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Network Elements Demand Estimating Model for Mobile LRIC

Jae Ho Byun*, Sung Lyong Kang**
변재호, 강성룡

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요 약

이동망의 착신접속서비스는 각국에서 bottleneck 서비스로 인식하고 규제당국에서 원가에 근거하여 규제하고 있다. 원가에 의한 규제 방식으로 과거에는 회계자료를 근거로 한 역사적 원가가 사용되어 왔으나 최근에는 유선망의 경우처럼 bottom-up 방식의 장기증분원가(Long Run Incremental Cost : LRIC)를 적용하는 사례가 증가하고 있다.

LRIC를 산정하기 위해서는 공학적인 기준에 따라 이동망을 설계하여 정확한 망 구성요소별 소요량을 측정하고 이를 투자비로 전환하는 작업이 필요하다. 유선망의 경우는 LRIC 산정을 위한 망 설계방법론이 비교적 잘 확립되어 있으나, 이동망의 경우는 망 설계 및 망 구성요소별 소요량 산정방법론에 대한 연구가 부족한 실정이다.

본 고에서는 bottom-up 방식의 이동망 LRIC 산정관련 해외 사례를 살펴보고 국내 실정에 적합한 이동망 설계 방법과 망 구성 요소별 소요량 산정 방법론을 제시해보고자 한다.

Key words : Mobile, LRIC, Interconnection, Cell Planning

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* ETRI 경쟁전략연구팀 팀장, E-mail: jhbyun@etri.re.kr
** 충북대학교 경영대학 교수, E-mail: slkang@chungbuk.ac.kr,

I. Introduction

With the rapid expansion of mobile telephone markets across the world, it is expected that mobile networks will carry more than 50% of all voice calls in the world by 2009(Analysys, 2004).

This sharp growth of mobile telephone markets is followed by increasing disputes over fixed-mobile and mobile-mobile termination charges. In order to resolve these disputes, regulators of many countries are considering to adopt the long run incremental cost (LRIC) for calculating mobile termination charge. In 2003, U.K. first applied the bottom up LRIC model to the mobile networks(Competition Commission, 2002). Other European countries are now reviewing the application of LRIC approach to their mobile networks.

Korea has decided to estimate mobile termination charges based on the bottom up LRIC from 2004, and has been developing the model since 2002.

The toughest tasks in estimating mobile LRIC based on the bottom up approach are to correctly estimate the required numbers of individual network elements, and using these, to estimate the investment cost and incremental cost of services. In the wireline sector, it is possible to estimate the required numbers of individual network components relying on a relatively wide range of studies that have been conducted. However, the mobile network sector lacks related studies and has no formal methodology available as yet.

In order to resolve this problem, this study analyzes existing mobile LRIC models and presents a more realistic model for estimating the required numbers of individual mobile components.

II. Characteristics and Problems of Existing Models

Top down and bottom up models are the two major approaches to estimating LRIC. The former estimates the costs of individual network components through allocation of the gross network cost. While the latter first estimates the cost of individual network components and then the gross network cost.

A number of top down and bottom up models have been developed in the wireline network sector. British BT model(BT, 1997) is the representative top down costing model, while US Hatfield model(Hatfield Associates, 1997), Benchmark Cost Proxy Model(INDETEC International, Inc, 1996) and British Interconnect Commercial Working Group model(NERA, 1996) are the representative bottom up models.

In the mobile network sector, however, UK Oftel model(Competition Commission, 2002), Australian model(Ovum, 2000) and Malaysian MCMC(Malaysian Communications and Multimedia Commission) model(MCMC, 2002) are all based on the bottom up approach.

Of these models, details of Australian model are little known, and UK and Malaysian models have basically equal characteristics. For this reason, this study reviews UK(Oftel) model as a typical bottom up LRIC model. At the first stage, Oftel model estimates the "numbers of individual network components required for coverage establishment," and the "numbers of individual network components required for traffic handling" separately. The former estimates the number of base stations(BS) by dividing the total land size by the average coverage size per BS. While, the latter estimates the number of BSs by dividing the total traffic demand by the cell capacity

At the second stage, the network components for coverage and network components for traffic are compared by area type(urban, suburban and rural), and the larger number of BSs required is determined as the number of BSs in the relevant area.

At the third stage, after the number of BSs is decided, the total investment cost is estimated by applying unit costs of equipment, and the incremental cost for services is estimated by dividing the total investment cost by the call volume.

