Cost/Revenue Optimisation in Multi-service Mobile Broadband Systems

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Abstract

A ‘net cost’ model is presented for the design tradeoffs between re-use pattern, K, the coverage distance, R, and the spectral efficiency, $S_{ef}(R)$ in MBS. It allows for the determination of the revenue per basic channel, R_{384}, that achieves a given value for the annual profit per kilometre. Comparing the urban and roads scenarios for R = 100 m and K = 2, whereas $(S_{ef})_{TOT}$ = 32.2 and 15.2 %, R_{384} has to be 0.005 and 0.045 €/min, respectively, i.e., the prices in the ROA scenario have to be around one order of magnitude higher than in the URB scenario.

1. Introduction

In the next years, a large demand is foreseen for mobile multimedia services, limitations on achievable data rates and system capacity leading to the use of mobile broadband communication systems operating at millimetre wavebands, e.g., MBS (Mobile Broadband Systems, [1]). MBS will be deployed mainly in urban areas, to cover hotspots in the centre of large cities, main roads and highways, where the highest demand will occur; moreover MBS will be multi-service systems, i.e., they will support several services simultaneously over the same platform, for different, or even the same, user(s). Owing to their high transmission data rate, and due to the saturation of the spectrum at lower frequency bands, MBS are intended to operate at the millimetre waveband (e.g., the 40 or 60 GHz bands), offering improved performance in system capacity [1].

MBS deployment optimisation can be achieved by seeking optimum values of a merit function taking into account both costs and revenues. The optimisation of costs and revenues provides a mean of joining together the several contributions from cellular planning: the determination of the re-use pattern and the coverage distance [2] plus the aspects of multi-service traffic engineering [3]. In practice, frequency re-use constraints impose the cost component, through the values of the coverage distance and the achieved re-use pattern, while multi-service traffic engineering determines the revenues, together with the frequency re-use aspects. The latter allows for the determination of the number of available channels in each cell, Fig. 1, and is determined by the characteristics of the combination of applications that make use of it, through data and video service components. The supported load (i.e., the sum of the supported kb/s) is a measure of the supported traffic (resulting from multi-service), and depends on the blocking and handover failure probability thresholds. The traffic from mobility has also a strong impact in revenue [4].

From the different hypothesis for the deployment scenarios [5], one considers the Urban (URB) and Main Roads (ROA) scenarios. The analysis is done for regular coverage geometries, the linear and the ‘Manhattan grid’ geometries. By no means is it intended to perform a complete economic study, but only to present initial contributions.

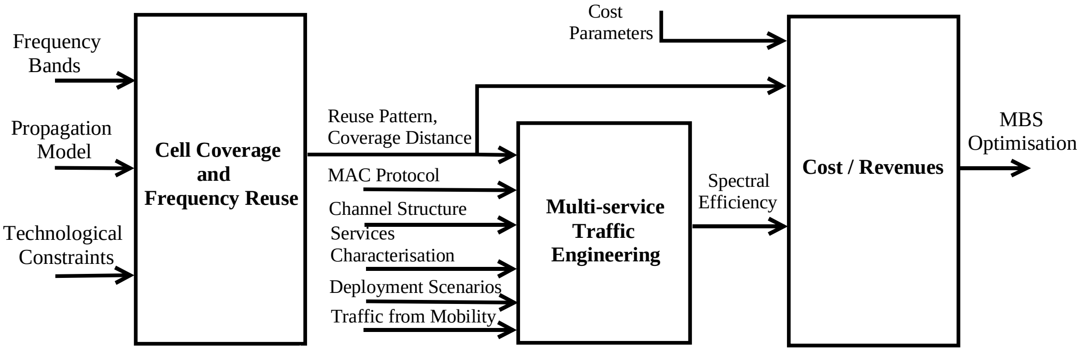


Figure 1: MBS optimisation.

A cost/revenue function has to be developed, taking into account the cost of building and maintaining the infrastructure, and the way the number of channels available in each cell affects operators' revenues. Fixed costs for licensing and bandwidth auctions (or 'beauty contests') should also be taken into account [6]. The economic analysis is referred as a cost/revenue performance analysis, because optimising costs do not necessarily mean optimising net revenues.

