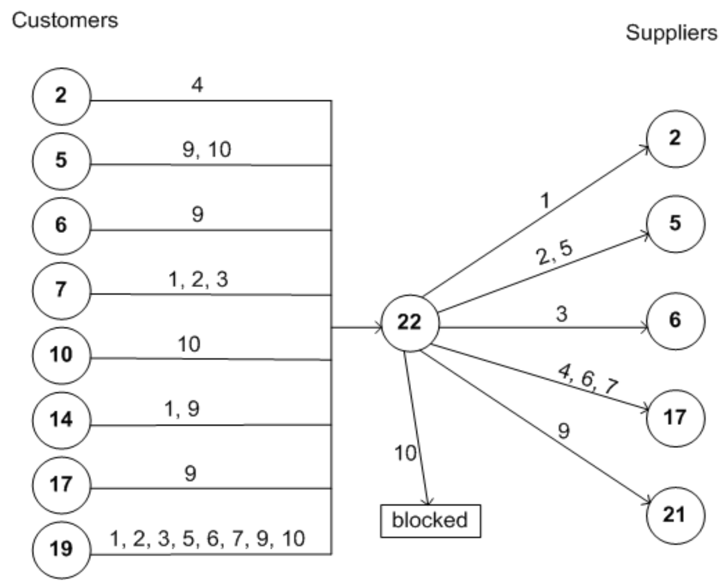
Routing Table

In the following plot where we consider destination 1, we notice that there are now four routing options. In terms of decreasing priority, these routes are nodes 2, 3, 17, and 5. So, with the given values of α, β, M, and N, node 17 has replaced node 5 as the third route choice.

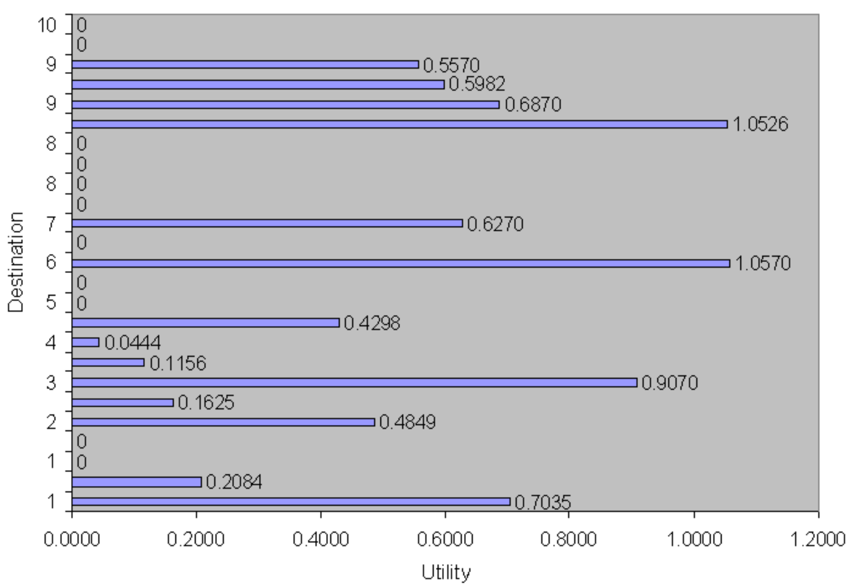


III: $(\alpha, \beta, M) = (0.03, 0.07, 0.04)$

With these settings, for α, β, M, and N, we notice in the following network diagram that destination 10 has been preferably blocked for all customers.