The strongest advantage of Oftel's mobile LRIC method is the relatively simple confirmation of the required numbers of network components.

However, in view of the fact that the required number of BSs, which accounts for the largest portion of the investment cost in the mobile network, is largely influenced by topological characteristics of the service area and the traffic volume distributed in the area, it can be seen that Oftel's method is unduly simplifying the reality. Despite the fact that the location and number of BSs may greatly differ according to topological characteristics, types of buildings and traffic distribution in the area, Oftel model assumes that all the areas have equal topological conditions and traffic distribution.

As a way of resolving this problem, an approach is presented in the following chapter for estimating the required number of mobile BSs by using real GIS data and the 3 dimensional (3D) propagation model.

III. Model for Estimating BS Demand Using GIS Data

As investment in BSs takes up the most portion of cost incurred in mobile sector, it is necessary to look at a variety of aspects in examining how to effectively reduce the number of BSs and how to manage BSs in response to traffic situations. Problems involved in the efficient set-up of BSs are being addressed by depending on theoretical studies and by using cell planning tools in the field. One example of theoretical studies is Stephen Hanly's study "On the Optimal Base-Station Density for CDMA Cellular Networks(Hanly and Mathar, 2002)." It provides a theoretical explanation on the determination of cell radius affected by data traffic and on the optimal demand for BSs. Another example is D. Hanif, et.al(1996)'s "Optimal location of transmitters for micro-cellular radio communication system design," which, relying on mathematical modeling and analyses, deals with a mobile design aimed at finding out the optimal location of one or multiple BS(s). Other studies also theoretically approached the set-up of BSs. However, details of ways in which various mobile operators set up their BSs are little known because they are protected as a proprietary know-how and competitive elements.

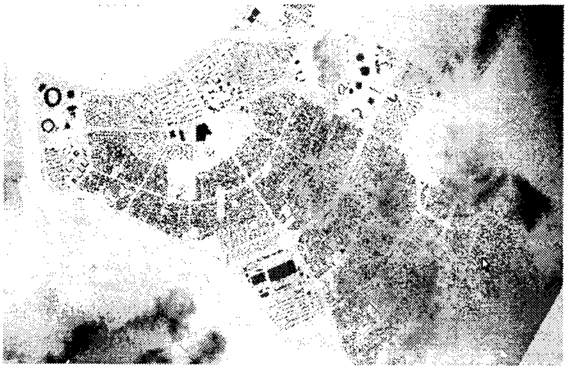
Therefore, in order to estimate the optimal demand for mobile BSs by taking account of the BS capacity, the subscriber density, geographic information and the call volume, this study obtains cell radii based on the 3D propagation model using accurate geographic information. Additionally, given traffic demand and cell capacity, this study aims to establish a simulator applicable to 2G systems, PCS and CDMA, through an algorithm which produces optimal number of BSs using the 3D propagation model and the subscriber density.

1. Construction of GIS data

To develop the model for estimating optimal BS numbers using GIS data, this study selected 3 sample areas(Songpa-Gu, Taejeon and Jangseong city) which represent urban, suburban and rural area respectively. GIS data of 3 sample areas includes topological data(height, contour), building data(height, types and size) and street data. <Figure 1> shows GIS data image of Songpa-Gu.

2. BS selection algorithm

The optimal algorithm for selecting BSs is basically aimed at finding out the optimal location and number of BSs once cell radius is determined. The algorithm forms a matrix, in which (x, y)=1 stands for the case when y mobile can receive service by x index of BS and (x, y)=0 for the case when y mobile cannot receive service. The algorithm keeps



<Figure 1> GIS data image of Songpa-Gu

eliminating BSs until all unnecessary BSs are removed and all mobiles in the area that want to receive services will be able to do so.

If a cell is designed using geographic information only without any consideration of traffic in the area, the threshold of pass loss, which is the gap between the BS output and the mobile received power, becomes the input value. At each index, the threshold of pass loss is compared with the pass loss attained from the 3D propagation model. As a result, a matrix is formed based on individual indexes of 0 or 1.

If subscriber density is taken into account, the occurrence of cell shrinking is assumed from the ratio of required capacity to cell capacity. A matrix is formed based on individual indexes of 0 or 1 in this case also(see <Table 1>).