This paper is organised as follows. In Section 2, after presenting the necessary details of the MBS concept, the components of the model for cost/revenue optimisation are presented and the model itself is proposed. In Section 3, the values for the parameters are presented and some assumptions are described. In Section 4, results are presented for the spectral efficiency, the cluster revenue-to-cost ratio, the net cost and the revenue associated with each basic channel. A comparison is presented between the URB and ROA scenarios. Conclusions are drawn at the end.

2. Cost/Revenue Model

2.1. MBS Concept

Although OFDM (Orthogonal Frequency Division Multiplexing) could be a solution for MBS, in this work one is still assuming TDMA/FDMA (Time/Frequency Division Multiple Access), following the approach from RACE-MBS (Research in Advanced Communications in Europe – Mobile Broadband System) and ACTS-SAMBA (Advanced Communications Technologies and Services – System for Advanced Mobile Broadband Applications) European Commission projects [7].

Because the MBS concept is not yet completely defined, it is important to clarify the boundaries in data rates, operation scenarios, and mobility. Under RACE initiatives in mobile communication systems, a first definition of MBS and related systems was presented, assuming that, in terms of terminal mobility and supported data rates, MBS operation will just begin where UMTS ends. At that time, it was assumed that UMTS would support data rates up to 2 Mb/s in every mobility scenario [1]. However, with the standardisation of UMTS, this concept evolved, and the current MBS/UMTS boundary is the following: 144 kb/s for fast mobile, 384 kb/s for slow mobile and 2 Mb/s for movable applications [8].

The high capacity desired for MBS and the high operating frequency lead to micro-cellular configurations, hence requiring a large number of BSs to be deployed. For cost efficiency, these BSs should be inexpensive to manufacture and install; in particular, a small number of types should exist, and their installation should not require extensive adjustments. In [9], the MODAL (Microwave Optical Duplex Antenna Link) project concept is proposed to providing an alternative technique for the generation of millimetre waves by using optical technology, offering the perspecti-ve of reduced installation and maintenance costs when compared to more conventional solutions.

Some useful cost/revenue models were already developed in [6] and [10], in a simpler context: a single service system is considered in the former case, while some simplifications (not considering the multi-service traffic analysis) were assumed in the latter one. As a hypothetical scenario, one is considering that MBS will succeed when the costs of deploying its infrastructure and operating the system will be of the order magnitude of today's voice systems, a little bit higher in an initial phase, decreasing down to values comparable to today's GSM ones in the following years. One is also expecting that, although the available average data rates increase from generation to generation by a factor near $10\cdot\sqrt{2}$ (from circa 10 kb/s in GSM to 144 kb/s in UMTS, and to 2 Mb/s in average in MBS; in what follows, 1 920 kb/s will be considered as an hypothesis), users will not be willing to spend much more per minute during a call (or equivalent). It is worthwhile to note that in MBS the referred 1 920 kb/s are faced as the net user load, i.e., the 'silent' periods of each application can be explored in order to allow for the use of the shared resources by other applications, hence they are not taxed. As ATM is used, resources are shared in a way that the multiplexing of different sources (the service components the applications have access to) is possible. Although one considers a project duration of five years as a working hypothesis, one will analyse costs and revenues in an annual basis. Furthermore, the analysis is made under the assumption of null discount rate.

2.2. Components

The economics of cellular systems can be viewed from the points of view of different entities: the subscribers, the network operators, the service providers, the regulator and the equipment vendors [10]. In this work, although one is aware that in future mobile multimedia systems the network operator and the service providers could be different entities, one is not distinguishing them. Thus, one is considering the operator/service provider's point of view, whose primary interest is to improve the bottom line of his business.

In the cellular planning process, the objective of the operator is to determine an optimal operation point that maximises its expected revenues. Examples of major decisions include the type of technology to be used, the size of the cell and the number of channels to use in each cell.

In this section the main components of system cost and revenues are identified, in particular those that bear a direct relationship to either the maximum cell coverage distance or the number of frequency groups. One will consider the cost per unit length (or unit area) of i) linear-coverage and ii) Manhattan grid urban geometries incurred during a year of system operation. It must be kept in mind that the system is considered to have a transmission structure formed by a set of frequency carriers, each supporting a TDMA frame structure, meaning that each BS comprises a number of transceivers equal to the number of carriers assigned to it.

System cost has two major parts: (i) capital costs (cell site planning and installation), and (ii) operating expenses (operation, administration and maintenance) [11], [12].

