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SERIES E: OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

Quality of service, network management and traffic engineering – Traffic engineering – Mobile network traffic engineering

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Terminal mobility traffic modelling

ITU-T Recommendation E.760

(Formerly CCITT Recommendation)

ITU-T E-SERIES RECOMMENDATIONS

OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

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ITU-T RECOMMENDATION E.760

TERMINAL MOBILITY TRAFFIC MODELLING

Summary

Terminal mobility traffic modelling for land terrestrial or satellite-based mobile systems (including cellular, cordless, paging and IMT-2000) presented in this Recommendation is intended to characterize the mobile user traffic demand associated with mobile services. This demand has significance for both the user and the signalling plane.

Source

ITU-T Recommendation E.760 was prepared by ITU-T Study Group 2 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on 13 March 2000.

FOREWORD

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NOTE

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CONTENTS

Recommendation E.760

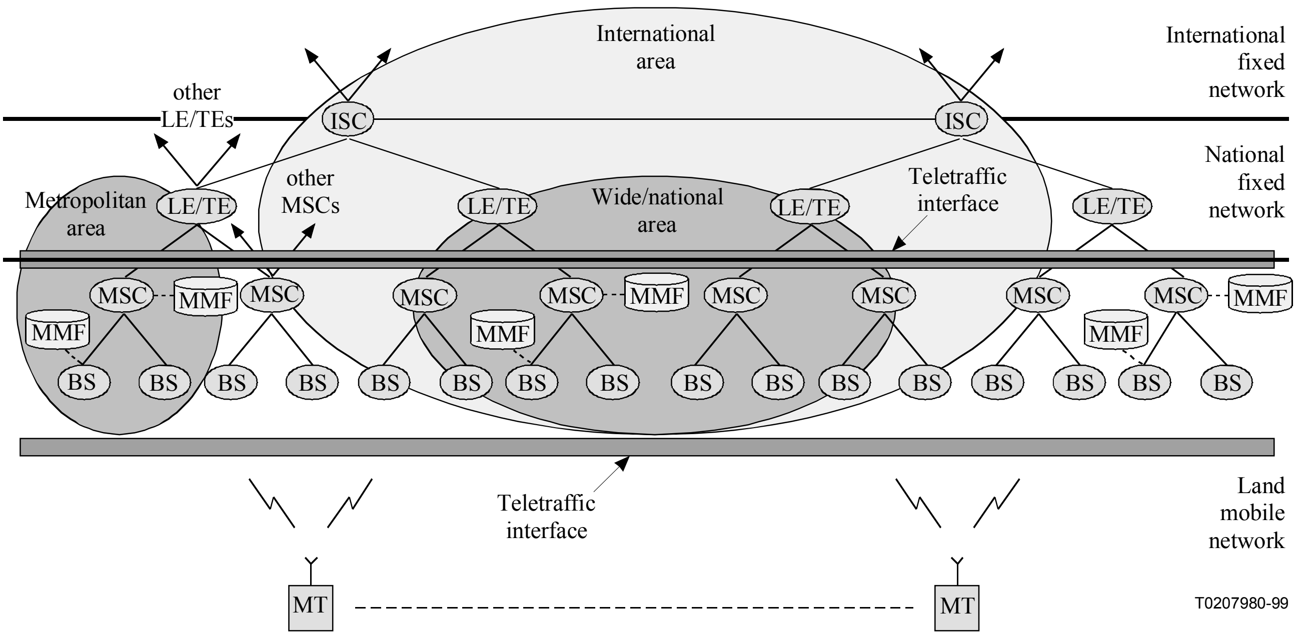
TERMINAL MOBILITY TRAFFIC MODELLING

(Geneva, 2000)

1 Objective and scope

1.1 Terminal mobility traffic modelling for land terrestrial or satellite-based mobile systems (including cellular, cordless, paging and IMT-2000) presented in this Recommendation is intended to characterize the mobile user traffic demand associated with mobile services. This demand has significance for both the user and the signalling plane.

1.2 The geographical scope of traffic demand and terminal mobility modelling ranges from metropolitan to international areas. As an example, Figure 1 shows the scope of Recommendation E.760 for the case of terrestrial-based cellular networks under the assumption of separated fixed and mobile networks (see Recommendation E.751). The figure indicates two teletraffic interfaces at which traffic demand has to be characterized for traffic engineering purposes. One traffic demand relates to the radio interface; the other is associated with the characterization of mobile related traffic which insists on the fixed network. This latter characterization is intended for the purposes of dimensioning fixed network resources used for supporting mobile services.