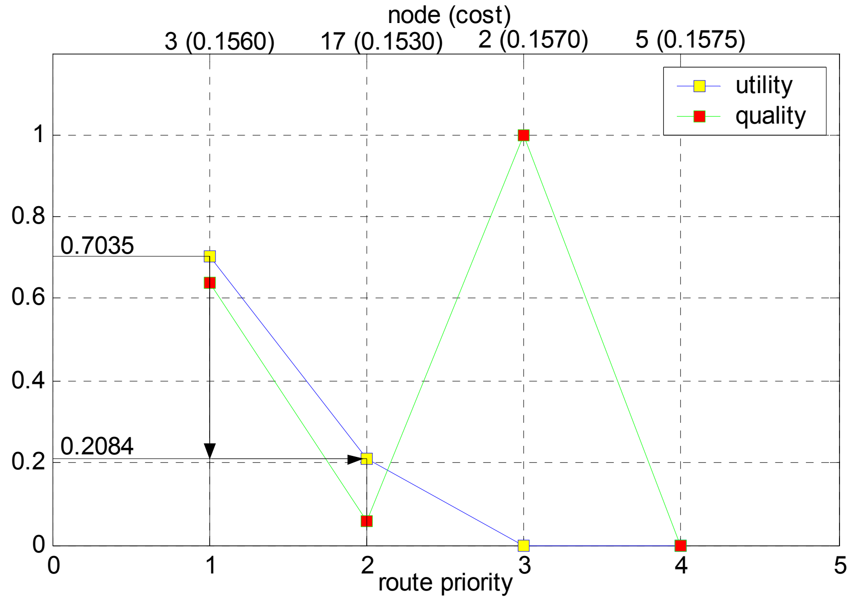
In the following utility diagram for all routes, we can see (for destination 1) that there are only two route choices. In terms of decreasing priority, these routes are node 3 and node 17. Node 3 has replaced node 3 as the first choice.



Destination	Route	Utility
1	3	0.7035
1	17	0.2084
1	2	0
1	5	0
2	5	0.4849
2	6	0.1625
3	6	0.9070
3	5	0.1156
4	17	0.0444
5	5	0.4298
5	7	0
5	15	0
6	17	1.0570
6	7	0
7	17	0.6270
7	6	0
8	5	0
8	7	0
8	17	0
9	21	1.0526
9	18	0.6870
9	17	0.5982
9	6	0.5570
10	17	0
10	18	0

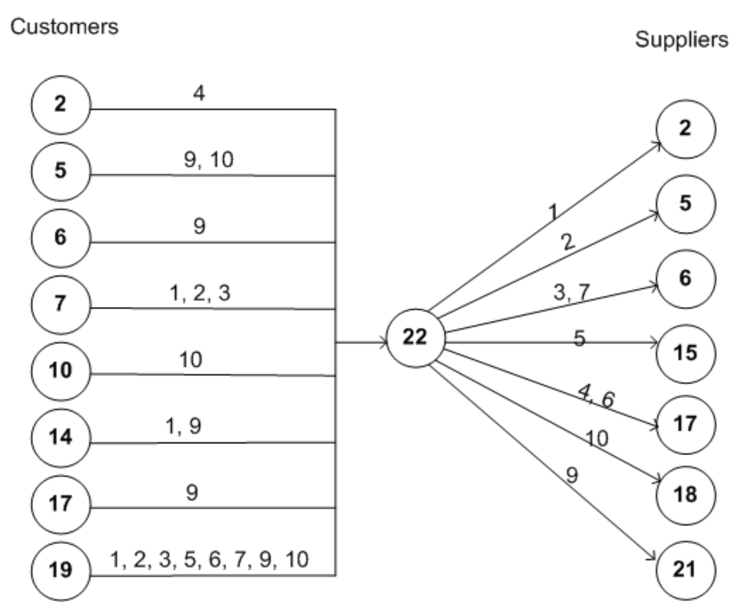
Routing Table

In the next plot, we explain the route management strategy for destination 1. Despite the supposedly very high quality offered by node 2, it is considered to be a very expensive route as a result of the parameter setting, which means the utility offered is 0. Thus, it is not included in the routing choices.