The capital cost is taken to consist of

- a fixed part (e.g., licensing and spectrum auctions or fees);
- a part proportional to the number of BSs per kilometre or square kilometre (e.g., the installation costs of the BSs, and the cost of hardware common to all);
- a part proportional to the total number of transceivers per kilometre or square kilometre (e.g., the cost of the transceivers).

One is assuming that the cost of the connection between BSs and the Switching Centre, i.e., the fixed part of the network (e.g., the cost of laying fibre), is not a fixed cost. Instead, one considers that it is proportional to the number of BSs, which can be true if, e.g., the mobile operator contracts this service from a fixed network operator. The operating cost during system lifetime is taken to contain

- a part proportional to the number of transceivers per kilometre or square kilometre, and
- a part proportional to the number of BSs per kilometre or square kilometre.

These costs (and revenues) will be taken in an annual basis. One will start by considering the linear coverage geometry, Fig.2. Let T be the number of carriers available, for each transmission link, up-/downlink, and N_{op} the number of MBS operators. For a linear geometry one then has

- the maximum cell coverage distance is R, Fig .2;
- the number of BSs per kilometre is given by $1/(2R_{[\text{km}]})$;
- the number of different frequency groups required is K;
- the number of carriers per cell is $T/(N_{op}\cdot K)$;
- the number of carriers per kilometre is $T/[K\cdot N_{op}\cdot(2R_{[\text{km}]})]$.

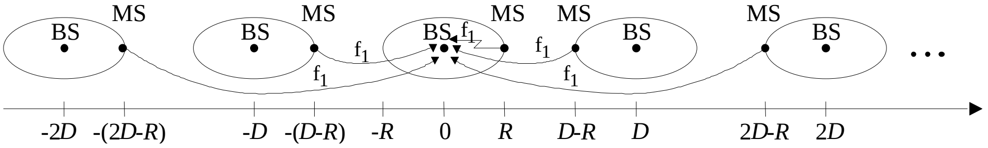


Figure 2: Linear coverage geometry.

Therefore, the system cost will contain a fixed term C_{fi}, and terms proportional to the number of BSs and to the number of transceivers. Letting C_{fb} and C_{ft} denote the corresponding coefficients, the overall cost per unit length per year is

$$C_{0\,[\text{€/km}]} = C_{fi\,[\text{€/km}]} + C_{fb\,[\text{€}]}\frac{1}{2R_{[\text{km}]}} + C_{ft\,[\text{€}]}\frac{T}{K\cdot N_{op}\cdot\left(2R_{[\text{km}]}\right)} \tag{1}$$

System capacity is usually defined with reference to QoS constraints, such as call blocking probability (for real time applications) or packet delay (for non-real time ones). Its calculation involves a multi-service traffic analysis, hence results from [3] are fed into the revenue function via the spectral efficiency, $S_{ef}(R)$, which depends on the maximum cell coverage distance. The revenue per cell per year, $(R_v)_{cell}$, depends on the revenue per transceiver per year, R_{vt}, and is given by

$$\left(R_v\right)_{cell\,[\text{€}]} = \frac{T\cdot S_{ef}\cdot R_{vt\,[\text{€}]}}{K\cdot N_{op}}. \tag{2}$$

The revenue per kilometre per year, R_v, apart from a constant that depends on the number of slots per frame (each frame, in turn, corresponding to a carrier) and on the number of busy hours per year, does depend on S_{ef}, K and R. It is obtained by multiplying the revenue per cell per year by the num-ber of cells per kilometre, which, for the linear geometry, is given by $N_{c/km[\text{km}^{-1}]} = 1/(2R_{[\text{km}]})$, yielding

$$R_{v\,[\text{€/km}]} = \frac{\left(R_v\right)_{cell\,[\text{€}]}}{2R_{[\text{km}]}} = \frac{T\cdot S_{ef}\cdot R_{vt\,[\text{€}]}}{K\cdot N_{op}\cdot\left(2R_{[\text{km}]}\right)}. \tag{3}$$

2.3. Net Cost

A ‘net cost’ function (in €/km/year) results from (1) and (3)

$$C_{n\,[\text{€/km}]} = C_{fi\,[\text{€/km}]} + \frac{C_{fb\,[\text{€}]}}{2R_{[\text{km}]}} + \frac{T}{K\cdot N_{op}\cdot\left(2R_{[\text{km}]}\right)}\cdot\left(C_{ft\,[\text{€}]} - R_{vt\,[\text{€}]}\cdot S_{ef}\right), \tag{4}$$

which can be simplified considering $C_{fi} = 0$. The analysis of the cases with $C_{fi} \neq 0$ can then be done by comparing the ‘net cost’ obtained for $C_{fi} = 0$ with the fixed cost threshold, $(-C_{fi})$. If C_n is lower than $(-C_{fi})$ the system becomes profitable.