NOTE – The figure shows the interconnection of (separated) fixed and mobile networks, Recommendation E.220, and the allocation of mobility management functions (MMF) within the mobile network, as is typically the case with second generation mobile systems (e.g. GSM). Depending on the actual implementations and traffic requirements, the MSC (Mobile Switching Centre) can be connected with the fixed network ant the LE (Local Exchange) or TE (Terminal Exchange) level. This is succinctly indicated through the combination LE/TE. In fact, the allocation of MMF has a range of possible options including the arrangements resulting from integrated mobile and fixed network, Recommendation E.751.

Figure 1/E.760 – Scope of traffic demand characterization for cellular networks (separated mobile and fixed network, mobile-to-mobile communication)

1.3 This Recommendation addresses traffic demand modelling related to land mobile systems and traffic demand associated with the radio interface. Modelling of traffic demand insisting on the fixed network is for further study. Finally, traffic modelling for other systems, e.g. cordless and paging systems, is also for further study.

2 Related Recommendations

The following Recommendations contain material that is either relevant to or provides background for this Recommendation.

– CCITT Recommendation E.201 (1991), *Reference Recommendation for mobile services*.

– CCITT Recommendation E.202 (1992), *Network operational principles for future public mobile systems and services*.

– ITU-T Recommendation E.220 (1996), *Interconnection of public land mobile networks (PLMN)*.

– ITU-T Recommendation E.600 (1993), *Terms and definitions of traffic engineering*.

– CCITT Recommendation E.711 (1992), *User demand modelling*.

– CCITT Recommendation E.712 (1992), *User plane traffic modelling*.

– CCITT Recommendation E.713 (1992), *Control plane traffic modelling*.

– ITU-T Recommendation E.751 (1996), *Reference connections for traffic engineering of land mobile networks*.

– ITU-T Recommendation E.771 (1996), *Network grade of service parameters and target values for circuit switched land mobile services*.

– ITU-T Recommendation E.773 (1996), *Maritime and aeronautical mobile grade of service concept*.

– ITU-T Recommendation F.115 (1995), *Service objectives and principles for future public land mobile telecommunication systems*.

– ITU-R Recommendation M.1034-1 (1997), *Requirements for the radio interface(s) for International Mobile Telecommunications-2000 (IMT-2000)*.

3 Definitions

3.1 For the purposes of this Recommendation, definitions provided in Recommendations E.600, E.751 and E.771 will be applicable.

Additional definitions used in this Recommendation are as follows:

3.1.1 Network attachment point: The physical location in the network used for terminating the routing of calls to/from the end-user system (terminal identifier). In the case where the segment spanned between the physical termination of the end-user system and the network access point has additional functions to the sheer electrical connection, access network functionality is required for user information and signalling transfer.

4 Abbreviations

This Recommendation uses the following abbreviations:

BS	Base Station
GSM	Global System for Mobile communications
IMT-2000	International Mobile Telecommunications-2000
ISC	International Switching Centre
LE	Local Exchange
MMF	Mobility Management Function
MSC	Mobile Switching Centre
MT	Mobile Terminal
TE	Terminal Exchange

5 Introduction

5.1 One unique feature characterizing the traffic demand of mobile users is spatial volatility. This relates to the changing geographical origin (or destination) of traffic associated with the same mobile user once a connection has been established (in-call mobility) and is due to user terminal mobility. Another aspect of terminal mobility relates to users changing their geographical location in-between calls (inter-call mobility): this results in a dynamic association between the identifier of the actual terminal device used by a user and the network attachment point for calls originated by (or destined to) the same user.

5.2 As a consequence of traffic volatility combined with traffic source activity and spectrum reuse typical of cellular systems, the radio channel quality is space- and time-dependent and appropriate actions, e.g. handover or combining, may be performed by the system to help maintain a minimum level for the quality of service. Although these actions may result in a consumption of the same resources utilized for accommodating call demands, the characterization of the related processes depends, among others, on how radio resources are engineered and managed. For this reason the characterization of these processes is covered in Recommendations of the E.750-series especially concerned with traffic dimensioning methods for land mobile systems.