<Table 1> Matrix of BS Selection Algorithm

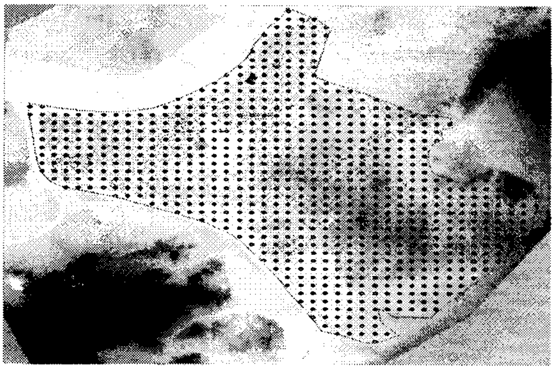
	[illegible]					
		1(5)	2(3)	3(5)	4(4)	5(2)
Index of sample point	1	1	0	0	1	1
	2	0	0	1	0	0
	3	1	1	1	1	0
	4	0	0	0	1	0
	5	1	1	1	0	0
	6	1	0	1	0	0
	7	0	0	1	0	0
	8	0	0	0	1	0
	9	1	1	0	0	0
	10	0	0	0	0	1

1) Generation of sample points

In practice, it is impossible to forecast pass loss for the entire areas on the map. Therefore, sample points are generated for the areas that want to receive service. These points are input and used as mobile indexes in judging whether an area can receive service or not. Sample points can be made at regular intervals, as shown in <Figure 2>, or at irregular intervals. The larger the number of sample points is, the more refined the simulation can be(but it requires longer time). In this study, sample points are selected at regular intervals in the service area.

2) Generation of candidate BSs

If sample points are generated, the entire area is partitioned at regular intervals to make grids. The interval between grids suggests the minimum distance between BSs. This distance is adjusted to 300m, 500m or 700m cross wise and length wise in order to locate candidate areas for BSs at the most suitable points.



<Figure 2> Screen of Sample Points Generated

3) Selection of BSs

A matrix is formed with candidate areas for BSs and sample points placed in rows and columns. BSs are selected by assigning 1 to the sample point which can receive service in each candidate area for BS and 0 to the sample point which cannot receive service.

Based on the algorithm which eliminates with priority candidate BSs of low efficiency, i.e. BSs with less number of sample points which can receive service, the elimination is repeated until all sample points are served by remaining BSs.

3. Cell decision based on pass loss

There are a wide range of factors affecting pass loss, including the frequency spectrum, the height of a building or an obstruction, the number of obstructions over the range of propagation, the height of BS antenna and the height of mobile antenna. Therefore, when forecasting the pass loss by considering all these factors, a model suitable to each situation and correct topological data should be used to obtain an estimate closest to the actual pass loss.

This study uses largely two pass loss models depending on the factors affecting the pass loss and utilizes accurate geographic information to forecast correct pass losses. The 3D propagation model forecasts free space loss, diffraction and dispersion loss appropriate to each situation in the case of NLOS (none line of sight: an obstruction exists within the range of wave propagation) through L_{VPM} (vertical plane model), a combination of the Knife edge-JRC model and the Walfisch model. In the case of LOS (line of sight: no obstruction exists within the range of wave propagation), the model forecasts free space loss, diffraction and dispersion loss appropriate to each situation using Walfish Ikegami model.

1) NLOS

The Knife edge-JRC model(L_{KJ}) is a combined model of Knife-edge model(L_k) and dual slope model(L_{DS}). The Knife-edge model, calculates the loss of diffraction when one obstruction gives great impact on pass loss in general compared to other neighboring obstructions. The dual slope model considers the pass loss incurred when the wave is reflected on the ground surface if the wave spreads farther than the range obtained after considering the height of BS antenna, the height of mobile antenna and the wave length, and if the wave is not affected by neighboring obstructions.

On the other hand, the Walfisch model(L_W), suitable to urban environment where buildings stand close together, forecasts the pass loss owing to diffraction and scattering caused by multiple obstructions.

NLOS of the 3D propagation loss model to be used in this study is defined as follows:

$$L_{VPM} = (1-g)L_{KJ} + gL_{W} \tag{1}$$

Here, "g", which combines the two models mentioned above, determines which one out of the Knife edge model and the Walfish model is better for the environment.