In the linear geometry, the number of cells per kilometre is given by $1/(2R_{[\text{km}]})$, while the ‘net cost’ per cell is given by the third term in (4), which allows to defining the cluster revenue-to-cost ratio

$$r_c = \frac{T}{N_{op}}\cdot\frac{R_{vt\,[\text{€}]}\cdot S_{ef} - C_{ft\,[\text{€}]}}{C_{fb\,[\text{€}]}}. \tag{5}$$

It provides the number of times the net revenue per cluster is higher than the cost associated with the installation and maintenance of a cell BS, and its associated equipment and infrastructures.

In the ‘Manhattan grid’ geometry [2], however, the cell *net street area* is $2\cdot l\cdot(2R-l/2)$, thus, the number of cells by net square kilometre is $1/[2\cdot l_{[\mathrm{km}]}\cdot(2R_{[\mathrm{km}]}-l_{[\mathrm{km}]}/2)]$, yielding to the following ‘net cost’ cost function for $C_{fi}=0$, in €/km^2/year,

$$C_{n\,[\text{€/km}^2]}=\frac{1}{2\cdot l_{[\mathrm{km}]}\left(2R_{[\mathrm{km}]}-l_{[\mathrm{km}]}/2\right)}\cdot\left(C_{fb\,[\text{€}]}+\frac{T}{K\cdot N_{op}}\left(C_{ft\,[\text{€}]}-R_{vt\,[\text{€}]}\cdot S_{ef}\right)\right). \tag{6}$$

For a two-dimensional system, it is rather natural to define a cost function, in €/km^2/year. Nevertheless, in order to have a quantitative comparison with the linear coverage geometry, one can consider that cells are formed by two orthogonal street portions forming a cross(ing), each with equivalent length $(2R-l/2)$ and width l. As a consequence, for each of the street segments composing the cell, one can consider a ‘linearised net cost’ function, as follows

$$\left(C_n\right)_{lin\,[\text{€/km}]}=\frac{1}{\left(2R_{[\mathrm{km}]}-l_{[\mathrm{km}]}/2\right)}\cdot C_{fb\,[\text{€}]}\left(1-\frac{r_c}{K}\right), \tag{7}$$

where the number of cells per kilometre is given by $N_{c/km[\mathrm{km}^{-1}]}=1/(2R_{[\mathrm{km}]}-l_{[\mathrm{km}]}/2)$. Analysing the ‘net cost’ function for $C_{fi}=0$, one concludes that r_c should be higher than the re-use pattern (i.e., the ‘cluster size’), in order to obtain a profitable system. This ‘linearised net cost’ function can be very useful for comparison purposes, and can consequently simplify the analysis. Thus, one can directly compare the linear and the ‘Manhattan grid’ geometries, the difference between them coming from the possibility of having different values of K, and from a slight difference in the number of cells per kilometre, as $1/(2R_{[\mathrm{km}]})$ is slightly different from $1/(2R_{[\mathrm{km}]}-l_{[\mathrm{km}]}/2)$ for low values of R.

3. Economic Analysis

3.1. Parameters

In order to understand the tradeoffs involved in the economic analysis, values for the model parameters have to be introduced for hypothetical scenarios. This is due to the dependence of the cluster revenue-to-cost ratio on R, which would make the analysis with a normalised cost function difficult. The goal is to grasp the impact of the choice of R and related frequency re-use parameters (e.g., the re-use pattern) on the MBS economic analysis. The ‘net cost’ function, C_n, has several parameters, namely R, K, N_{op}, S_{ef}, C_{fb}, R_{vt} and C_{ft}. Besides, one is considering coverage distances up to 500 m.

