COST / REVENUE OPTIMISATION IN MULTI-SERVICE MOBILE BROADBAND SYSTEMS

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Abstract - Multi-service traffic has a strong impact in Mobile Broadband Systems (MBS) revenues, allowing one to obtain merit functions for optimisation purposes. A 'net cost' model is presented for the design trade-offs between re-use pattern, K, the coverage distance, R, and the spectral efficiency, $S_{ef}(R)$. 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 with the 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 roads scenario (with higher terminal mobility) have to be around one order of magnitude higher than in the urban one.

Keywords - Mobile Broadband Systems, multi-service, mobility, costs, revenues, deployment scenarios.

I. 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 they will support several services simultaneously over the same platform, for different, or even the same, user(s).

Although OFDM (Orthogonal Frequency Division Multiplexing) can be a solution for MBS, in this work one is still assuming TDMA/FDMA (Time / Frequency Division Multiple Access), following the approach from RACE and ACTS European Commission projects [2]. Because the MBS concept is not yet completely defined, it is important to clarify the boundaries in data rates, operation scenarios, and mobility. Although one is aware that enhanced versions of UMTS will arise, the current MBS/UMTS boundary, after UMTS standardisation, is the following: 144 kb/s for fast mobile, 384 kb/s for slow mobile and 2 Mb/s for movable applications [3].

MBS deployment optimisation can be achieved by seeking optimum values of a merit function, whilst taking costs and revenues into account. The optimisation of cost/revenue provides a mean of putting together the several contributions from cellular planning: the determination of the re-use pattern and the coverage distance [4] plus the aspects of multi-service traffic engineering [5]. 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 revenues, together with frequency re-use aspects. The latter allows for the determination of the number of available channels in each cell, 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 multi-service traffic, and depends on the blocking and handover failure probability thresholds. The traffic from mobility has also a strong impact in revenue [6]. By no means is it intended to perform a complete economic study, but only to present initial contributions.

A cost/revenue function has to be developed, that copes with 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') have also to be taken into account. The economic analysis is referred as a cost/revenue analysis, because optimising costs do not necessarily mean optimising net revenues.

As a hypothetical scenario, one expects 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 MBS; in what follows, 1 920 kb/s will be considered as a hypothesis), users will not be willing to spend much more per minute during a call (or equivalent).

This paper is organised as follows. In Section II, after presenting some details of the MBS concept, the model for cost/revenue optimisation is presented. In Section III, values for the parameters are presented and assumptions are described. In Section IV, 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 urban and roads scenarios. Conclusions are drawn in Section V.

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II. COST/REVENUE MODEL

A. Components

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, and one is considering their point of view [7]. 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. For cost efficiency, Base Stations (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 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. Although one considers a project duration of five years, one will analyse costs and revenues on an annual basis. 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 [8]: (i) capital costs (cell site planning and installation), and (ii) operating expenses (operation, administration and maintenance).

Both the capital and the operating cost during system lifetime are taken to consist of:

- 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, plus their maintenance),
- a part proportional to the total number of transceivers per kilometre, or square kilometre (e.g., the cost of the transceivers and its maintenance).

Besides, the capital cost has also a fixed part (e.g., licensing and spectrum auctions or fees). 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.

One will start by considering the linear coverage geometry, Fig. 1. Let T be the number of carriers available, for each transmission link, up-/downlink, and N_{op} the number of operators. For a linear geometry one then has:

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

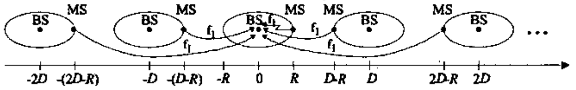

Fig. 1 - Linear coverage geometry.

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

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

System capacity is usually defined with reference to QoS (Quality-of-Service) constraints, such as blocking probability (for real time applications) or packet delay (for non-real time ones). Their calculation involves a multi-service traffic analysis. The load supported by the system, in kb/s, is proportional to the supported fraction of active users, which is a measure of system capacity. However, the 'net cost' defined in this work is proportional to the spectral efficiency. Hence, results from [5] are fed into the revenue function via the total spectral efficiency, $(S_{ef}(R))_{TOT}$, which copes with the simultaneous contributions of the up- and downlinks, and 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

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

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 number of cells per kilometre, which, is given by $N_{c/km[\mathrm{km}^{-1}]} = 1/(2R_{[\mathrm{km}]})$ for the linear geometry, yielding:

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

Both the overall cost and the revenue per kilometre will be fed into the 'net cost' function.