The value of "g" is determined by the uniformity in the height of obstructions and the width of streets between buildings, and defined as follows:

$$g = g_h * g_w \tag{2}$$

① CH decision criteria

$CH = Hr/\sigma_h$, if no. of buildings>1

$CH = 0$, if no. of buildings ≤ 1

② g_h decision criteria

$g_h = 1$, if CH>3

$g_h = 0$, if CH<1

$g_h = \frac{CH-1}{2}$, if 1<CH<3

③ g_w decision criteria

$g_w = 1$, if w<50m

$g_w = 0$, if w>100m

$g_w = \frac{100-w}{50}$, if 50m<w<100m

Terms to be used in the 3D propagation model are explained in the notation below. When considering all heights to obtain correct pass loss value, heights of grounds are also used to calculate relative heights (lowest ground is used as the base).

[Notation]

Hr : height of ground + height of buildings

ht : height of ground + height of buildings +height of BS antenna

hr : height of ground + height of buildings +height of mobile antenna

σ_h: standard deviation of height of buildings

w : width of street

dkm : distance from BS to mobile

d1 : distance from BS to buildings

d2 : distance from mobile to buildings

λ : 300,000,000/f[Hz]

(1) Knife edge-JRC model(L_{KJ})

The smaller the g value obtained above is, i.e. the less uniform the heights of buildings are and the fewer the buildings there are, the larger the path losses obtained by the Knife edge-JRC models become. Here, the Knife edge-JRC model is defined as follows:

$$L_{KJ} = max(L_{FS}, L_{DS}) - F$$

a. Free space loss model(L_F) & Dual slope model(L_{DS})

After comparing L_{FS}, the value of pass loss in case of free space loss, and L_{DS}, the part of pass loss in case of ground reflection, the larger value is taken as the pass loss.

- Free space loss:

$$L_{FS} = 32.45 + 20 log\ d_{km} + 20 log\ f_{MHz}$$

- Ground reflection + free space loss:

$$R_b = \frac{4h_t h_r}{\lambda}, \quad L_b = \left| 20\log\left(\frac{\lambda^2}{8\pi h_t h_r}\right) \right|$$

$$L_{DS} = \begin{cases} L_b + 20log\left(\frac{d}{R_b}\right) & d \le R_b \\ L_b + 40log\left(\frac{d}{R_b}\right) & d \le R_b \end{cases}$$

b. Knife edge model(L_K)

If one obstruction with the height of H_r gives great impact on the transmission loss, the Knife edge model produces the diffraction loss F by using the height of the obstruction, the height of BS antenna, the height of mobile antenna, the location of the obstruction and wave length.

$$F = \begin{cases} 0 & 1 \le v \\ 20\log(0.5 + 0.62v) & 0 \le v < 1 \\ 20\log\left(0.5e^{0.95v}\right) & -1 \le v < 0 \\ 20\log\left(0.4 - \sqrt{0.1184 - (0.1v + 0.38)^2}\right) & -2.4 \le v < -1 \\ 20\log(-0.225/v) & v < -2.4 \end{cases}$$

$$v = -H\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)}$$

$$H = Hr + \frac{(h_t - h_r)d1}{(d1 + d2)} - h_t$$

2) Walfisch model($L_{u'}$)

This model, applicable to the frequency bands of 800MHz and 2000MHz, is suitable to urban areas filled with buildings. Accordingly, the larger the value of g is, i.e. the more uniform the heights of buildings are and the narrower the width of streets are, the larger the portion this model takes up in the entire pass loss becomes.

The Walfisch model, as defined below, consists of diffraction by buildings(L_{rts}), scattering loss and multiscreen loss(L_{msd}) in addition to free space loss(L_{FS}).

$$L_W = L_{FS} + L_{rts} + L_{msd} \qquad L_{rts} + L_{msd} \geq 0$$

$$L_W = L_{FS} \qquad L_{rts} + L_{msd} < 0$$

2) LOS

If there is no obstruction in the coverage, the pass loss is estimated by the Walfish Ikegami LOS($L_{WIM-LOS}$)model.

$$L_{WIM-LOS} = 42.64 + 26 log\ d_{km} + 20 log\ f_{MHz} \quad d_{km} \geq 0.02$$

When these formulas are used to obtain pass loss, service availability is determined by the BS output and the mobile received power threshold and the cell radius is determined based on the channel signal.

4. Cell decision in consideration of the subscriber density

If a cell coverage is decided through the 3D propagation model, it does not satisfy the needs of all subscribers in the area. The cell radius should shrink back to the extent of where the capacity of BS can meet the demands based on the subscriber density.

In this study, therefore, the cell coverage is determined using the cell shrinking model based on the relationship between subscriber density and cell capacity.