The re-use pattern depends on the frequency band, and on the coverage and re-use geometries. Values taken from the analysis in [2] are considered:

- $K=2$ in the [62, 63] GHz sub-band of the 60 GHz band for $R\geq 66$ m, in the linear geometry;
- $K=2$ in the [62.0, 62.5] GHz sub-band of the 60 GHz band for $R\geq 175$ m, in the ‘Manhattan grid’ geometry (lower *R*s being however allowed for frequencies near 62 GHz);
- $K=3$ in the remaining 60 GHz band (because oxygen attenuation imposes a different atenuation along the band) and in the 40 GHz one, for both linear and ‘Manhattan’ geometries;

One considered four system operators per band, i.e., $N_{op}=4$, each using a 0.5 GHz bandwidth, from a total of 2 GHz. The values for the spectral efficiency arise from the analysis in [3], where the total spectral efficiency, $(S_{ef})_{TOT}$, copes with the simultaneous contributions of up- and downlinks.

As a hypothesis, one uses the data extracted from [10] for the costs. One has also assumed that MBS will only be viable when the cost of deploying and operating the system will decrease to the order of magnitude of the costs associated with today’s systems. One assumes that the average load is 1 920 kb/s; one assumes that a unidirectional 1 920 kb/s MBS connection will cost approximately as much as a today GSM call. Thus, e.g., a 8 064 kb/s unidirectional connection will cost 4.2 times more than it, whereas a 384 kb/s call (thus, using a basic channel) will cost a fifth. Consequently, it is also natural to consider that the cost associated with the usage of the correspondent *fraction* of the transceiver infrastructure (supporting 1 920 kb/s, unidirectionally) will cost as much as a second generation system channel. As each frame has 48 slots [3], there are 48 basic units of 384 kb/s associated to the carrier, and there are 48/5 = 9.6 times 1 920 kb/s available; consequently, under our assumptions, the cost of an MBS transceiver will be 9.6 times the cost of a today's second generation channel (note however that a GSM carrier has eight channels, instead of '9.6').

As only micro-cells are used in MBS, one only considers the case of cell ranges of 300 m (case 1 of [10]). In this case, the setup cost is $C_{BS\text{-}tower}$ = 20 000 €, the channel cost is C_{1920} = 300 €/year (1 920 kb/s corresponds to five basic channels of 384 kb/s) and the maintenance and operation costs are $C_{mnt\&op}$ = 2 500 €/year. Consequently the cost of a basic channel is C_{384} = 60 €/year. These costs are presented in Euros (€), differently from the ones in [10], assuming parity between US Dollar and Euro. One also assumes that the estimated BS tower life is five years [10], and that the duration of the project is five years, N_{year}.

Finally, $C_{BS\text{-}tower}/N_{year}$ represents the annual cost of a BS equipment and infrastructure, which is true in the approximation of a null discount rate, if the calculations were made in real terms, i.e., in constant Euros [13]. Such is the approach followed here. A complete economic analysis based on discounted cash flows (e.g., to compute the net present value) will need the appropriate adaptations. As a consequence, in the model from (6) one has $C_{fb} = C_{BS-tower}/N_{year} + C_{mnt\&op}$ and $C_{ft} = 9.6\cdot C_{1920}$.

Furthermore, there is a fixed cost of licensing and frequency auctions (or 'beauty contests') to be taken into account. In a country like Portugal, if a 0.5 GHz license costs 200 000 000 € (twice the price of an UMTS license), under the simple assumptions of null rate of interest, one obtains an annual fixed cost of 40 000 000 €. Dividing this value by the number of kilometres covered by the MBS network in a medium phase of operation (e.g., 2 000 km in Portugal), one obtains an annual fixed cost per kilometre $C_{fi}(N_{op}=4) = 40\,000\,000/2\,000 = 20\,000$ €/km/year. One will further consider, as a hypothesis, an operator's target net revenue per kilometre per year of 130 000 ± 15 000 €/km.