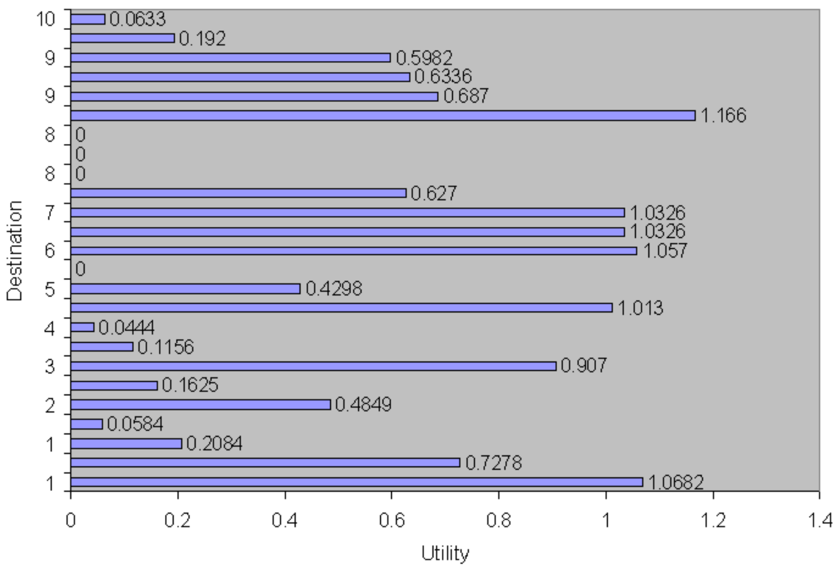


IV: **(α, β, M) = (-0.1, 0.1, 0.01)**

With these settings, we can see that the bought destinations can all be switched - nothing has been blocked.



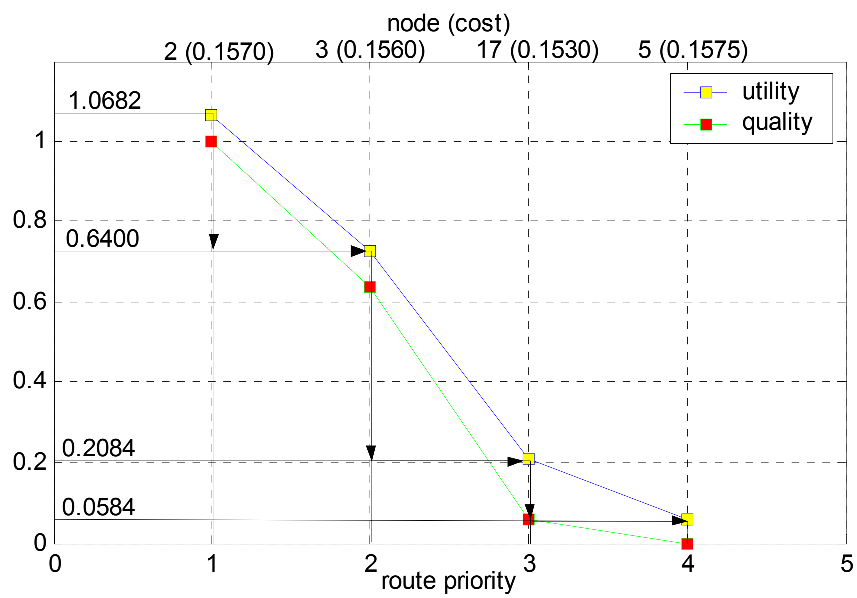
Next, in the following utility diagram and routing table, looking at destination 1 as example, we notice that the route choices in terms of decreasing priority are nodes 2, 3, 27, and 5.



Destination	Route	Utility
1	2	1.0682
1	3	0.7278
1	17	0.2084
1	5	0.0584
2	5	0.4849
2	6	0.1625
3	6	0.907
3	5	0.1156
4	17	0.0444
5	15	1.013
5	5	0.4298
5	7	0
6	17	1.057
6	7	1.0326
7	6	1.0326
7	17	0.627
8	5	0
8	7	0
8	17	0
9	21	1.166
9	18	0.687
9	6	0.6336
9	17	0.5982
10	18	0.192
10	17	0.0633

Routing Table

The routing here, for destination 1, is similar to that in case II except for the fact that the utility offered by route 2 (i.e., node 3) has decreased from 0.7282 (in II) to 0.6400 (in IV).



Chapter 6

CONCLUSIONS

6.1 Discussion

In this project, we have studied the activities that are needed for a call to be successfully routed from one end-user to the other. These activities have been considered as switching, routing, and pricing. In the carrier business, we have seen that switching and routing are overlapped. Details like the routing number formats (i.e., destination prefixes) are used by the switching equipment to effectively send a call to an outgoing route. The choice of a route for a given destination is determined by the cost price. This has led to the universally adopted LCR, which most often does not satisfy customer needs as high priority routes could render very poor call quality. This brought us to the need for including quality (in addition to cost) as another criterion for routing.

The study of quality means the consideration of the media in which voice is transported, i.e., SS7 and VoIP, and the protocols involved in each. In this study, we have discovered that routing between carriers has gradually been drifting from SS7 trunk lines to VoIP. In fact, at the moment, almost 98% of switched traffic is VoIP. SS7 trunk lines between carriers are being disconnected in succession. They are now used mainly for inter-machine connections within a carrier's switching network. So, our quality study has been based mainly on VoIP problems between carriers and channel availability within a route's switching network. VoIP quality is mainly determined by the codec scheme used in which the two carriers have to agree upon, which yields best effort quality.