5.3 One way of capturing traffic volatility for engineering purposes is via a distribution in space and time of the user population over a considered area. This distribution shall then be mapped onto user demand, while retaining the space and time dependence.

Factors affecting this distribution include:

- environment type (indoor/outdoor, business, residential, etc.);
- geography of and mobility patterns on the considered area (open space, urban layout, city precinct, etc.);
- mobility characteristics (pedestrian/car mobility behaviour, speed, etc.);
- service penetration.

5.4 Although efficient use of the available spectrum might be attained by using various forms of dynamic bandwidth allocation to cope with the volatility of mobile traffic, most existing systems are dimensioned according to a worst-case approach with relationship to a static population of users. This implies that the highest traffic demand insisting on a given area (usually corresponding to a cell) is estimated and the number of radio channels related to that area is determined accordingly. The estimate is based on such data as density of residing population, service penetration, geographic characteristics, traffic per subscriber, etc.

This Recommendation is concerned with the worst-case approach as defined above; estimation of the traffic demand based on explicit consideration of the time and space traffic volatility is for further study.

5.5 Finally, to decouple the traffic demand characterization from the dimensioning and control procedures and harmonize with the methodology used for traffic engineering for fixed networks and services, the traffic demand processes for systems supporting mobile services have to be kept distinct from processes induced by network operation, such as channel quality maintenance and handover handling.

6 Estimation of traffic demand for cellular networks

6.1 Rationale

6.1.1 For traffic engineering of cellular systems, information on geographical population distribution is of vital importance to an operator. For new entrants to a market, this information can normally only be estimated using published census information. This may vary in resolution, with the better ones being rather detailed, and may resolve down to municipal or district level. From the census database and the size of the geographical area, it is possible to estimate the population density for the location. Together with the year-on-year user penetration forecast and the average traffic intensity per subscriber, the traffic demand can be obtained.

6.1.2 In parallel with the traffic engineering process, radio coverage planning is also performed to enable network infrastructure roll-out. Based on the terrain database and the morphology database together with the desired signal level necessary to provide suitable in-building and outdoor services, base site locations are identified. Frequently, contiguous coverage is required and, hence, the coverage area of base sites are packed closely together in order to eliminate coverage gaps as far as possible. In reality, the terrain is rather undulated. In order to eliminate the majority of the coverage gaps, it is required to significantly overlap the coverage between base stations. Thus the dividing lines defined by the equal signal level from two or more base sites will form the boundary of the "best server" region for individual base sites. In other words, when a mobile is within the best server region of a specific base site, it will receive the strongest signal from that base site even though the signal from other base sites may still be adequate for communications. By associating mobile stations with the base site of a best server region, the highest downlink carrier-to-interference ratio can be obtained[1].

6.1.3 As the best server regions are rarely regular in shape due to terrain undulation and other geographical features, the traffic capture ability of each base site could be quite different. By mapping the best server region into the population density map, a first order estimation of the traffic demand per sector can be realized. However, this may lead to substantial inaccuracies since users are generally congregated along roads and buildings and rarely located in open spaces. A method to obtain a more accurate estimation of the traffic demand is to polarize the population into areas where it is most likely to be located.

This can be achieved by assigning weightings to different geographical features. Based on these weightings, the traffic for each cell can be more accurately estimated. Evidently, for a cell which contains several open spaces, the amount of traffic is expected to be very low. By contrast, for a cell which contains buildings and shopping areas, the traffic density is expected to be high.

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[1] In addition, when power control is used in the uplink, a minimum transmit power is required which could in turn prolong battery life of the handsets.

6.2 Methodology

6.2.1 The input data to the procedure enabling the estimation of the traffic demand is as follows:

Input

- size of the service area[2] (height, width);
- number and location of the base station sites insisting on the service area;
- contour of the best server region around each base station site;
- size of the (identical) elemental areas (height, width) comprising an ideal grid superposed to the service area;
- population on the service area;
- service penetration rate;
- traffic per user;
- weighting factors accounting for the geographical features of the service area (see Table 1).

Table 1/E.760 – Weighting factors for the traffic demand in relationship to the geographical features

Feature	Weight
Road	ffs
Open space	ffs
Water	ffs
Road and building	ffs
Open space and road	ffs
Open space and building	ffs
Open space and water	ffs

6.2.2 The output of the procedure is:

Output

- traffic demand associated with each base station site comprised in the service area.