3.2. Assumptions

Taking costs and revenues on an annual basis, one follows the approach of considering six busy hours per day, 240 busy days per year [10] and a 384 kb/s basic channel revenue $R_{384\,[€/\mathrm{min}]}$. The revenues are then proportional to the load supported by the system, in kb/s, which is reflected in the analysis via the spectral efficiency. It is, in turn, the minimum S_{ef} obtained from the blocking and handover failure probabilities constraints (i.e., between the cases P_b = 2 % and $P_{hf} = (P_{hf})_{max}(R)$), since the traffic from mobility has a strong impact. The revenue per cell per year is then obtained by

$$\left(R_v\right)_{cell\,[€]} = \frac{6\cdot 240\cdot 60\cdot S_{ef}\cdot T\cdot 48\cdot R_{384\,[€/\mathrm{min}]}}{K\cdot N_{op}} \tag{8}$$

where $T\cdot 48/N_{op}$ gives the number of 384 kb/s channels available in the cell. Note that 48 denotes the number of slots per frame, numerically corresponding to the number of basic channels (of 384 kb/s) per carrier, i.e., $R_{vt} = 48\cdot R_{384}$. Thus, the revenue per transceiver is $R_{vt\,[€]} = 86400\cdot 48\cdot R_{384\,[€/\mathrm{min}]}$.

Replacing the cost per carrier/transceiver, C_{ft}, by $48\cdot C_{1920}/5 = 9.6\cdot C_{1920}$, where C_{1920} is the cost associated with a 1 920 kb/s set of channels, and further considering T = 72 and C_{fi} = 0, one obtains

$$C_{n\,[€/\mathrm{km}]} = \frac{1}{2R_{[\mathrm{km}]}}\cdot\left[C_{fb\,[€]} - \frac{3456}{K\cdot N_{op}}\left(86400\cdot S_{ef}\cdot R_{384\,[€/\mathrm{min}]} - C_{1920\,[€]}/5\right)\right] \tag{9}$$

for the linear coverage geometry, with the restriction that $3456/(K\cdot N_{op})$ should be multiple of 48 (the number of slots per frame). Note that $T\cdot 48$ = 3456 represents the sum of slots from of all carriers (each carrier contributing with one frame).

In Table 1, besides the values of C_{fb} and C_{1920}, one presents the values of R_{384} for eight different cases (A, B, C, …, H), which will label the plots with results. The values in this table correspond to the URB scenario and K = 3 (in the presence of mobility). Results are being presented for i) K = 3/URB scenario (288 channel/cell) and ii) K = 2/ROA scenario.

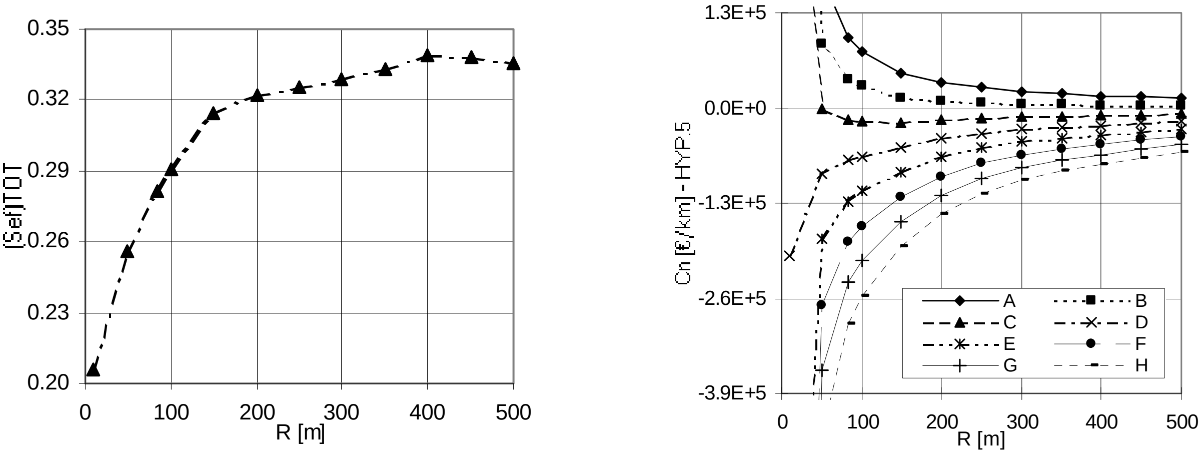
Table 1 – Assumptions for K = 3 (288 channel/cell) in the URB scenario (in the presence of mobility).

C_{fb} [€/year]	C_{1920} [€/year]	R_{384} [€/min]							
		A	B	C	D	E	F	G	H
6 500	300	0.00125	0.0025	0.00375	0.005	0.00625	0.0075	0.00875	0.01

For instance, R_{384} = 0.0075 €/min corresponds to the case F for the URB scenario, represented by a grey cell background in the table.