We then used the universally adopted ASR to be the metric for a route's quality and then found an optimal match in cost and quality for a given destination. The ASR has been considered for the busy hour when a carrier's throughput is highest. In our analysis, we have used a metric that we call the utility, which is a function of cost and quality. Route priority is then given by the utility. The greater the utility, the higher the priority and vice versa. During modeling, we introduced some parameters; α, β, M, and N and ran the model for different values of these parameters, of which some of the results have been shown in Chapter 5. After having run the model, we discovered that the number of routing choices is determined by the parameters α, β, and N. We also found that the value of M influences the utility. The greater M is, the greater the utility and vice versa (see Equation 4.5 and Constraint 4.12).

6.2 Future Research

Although there are two measures of route quality, i.e., the ASR and the ACD, the latter has not been considered in our utility function. Carriers seldom consider the ACD in defining SLAs. Their focus is only the ASR. The incorporation of the ACD together with the ASR as our quality measures in the utility function should be our next point of focus.

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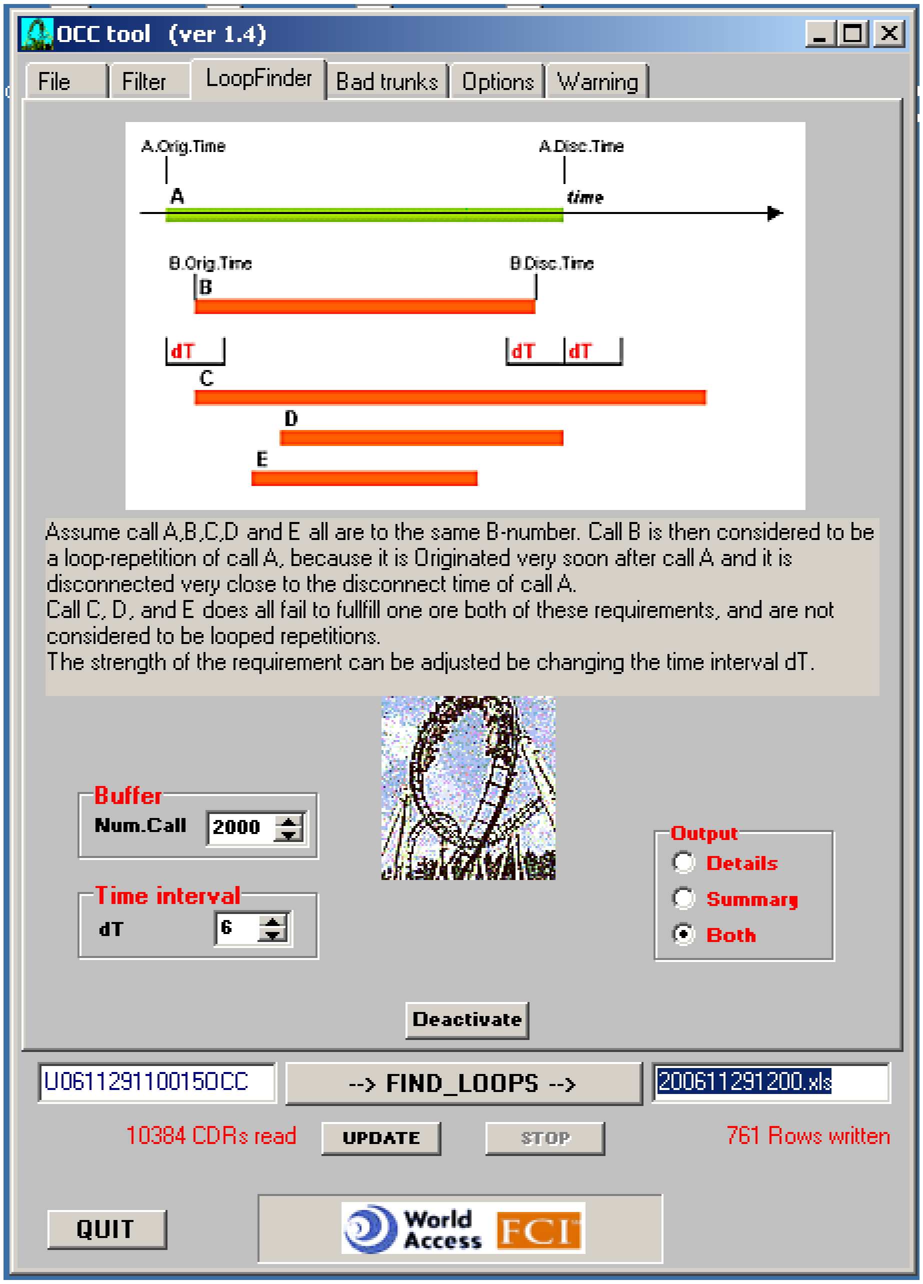
Appendices