B. Net Cost

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

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

which can be simplified by 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 defining the cluster revenue-to-cost ratio

$$r_c = \frac{T}{N_{op}} \cdot \frac{R_{vt[€]} \cdot S_{ef} - C_{fi[€]}}{C_{fb[€]}} . \qquad (5)$$

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

In the 'Manhattan grid' geometry [4], however, the cell *net area* is $2 \cdot l \cdot (2R - l/2)$, thus, the number of cells by net square kilometre is $1/[2 \cdot l_{[\text{km}]}(2R_{[\text{km}]} - l_{[\text{km}]}/2)]$, yielding the following 'net cost' cost function for $C_{fi} = 0$, in €/km²/year,

$$C_{n[€/\text{km}^2]} = \frac{1}{2 \cdot l_{[\text{km}]}\left(2R_{[\text{km}]} - l_{[\text{km}]}/2\right)} \cdot C_{fb[€]}\left(1 - \frac{r_c}{K}\right) . \qquad (6)$$

Analysing this function, 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.

For a two-dimensional system, it is rather natural to define a cost function, in €/km²/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

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

This 'linearised net cost' function can be very useful for comparison purposes because it simplifies 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 $1/(2R_{[\text{km}]})$ is slightly different from $1/(2R_{[\text{km}]} - l_{[\text{km}]}/2)$ for low values of R.

III. ECONOMIC ANALYSIS

A. Cost Parameters

The goal of the economic analysis is to grasp the impact of the choice of R and related frequency re-use parameters (e.g., the re-use pattern) in MBS optimisation. The 'net cost' function, C_n, has several parameters, namely R, K, N_{op}, S_{ef}, C_{fb}, R_{vt} and C_{fi}. The re-use pattern depends on the frequency band, and on the coverage and re-use geometries. Values of $K = 3$ are achievable at the 40 and 60 GHz bands, whereas $K = 2$ in only achieved in the lower sub-band of the 60 GHz band. It is assumed that each operator uses a 0.5 GHz bandwidth, from a total of 2 GHz, hence, $N_{op} = 4$.

As a hypothesis, one uses the data extracted from [6], [7] 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 a unidirectional 1,920 kb/s connection (the average load of an MBS application) will cost approximately as much as a today' s GSM call, a little bit higher in an initial phase, decreasing down to values comparable to today's GSM ones in the following years. 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. As each frame has 48 slots [5], there are 48 basic units of 384 kb/s associated to the carrier/transceiver, and there are 48/5 = 9.6 times 1,920 kb/s available; in view of these facts, one considers that 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 9.6 kb/s channels, instead of '9.6').

As only micro-cells are used in MBS, one considers values for costs for cell ranges up to 300 m [6], [7]. If the calculations are made in real terms, i.e., in constant Euros, in the approximation of null discount rate, $C_{BS\text{-}tower}/N_{year}$ represents the annual cost of a BS equipment and infrastructure ($C_{BS\text{-}tower}$ is the setup cost and N_{year} is the project duration). Besides, $C_{mnt\&op}$ is the maintenance & operation cost. In this case, values of $C_{BS\text{-}tower}$ = 20 k€, $C_{mnt\&op}$ = 2.5 k€/year and N_{year} = 5 are used to compute

$$C_{fb} = C_{BS\text{-}tower} / N_{year} + C_{mnt\&op} . \qquad (8)$$

The channel cost is C_{1920}=300 €/year and

$$C_{fi} = 9.6 \cdot C_{1920} . \qquad (9)$$

These costs are presented in Euros (€), differently from the ones in [6], [7], assuming parity between US Dollar and Euro. One also assumes that the estimated BS tower life is five years [7]. A complete economic analysis based on discounted cash flows (e.g., to compute the net present value) will need the appropriate adaptations.

Furthermore, there is a fixed cost of licensing and frequency auctions (or 'beauty contests') to be taken into account. In a country like Portugal, assuming N_{op}=4, one has considered a fixed cost per kilometre C_{fi} = 20,000 €/km/year, as a hypothesis. One further considers, as a hypothesis, an operator's target net revenue per kilometre per year of 130 ± 15 k€/km.

B. Assumptions for Revenues

Taking costs and revenues on an annual basis, one follows the approach of considering six busy hours per day, 240 busy days per year [7] and a 384 kb/s basic channel revenue $R_{384\,[€/\mathrm{min}]}$. Note that considering a number of equivalent busy hours per day is an approximation, and will need validation. 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, since traffic from mobility has a strong impact. The revenue per cell per year is then obtained by

$$(R_v)_{cell\,[€]} = \frac{6 \cdot 240 \cdot 60 \cdot S_{ef} \cdot T \cdot 48 \cdot R_{384\,[€/\mathrm{min}]}}{K \cdot N_{op}} \tag{10}$$

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

$$R_{vt\,[€]} = 86{,}400 \cdot 48 \cdot R_{384\,[€/\mathrm{min}]} \cdot \tag{11}$$

The cost per carrier/transceiver is

$$C_{ft} = 48{\cdot}C_{1920}/5 = 9.6{\cdot}C_{1920}, \tag{12}$$

where C_{1920} is the cost of a 1 920 kb/s set of channels. Further considering $T = 72$ and $C_{ft} = 0$, one obtains

$$C_n = \frac{1}{2R_{[\mathrm{km}]}}\left[C_{fb} - \frac{3{,}456}{K\,N_{op}}\left(86{,}400 S_{ef} R_{384} - C_{1920}/5\right)\right] \tag{13}$$

for the linear coverage geometry, with the restriction that $3{,}456/(K{\cdot}N_{op})$ should be multiple of 48 (the number of slots per frame). Note that $T{\cdot}48 = 3{,}456$ represents the sum of slots from all carriers (each carrier contributing with one frame).