4. Results

The spectral efficiency gives the percentage of basic (384 kb/s) channels that can be supported for given blocking and call dropping probabilities (P_b = 2 % and P_d = 0.5 % [4]). For the set of services one considered in the urban scenario [5], one obtained the supported total spectral efficiency [5] that takes the simultaneous contribution of the up- and downlinks into account, Fig. 3.a).



a) Total spectral efficiency.

b) Net cost.

Figure 3: Results for the URB scenario (K = 3).

From the total spectral efficiency, one has obtained the 'net cost' for the URB and ROA scenarios (the 'linearised net cost is considered for the latter). Results for $C_n(R)$ are presented in Fig. 3.b) for the URB scenario, where the values of R_{384} are labelled with A, B,…, G and H. For cases D-H, the net revenue increases whereas R decreases (corresponding to a decrease of the net cost). However, as the initial investment associated with a system with smaller cells is much higher (and it will not be immediately compensated with revenues), MBS deployment strategies should consider larger cells in an initial phase. In a later phase, the installation of additional BSs in between the initial ones will provide smaller cells and higher system capacity.

It is important to analyse the values obtained for r_c, C_n, and R_{384}, so that the operator achieves a net revenue of 150 000 ± 15 000 €/km/year, while the annual payment of the fixed cost associated with licensing is 20 000 €/km/year, Table 2. One has considered K = 2 and 3, while R = 100 m (corresponding to a potential number of users in a cell M_T = 100 and 66, in the URB and ROA scenarios, respectively). Results are included for the supported number of user/km. Values are also included for K = 2 in the URB scenario (in presence of mobility), in order to enable the comparison between the URB and ROA scenarios for K = 2 and R = 100 m.

Table 2 – Results for r_c, C_n and R_{384} as a function of K and the scenario (R = 100 m).

Scenario	K	M_T	Mobility	r_c	C_n [€/km]	R_{384}[€/min]	Supported no. user/km
URB	3	100	Absence	15.75	-146 221	0.01	-
			Presence	17.07	-161 302	0.0075	74
ROA	2	66	Absence	10.25	-133 986	0.0875	-

			Presence	11.68	-166 495	0.045	50
URB	2	100	Presence	10.49	-146 021	0.005	117

To achieve an annual ‘net revenue’ (or profit) of 150 000 €/km, R_{384} should be higher for the deployment scenarios with lower associated spectral efficiency (for a given value of K). Whereas the spectral efficiency takes values $(S_{ef})_{TOT}$ = 32.2 and 15.2 % for the URB and ROA scenarios, the revenue from each basic channel has to be at least R_{384} = 0.005 and 0.045 €/min, respectively, i.e., the prices in the ROA scenarios have to be one order of magnitude higher than in the URB scenario. From these results for R_{384}, price lists can be obtained for MBS applications. The billing is done in a ‘per min’ basis, and not by volume of information. However, the volume of information is reflected in the price per min of each service component, as it is proportional to the service component data rate. It is also worthwhile to note that, as a consequence of this approach, Available Bit Rate applications will only be billed by the application minimum guaranteed data rate.

5. Conclusions

A ‘net cost’ model was presented for the design trade-offs between re-use pattern, K, the coverage distance, R, and the spectral efficiency, $S_{ef}(R)$, which allows for optimising the cellular planning in linear and regular urban geometries. This model allows for the determination of the revenue per channel that achieves a given value for the annual profit per kilometre. The existence of profitable cell configurations for the system was seen to depend critically on the relation between the re-use pattern and the cluster revenue-to-cost ratio. Results were achieved for the cluster revenue-to-cost ratio and for the ‘net cost’ for the cases URB scenario / $K = 3$ (and $K = 2$, for comparison purposes) and ROA scenario / $K = 2$. In order to achieve an annual ‘net revenue’ of 150 000 €/km, the revenue per basic channel should be higher for the scenario with lower associated spectral efficiency. For example, comparing the URB and ROA scenarios for R = 100 m and $K = 2$, whereas the spectral efficiency takes values $(S_{ef})_{TOT}$ = 32.2 and 15.2 %, the revenue from each basic channel has to be R_{384} = 0.005 and 0.045 €/min, respectively, i.e., the prices in the ROA scenario have to be around one order of magnitude higher than in the URB scenario.

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