Appendix A: Loop finder



Looping is characterized by very short inter-arrival times of calls in which the CDR shows that the calling numbers (A-numbers) are identical and the called numbers (B-numbers) are as well identical. When the inter-arrival time *dt* is between 5 – 7 seconds, the calls are seen as exactly the same call, hence signifying a loop. In the loop finder input screen shown above, *dt* is set to 6 seconds and the buffer (i.e., the maximum number of results we want) is set to 2000. Looped calls are studied in the CDR file U0611291100150CC and the results are written in the Excel file 200611291200.xls.

Appendix B: VoIP codecs used

Codec	Bite rate (Kbps)	Sample size (Bytes)	Sample interval (ms)	Nominal Ethernet Bandwidth (Kbps)	Packets per second	Mean Opinion Score
G.711	64	80	10	87.2	50	4.1
G.723.1	6.3	24	30	21.9	34	3.9
G.723.1	5.3	20	30	20.8	34	3.9
G.726	32	20	5	55.2	50	3.9
G.726	24	15	5	47.2	50	
G.728	16	10	5	31.5	34	3.6
G.729	8	10	10	31.2	50	3.9

The best voice quality is obtained by using the G.711 codec, which uses no compression (i.e., voice bit rate stays at 64 Kbps). There are two versions: *a-Law* and *μ-Law. a-Law* is used for the traditional T1 trunks (with 24 voice channels per T1) in USA and Japan whereas *μ-Law* is used for E1 trunks (with 30 voice channels per E1) for the rest of the world.

Appendix C: Destination listing (A-Z)

c	Routing Nr Format	Destination Name
1	93	Afghanistan
2	937	Afghanistan Cellular
3	9377	Afghanistan Cellular Areeba
4	9375	Afghanistan Cellular AT
5	9370	Afghanistan Cellular AWCC
6	9378	Afghanistan Cellular Etisalat
7	9378	Afghanistan Cellular Roshan
8	9340	Afghanistan Herat
9	9320	Afghanistan Kabul
.	.	.
.	.	.
.	.	.
2436	31	Netherlands
2437	3120	Netherlands Amsterdam
2438	31660	Netherlands Cellular
2439	316	Netherlands Cellular
2440	31656	Netherlands Cellular KPN
2441	31658	Netherlands Cellular KPN
2442	31657	Netherlands Cellular KPN
2443	31665	Netherlands Cellular KPN
2444	31659	Netherlands Cellular KPN
2445	31623	Netherlands Cellular KPN
2446	31622	Netherlands Cellular KPN
2447	31630	Netherlands Cellular KPN
2448	31651	Netherlands Cellular KPN
2449	31620	Netherlands Cellular KPN
2450	31612	Netherlands Cellular KPN
2451	31610	Netherlands Cellular KPN
2452	31653	Netherlands Cellular KPN
2453	31613	Netherlands Cellular KPN
2454	31648	Netherlands Cellular Orange
2455	31638	Netherlands Cellular Orange
2456	31618	Netherlands Cellular Orange
2457	31628	Netherlands Cellular Orange
2458	31640	Netherlands Cellular Tele2