The degree of cell shrinking is adjusted by replacing D in the 3D transmission loss model with D/A. A is the 1/2 times the inverse number of the cell capacity required by subscribers. Theoretically, the cell radius is in inverse proportion to 1/2 times the traffic volume, so the cell radius after considering the subscriber density can be determined by replacing D with D/A in the transmission loss formula.

D: Distance between a BS and each sample point

A: {(B * no. of FA) / K }^ 0.5

B: capacity by number of sectors / average cell area (sq. km) obtained from the pass loss formula

K: B * number of FA

(number of subscribers per Km^2 * erlang per subscriber< B * FA),

Number of subscribers per Km^2 * erlang per subscriber

(number of subscribers per Km^2 * erlang per subscriber> B *FA)

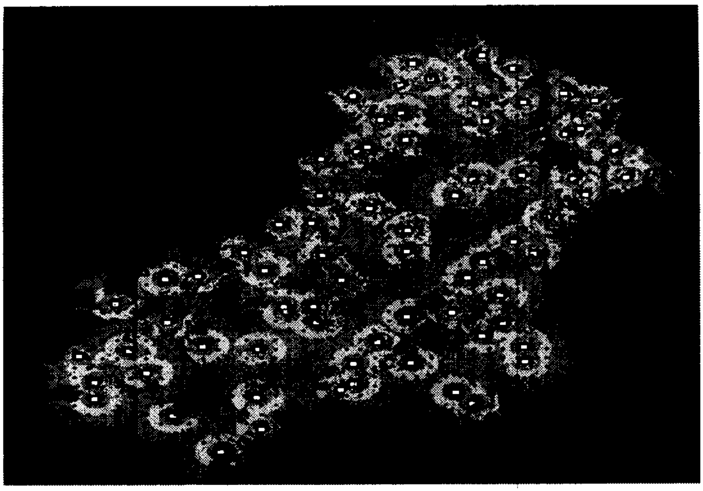
The cell capacity used here is gained by inputting the outage probability after considering the frequency reuse efficiency, voice activity rate and sectorized gain. The erlang per subscriber is normally between 0.02 and 0.03. This can be applied differently according to BHCA and the call duration.

1) Simulation

This study created a simulator showing optimal location and number of BSs by inputting such variables as GIS data, frequency spectrum, capacity of BS, outage probability and the threshold of received power into the simulator made by using the algorithm presented above.

<Figure 3> shows the required number and optimal location of BSs obtained through the simulator in a sample area.

<Table 2> lists the optimal numbers of BSs obtained by the simulator. The values are based on the subscriber density in the frequency bands of 800MHz and 1859MHz for 3 areas representative of urban, suburban and rural areas.



(1850MHz, 30 people/km^2, 1FA, 2 sectors, outage pro. 2%, 0.02 erlang/person, transmission loss limit: 110 dB)

<Figure 3> Simulator output

<Table 2> Numbers of BSs Based on Subscriber Density by Area

[illegible]	[illegible]	[illegible]	[illegible]
Area U (urban)	coverage	5	12
	4000	14	47
	6000	17	63
Area S (Suburban)	coverage	41	103
	500	60	109
	1000	-	161
Area R (Rural)	coverage	37	70
	30	37	70
	50	37	70

<Table 3> Input Parameters for Estimating the Required BSs by Area

Area	Size(km^2)	FA	Sector	Outage pro.	Erlang per person
U	31.25	5	3	2%	0.02
S	540.09	3	3		
R	520.01	1	2		

<Table 4> Average cell radii without Consideration of Subscriber Density

Area	800MHz	1850Mhz
U	2.294	1.851
S	3.108	2.196
R	3.257	2.335

Comparison of the average radii of cell shown in <Table 4> provides the 3 areas' differences in the coverage caused by different topological characteristics and obstructions and by the frequency band. As there are many obstructions in urban areas, the urban areas have a shorter cell radius than suburban and rural areas. In addition, comparison of the frequency bands of 800MHz and 1850MHz shows that the cell coverage in 800MHz is 1.5~2times larger than in 1850MHz.