In Table 1, besides the values of C_{fb} and C_{1920}, one presents eight different cases (A, B, C, ..., H) which correspond to different values of R_{384}, i.e., these labels will distinguish the values of the revenue per basic channel of 384 kb/s in the plots with results. The values in this table correspond to the urban (URB) scenario and $K = 3$ (288 channel/cell), in the presence of mobility. For instance, R_{384} = 0.0075 €/min corresponds to the case F for the urban, URB, scenario, represented by a grey cell background in the table.

Table 1 – Assumptions for $K = 3$, URB scenario.

C_{fb}	C_{1920}	R_{384} [€/min]							
[€/year]		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

Results are being presented for (i) $K = 3$ / URB scenario (288 channel/cell) and (ii) $K = 2$ / ROA (roads) scenario.

IV. 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 % [5]). For the set of services one considered in the URB and ROA scenarios [9], one obtained the supported total spectral efficiency as a function of R [5], Fig. 2 (urban scenario, $0 < R \leq 500$ m), which is a measure of the supported traffic. As our approach consists of considering an equivalent number of busy hours per day, to use the supported traffic is appropriate since system operation near the saturation is properly modelled.

The 'net cost' was obtained from it (where the 'linearised net cost' was considered for the latter), Fig. 3 (urban scenario), where the values of R_{384} are labelled with A, B,..., G and H. For cases D-H, the net revenue increases when 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.

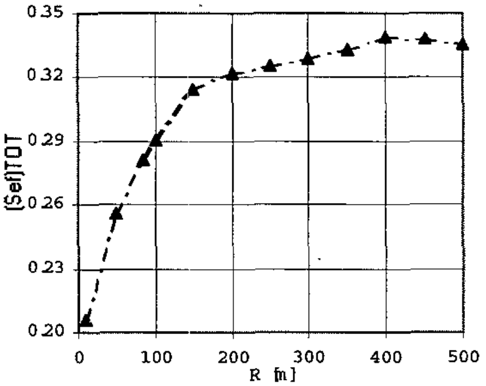

Fig. 2 - Total spectral efficiency, URB scenario ($K = 3$).

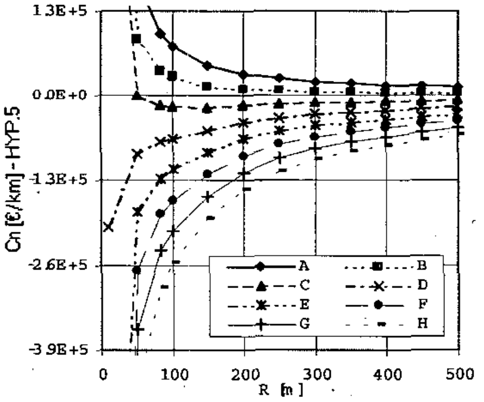

Fig. 3 - Net cost, URB scenario ($K = 3$).

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 (directly proportional to S_{ef}), C_n, and R_{384}, so that the operator achieves a net revenue of 150 ± 15 k€/km/year, while the annual payment of the fixed cost associated with licensing is 20 k€/km/year, Table 2. One has considered K = 2 and 3, cells with R = 100 m and the presence of mobility [5] (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 per km. Values are also included for K = 2 in the URB scenario, in order to enable the comparison between both scenarios for K = 2 and R = 100 m.

Table 2 – Results for r_c, C_n and R_{384} (R = 100 m) in presence of mobility.

Scenario	K	M_T	r_c	C_n [€/km]	R_{384} [€/min]	Supported no.user/km
URB	2	100	10.49	-146 021	0.005	117
	3		17.07	-161 302	0.0075	74
ROA	2	66	11.68	-166 495	0.045	50

To achieve an annual 'net revenue' (or profit) of 150 k€/km, R_{384} should be higher for the deployment scenarios with lower associated spectral efficiency (for a given 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 one. The lower spectral efficiency in the ROA scenario is mainly owing to fast mobility. From these results for R_{384}, price lists can be obtained for MBS applications. Billing is done on a 'per min' basis, and not by volume of information. However, the volume of information is reflected in the price per minute 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, ABR applications will only be billed by the application minimum guaranteed data rate.

V. 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 k€/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 (with higher terminal mobility) have to be around one order of magnitude higher than in the URB scenario.

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