c	Routing Nr Format	Destination Name
2459	31636	Netherlands Cellular Tele2
2460	31644	Netherlands Cellular Telfort
2461	31633	Netherlands Cellular Telfort
2462	31626	Netherlands Cellular Telfort
2463	31649	Netherlands Cellular Telfort
2464	31647	Netherlands Cellular Telfort
2465	31645	Netherlands Cellular Telfort
2466	31619	Netherlands Cellular Telfort
2467	31617	Netherlands Cellular Telfort
2468	31616	Netherlands Cellular Telfort
2469	31642	Netherlands Cellular T-Mobile
2470	31641	Netherlands Cellular T-Mobile
2471	31614	Netherlands Cellular T-Mobile
2472	31643	Netherlands Cellular T-Mobile
2473	31624	Netherlands Cellular T-Mobile
2474	31611	Netherlands Cellular Vodafone
2475	31654	Netherlands Cellular Vodafone
2476	31655	Netherlands Cellular Vodafone
2477	31650	Netherlands Cellular Vodafone
2478	31652	Netherlands Cellular Vodafone
2479	31627	Netherlands Cellular Vodafone
2480	31625	Netherlands Cellular Vodafone
2481	31621	Netherlands Cellular Vodafone
2482	31646	Netherlands Cellular Vodafone
2483	31615	Netherlands Cellular Vodafone
2484	31629	Netherlands Cellular Vodafone
.	.	.
.	.	.
.	.	.
3792	263	Zimbabwe
3793	26391	Zimbabwe Cellular Econet
3794	26311	Zimbabwe Cellular NetOne
3795	26323	Zimbabwe Cellular Telecel
3796	2634	Zimbabwe Harare

Appendix D: Matlab code for calculating the utility

```
load A.m; % Suppliers
load B.m; % Customers

[P Q] = size(A);
[R S] = size(B);

w = 100; %total number of destinations
a = -0.01; %alpha
b = 0.05; %beta
M = 0.05; %

U = zeros(1,P);

for c = 1:w % destinations

    for i = 1:P     %suppliers
        m = zeros(1,R);
        mk = 0;

        for j = 1:R % customers
            if (A(i,1) == c) && (B(j,1) == c) &&dests must be identical
                  m(j)= (B(j,3) - A(i,3))/A(i,3); %frnal profit margin

                if (m(j)>=a) && (m(j)<=b)
                else
                    m(j)=0;
                end

            else
                m(j)=0;
            end
            mk = sum(m);
        end

        if mk >= M
            U(i)=A(i,4)+ mk; %Utility
        else
        end

    end
end;
```

Appendix E: Routing table for the first 100 destinations

with (α, β, M, N) = (-0.1, 0.1, 0.01, 4).