By the use of the approximate value of actual cellular and PCS subscriber density in each area, and FA, sector, outage probability and per person erlang of the areas, shown in <Table 3>, which determine the capacity of a BS, the required numbers of BSs after consideration of subscriber density are estimated in <Table 2>. As the subscriber density grows in general, the required number of BSs increases from the number(the number of BSs required for securing coverage) required when only pass loss is considered. This is because the capacity of BS is not enough to service subscribers in the cell coverage area for which the only pass loss is considered. That is, as the cell coverage area is determined at the level meeting the required capacity, the required number of BSs increases. However, since the subscriber density in the rural area is lower than in the urban or suburban area, the rural area can fully satisfy the required subscriber density with the BSs for coverage.

These results provide some important suggestions in estimating mobile LRIC. Costs of BSs can be divided into incremental costs sensitive to traffic and fixed costs insensitive to traffic. The numbers of BSs for coverage presented in <Table 2> are irrelevant to traffic, so they can be seen as a fixed cost. The difference between the number of BSs for subscribers and the number of BSs for coverage can be seen as an incremental network cost arising from traffic. Incremental cost can occur more in the urban area than in the rural area and more in PCS than in cellular.

VI. Conclusion

The most controversial issues in estimating mobile LRIC based on the bottom up approach are about how to estimate the required number of BSs that account for the most portion of investment in the mobile network, and how to differentiate the "fixed cost insensitive to the change of traffic" and the "incremental cost occurring with the increase of traffic." This study has proposed a method by which the required number of BSs can be estimated using actual GIS data and the 3D pass loss model. It is expected that the estimation model for BS demand, proposed in this study, will allow applying more realistic situations in estimating mobile LRIC. The algorithm for BS selection, also proposed in the study, can be used as a practical tool for systematic design of BSs as the number of BSs needs to be extended to meet the growing usage of mobile services in the future.

Reference

ACCC, *Pricing Methodology for the GSM Termination service,* 2001.

Analysys, Roadmap for the LRIC Model of UK Mobile Network Costs, April, 2002.

Analysys, *The Road to Fixed-Mobile Substitution Starts with 3G,* June 2004.

BT, *Long Run Incremental Cost Methodology*, 1997.

Competition Commission, *Vodafone, O2, Orange and T-Mobile; Reports on references under section 13 of the Telecommunications Act 1984 on the charges made by Vodafone, O2, Orange and T-Mobile for terminating calls from fixed and mobile networks,* 2002.

Cheung, J.C.S., S.G. Chard and M.A. Beach, "Propagation Measurements to Support Third Generation Mobile Radio Network Planning", Eighth International Conference on Antennas and Propagation(IEEE), Proceedings vol.2, no.370(1993), pp.857-860.

Deygout, J., "Multiple Knife-Edge Diffraction of Microwaves", Antennas and Propagation, IEEE Transactions on Antennas and Propagation, vol.14, no.4(1996), pp.480-489.

Europe Economics, *Study on the Preparation of an Adoptable Bottom Up Costing Model for Interconnection and Access Pricing in EU*, 2000.

Hanif, D., C.M. Pendyala and T.S. Rappaport, "Optimal Location of Transmitters for Micro-Cellular Radio Communication System Design", IEEE Journal on Selected Areas in Communications, vol.14, no.4(1996), pp.662-673.

Hanly, S. and R. Mathar, "On the Optimal Base-Station Density for CDMA Cellular Networks", IEEE Transactions on Communications, vol.50, no.8(2002), pp.1274-1281.

Hatfield Associates Inc., *Hatfield Model Release 3.1 Model Description*, 1997.

INDETEC International Inc., *Benchmark Cost Proxy Model(BCPM)*, 1996.

INDETEC, *Mobile Interconnection Report,* September 2000.

Kurner, K and A. Meier, "Prediction of Outdoor and Outdoor-to-Indoor coverage in Urban Areas at 1.8 GHz", IEEE Journal on Selected Areas in Communications, vol.20, no.3(2002), pp.496-506.

MCMC, A *Consultation Study on Access Pricing*, 13 May. 2002.

MMC, *Report on references under section 13 of the Telecommunications Act 1984 on the charges made by Cellnet and Vodafone for terminating calls from fixed line networks,* December 1998.

NERA, *The Methodology to Calculate Long Run Incremental Costs*, 1996.

Oftel, *Review of the Charge Control on Calls to Mobiles,* 26 September 2001.

Ovum, *Mobile Termination Rates*, 2000.

Walfisch, J. and H.L. Bertoni, "A Theoretical Model of UHF Propagation in Urban Environments", IEEE Transactions on Antennas and Propagation, vol.36, no.12(1988), pp.1788-1796.