Destination	Route	Utility	ASR	Price(€/min)
1	2	1.0682	1	0.157
1	3	0.7278	0.64	0.156
1	17	0.2084	0.06	0.153
1	5	0.0584	0	0.1575
2	5	0.4849	0.41	0.1523
2	6	0.1625	0.06	0.1503
3	6	0.907	0.75	0.1503
3	5	0.1156	0	0.1523
4	17	0.0444	0	0.153
5	15	1.013	1	0.046
5	5	0.4298	0.33	0.0441
5	7	0	0	0.047
6	17	1.057	1	0.114
6	7	1.0326	1	0.1167
7	6	1.0326	1	0.1167
7	17	0.627	0.57	0.114
8	5	0	0	0.0259
8	7	0	0	0.0266
8	17	0	0.8	0.026
9	21	1.166	1	0.0494
9	18	0.687	0.5	0.0492
9	6	0.6336	0.35	0.0483
9	17	0.5982	0.39	0.049
10	18	0.192	0.17	0.05
10	17	0.0633	0	0.049
11	5	0.605	0.33	0.088
11	17	0.2678	0.11	0.09
11	21	0.1963	0.05	0.0902
11	16	0.1521	0	0.0901
11	3	0.1011	0	0.091
12	3	0	0.61	0.9349
12	6	0	0.24	0.931
12	7	0	0	0.932
12	13	0	0.25	0.94
12	17	0	0.47	0.93
12	18	0	0.67	0.935
12	21	0	0.5	0.933
13	6	0.635	0.6	0.08
13	3	0.6124	0.58	0.0802
13	13	0.5421	0.49	0.0787
13	17	0.0286	0	0.0805
13	5	0.0248	0	0.0808
14	7	1.1307	1	0.0176
14	13	0.1667	0	0.0174
15	7	1.2643	1	0.1396
15	6	0.3919	0.12	0.1394
15	16	0.3254	0	0.138
16	3	0.0419	0	0.0859
16	7	0.0347	0	0.0865
17	7	0.0347	0	0.0865
18	7	0.7061	0.67	0.1245
18	3	0.523	0.5	0.1261
18	5	0.272	0.23	0.1238
19	5	0	0	0.3345
20	7	0.9658	0.85	0.0095
20	5	0.3296	0.17	0.0094
21	5	0	0.67	0.004
21	7	0	0.75	0.0041
22	17	1.0475	0.88	0.04
22	5	0.0827	0	0.0411
23	5	0	0.41	0.0047
24	5	0	0.34	0.0047
25	5	0	0.35	0.0047
26	5	0	0.33	0.0047
27	5	0	0.13	0.0047
27	7	0	1	0.0048
28	13	0.3649	0.27	0.0453
28	3	0.1136	0	0.0449
28	10	0.1042	0	0.0451
29	3	0.4698	0.28	0.1043
29	6	0.4216	0.28	0.1059
29	22	0.2822	0.03	0.1023
29	2	0.277	0.05	0.1031
29	13	0.2176	0	0.1034
30	3	0.4237	0.3	0.1043
30	22	0.3352	0.17	0.1023
30	2	0.2452	0.08	0.1023
30	13	0.1422	0	0.1034
31	5	0.0624	0	0.0449
31	3	0	0.33	0.05
32	3	0	0.5	0.0244
32	5	0	1	0.024
33	7	0	0	0.2962
34	17	0.4294	0.08	0.0083
34	5	0.2114	0.2	0.0088
34	7	0	0.72	0.009
35	5	0.6507	0.5	0.0073
35	7	0.6333	0.54	0.0075
36	5	0.6029	0.37	0.0073
36	7	0.5767	0.43	0.0075
37	7	0.5895	0.55	0.0076
37	5	0.4422	0.36	0.0073
38	5	0	0.57	0.0073
38	7	0	0.76	0.0076
38	18	0	0.55	0.0075
39	5	0.9107	0.76	0.0073
39	7	0.8158	0.75	0.0076
40	7	1.0658	1	0.0076
40	5	0.8418	0.65	0.0073
41	5	1.0707	0.92	0.0073
41	7	0.8158	0.75	0.0076
41	17	0.0986	0	0.0071
42	13	0.8736	0.26	0.0088
42	15	0.7241	0	0.0087
42	7	0	0.54	0.0082
42	17	0	0	0.0085
42	18	0	0	0.0083
43	17	0	0	0.0085
44	3	1.1294	1	0.102
44	15	1.0463	0.92	0.1021
44	6	0.1417	0	0.1016
45	13	1.1145	1	0.0873
45	14	1.0188	0.95	0.0886
45	3	0.9726	0.77	0.0849
45	22	0.8898	0.8	0.088
46	14	1.0659	0.85	0.0991
46	5	0.9565	0.73	0.0989
46	3	0.6229	0.5	0.1009
47	14	1.0342	1	0.0876
47	18	0.7966	0.76	0.0875
47	7	0.6491	0.56	0.0853
48	6	0.2174	0.12	0.1016
48	5	0.0712	0.03	0.1044
49	13	1.1838	0.69	0.0081
49	15	1.1676	0.87	0.0084
49	7	0.9814	0.62	0.0083
49	3	0.4368	0.01	0.0082
50	17	0.0423	0	0.071
50	13	0.0292	0	0.0719
51	5	0.3388	0.23	0.0432
51	13	0.1039	0	0.0433
52	22	0.6093	0.5	0.0869
52	5	0.4493	0.34	0.0869
52	3	0.4053	0.32	0.0879
53	6	0.0769	0	0.0195
53	17	0	1	0.2
54	2	1.0479	1	0.0334
54	7	0.8574	0.8	0.0331
54	5	0.3242	0.27	0.0332
55	7	0	0.44	0.0543
55	17	0	0	0.0565
56	7	0.8633	0.71	0.1318
56	16	0.3937	0.25	0.1322
57	7	0.7652	0.67	0.1292
57	3	0.7356	0.57	0.125
57	5	0.6786	0.62	0.1315
57	17	0.4784	0.33	0.126
57	2	0	0.56	0.122
57	22	0	0.44	0.12
57	11	0	0	0.1175
58	6	0.3649	0.2	0.1255
58	11	0	0.01	0.1175
59	5	0.6402	0.59	0.1136
59	22	0.4009	0.33	0.1114
59	10	0.2671	0.2	0.1118
59	13	0.1847	0.14	0.1142
60	14	0.8504	0.51	0.0094
60	5	0.4565	0	0.0092
61	14	0.6645	0.59	0.0094
61	5	0.0978	0	0.0092
61	3	0.086	0	0.0093
62	14	1.2297	0.97	0.119
62	3	0.6873	0.4	0.118
62	17	0.4025	0.17	0.12
62	7	0	0.15	0.115
63	15	0.894	0.88	0.15
63	17	0.5365	0.24	0.142
64	17	1.0634	1	0.142
64	14	1.0379	0.93	0.139
64	6	0.6729	0.58	0.14
64	3	0.6159	0.52	0.1398
64	7	0.5678	0.44	0.1377
64	13	0.368	0.29	0.141
65	13	0.0424	0	0.0966
66	5	0.3586	0	0.0527
66	7	0.3376	0	0.0542
67	3	0.8108	0.63	0.0542
67	5	0.2713	0	0.0527
67	6	0	0.49	0.56
67	13	0	0.26	0.5699
67	17	0	0.44	0.5435
68	6	0.7019	0.55	0.0553
68	5	0.5307	0.35	0.0548
68	13	0.364	0.16	0.0544
68	17	0.3465	0.16	0.0547
68	3	0.2791	0.11	0.055
69	7	1.1633	1	0.0551
69	6	0.5091	0.34	0.055
69	13	0.364	0.16	0.0544
69	3	0.3423	0.15	0.0546
69	17	0.2765	0.09	0.0547
69	5	0.2407	0.06	0.0548
70	7	1.0817	1	0.0551
70	3	0.7807	0.68	0.0546
70	13	0.4685	0.36	0.0544
70	6	0.4155	0.33	0.055
70	17	0.2669	0.17	0.0547
71	6	0.4291	0.3	0.055
71	3	0.3847	0.24	0.0546
71	13	0.2626	0.11	0.0544
71	17	0.2308	0.09	0.0547
71	5	0.1369	0	0.0548
72	18	0	0	0.0382
73	7	1.3121	1	0.0471
73	6	0.399	0.04	0.0468
73	5	0.3521	0.04	0.0471
73	8	0.2858	0.02	0.0474
73	9	0.1934	0.01	0.0447
74	5	0.371	0.33	0.0634
74	13	0.191	0.15	0.0634
74	3	0.1694	0.13	0.0635
74	8	0.0313	0	0.064
75	5	0.6373	0.43	0.0275
76	5	0.6468	0.42	0.0269
77	5	0.9924	0.91	0.0279
77	8	0.2258	0.18	0.0284
78	18	0.607	0.6	0.086
78	7	0.0474	0	0.0843
78	17	0.0306	0	0.085
79	13	0	0.38	0.1175
80	13	1.0721	1	0.1345
80	5	0.159	0	0.1308
80	6	0.0744	0	0.1344
80	11	0	0	0.1175
81	15	0.5803	0.5	0.1308
81	13	0.523	0.5	0.1345
81	11	0	0	0.1175
82	17	0.7155	0.7	0.084
82	3	0.5277	0.5	0.083
82	13	0.129	0.1	0.0829
82	5	0.0119	0	0.0843
83	17	1.0882	1	0.0499
83	5	0.0924	0	0.0498
83	3	0.084	0	0.05
84	5	0.5929	0.36	0.0498
85	7	1.0596	1	0.104
85	5	0.2627	0.2	0.1037
86	5	0	1	0.1037
87	7	0.8388	0.73	0.0193
87	6	0.4498	0.33	0.0192
87	5	0.1179	0.02	0.0194
87	17	0.0872	0	0.0195
88	5	0	0	0.0194
88	6	0	0	0.0192
88	7	0	0.93	0.0193
88	20	0	0	0.0195
89	5	0.0412	0	0.0194
90	6	1.0521	1	0.0192
91	6	0.0417	0	0.0192
92	2	0	0	0.0774
92	7	0	0.63	0.0775
92	9	0	0	0.078
92	17	0	0	0.0773
92	21	0	0.8	0.0778
93	7	1.0917	1	0.012
93	5	0	0	0.0119
94	7	0.3021	0.25	0.0192
95	6	0.0938	0	0.0192
95	17	0.0722	0	0.0194
95	8	0	0	0.0153
96	5	0	0	0.0115
97	5	0	0	0.0111
98	6	0.5163	0.36	0.0192
98	3	0.1563	0	0.0192
98	5	0.1237	0	0.0194
98	17	0.0149	0	0.0201
99	5	0	0.01	0.0119
100	7	0	0.25	0.0138

The route names of the respective routes are as shown in Figure 4.2.

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