6.2.3 The estimation of the traffic demand associated with the radio interface of cellular mobile systems is organized according to the following steps:

Procedure

Step a) The best server regions associated with the base station sites are noted.

Step b) The ideal grid comprised of the elemental areas is superimposed to the service area.

Step c) The contour of each best service region is approximated by the sequence of the closest sides of the elemental areas. This way a discretization of the best server region is realized, with granularity depending on the size of the elemental areas.

Step d) Each elemental area is assigned a weighting factor depending on the geographical features of the underlying portion of service area. The type of weighting factors are as given in Table 1.

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[2] The service area is assumed rectangular in shape to simplify the description of the methodology. While no generality is lost in the description, in practice the portions of the best server regions beyond the borders of a rectangular service area have to be accounted for by extending to them the use of the procedure.

Step e) Traffic demand is allocated to each elemental area. The details of the computations are as follows:

i) normalization factors associated with each elemental area in the ideal grid are computed based on the related weightings given as in Step d). The normalization factors are used to apportion the traffic offered in the service area to the best service regions and, ultimately, to the base station sites;

ii) an initial average traffic demand per elemental area is computed by multiplying the traffic offered per user by the user density in an elemental area (the user density in an elemental area is obtained by dividing the total population by the surface of the service area, and multiplying by the service penetration);

iii) the initial average traffic per elemental area under ii) above is multiplied by the related normalization factor. This yields the traffic demand associated with each elemental area.

Step f) The products in iii) under Step e) related to the elemental areas comprising the same best server region are summed up: this gives the traffic demand associated with each base site.

An example of how traffic demand can be derived based on the procedure is given in Appendix I.

6.3 Upgrading of the procedure for estimating the traffic demand

Upgrading of the procedure described for estimating the traffic demand is possible. For example, socio-economic information could explicitly impact the weightings used for characterizing the traffic demand associated with individual base station sites. The use of additional information to impact the weighting scale is for further study.

7 Mobility modelling and impact on signalling traffic

7.1 Mobile networks require dedicated signalling functionality to perform tasks essential to supporting mobile services (e.g. registration, authentication, location and location updating, channel quality monitoring and restoration, etc.) Although explicit consideration of the traffic and mobility processes on the signalling plane is for further study, a model intended to account for the user mobility behaviour is addressed in Appendices II and III. The aim of this model is to represent a basis on which future Recommendations dedicated to dimensioning aspects of mobile networks could expand. This model considers the transition rate of users across the boundary between adjacent regions with significance for mobile networks, such as radio cells (Appendix II) and location areas (Appendix III). The user transition rate is an element which has a direct impact on signalling processes, and hence traffic engineering associated with the signalling plane.

8 History

8.1 Recommendation first published in 2000.

Bibliography

– GRILLO (D.), SKOOG (R.A.), CHIA (S.), LEUNG (K.K.): Traffic Engineering for Personal Communications in ITU-T Work: The Need to Match Practice and Theory, *IEEE Personal Communications*, Vol. 5, No. 6, pp. 38-58, December 1998.

APPENDIX I

Estimating the traffic demand

I.1 This appendix illustrates how to derive the traffic demand based on the procedure described in 6.2.3. Steps a) to e) of the procedure are illustrated in Figure I.1 with relationship to the following values:

Input

- size of the service area (height: 1.6 km, width: 1.1 km);
- number of the base station sites insisting on the service area: 8, location of the base station sites: as in Figure I.1 a);
- contour of the best server region around each base station site: as in Figure I.1 a);
- size of the (identical) elemental areas (height: 100 m, width: 100 m) comprising an ideal grid superposed to the service area;
- population on the service area: 17 600;
- service penetration rate: 5%;
- traffic per user: 20 mErlang;
- weighting factors accounting for the geographical features of the service area: as in Table I.1.

Specifically, Figure I.1 a) shows the geographical features and the best server regions of the area under consideration. Figure I.1 b) shows the $100 \times 100\ m^2$ grid overlay on the area. This represents the resolution of the digital terrain database which will eventually determine the resolution of the best server map as well as the traffic distribution map. Assuming that census information indicates that the $1.1 \times 1.6\ km^2$ area has a population of 17 600 people, this corresponds to a population density of one person per $100\ m^2$. With a service penetration rate of 5%, there will be 880 subscribers in the area. Given that each user will generate 20 mErlangs of traffic, the total traffic in the area amounts to 17.6 Erlangs. This corresponds to an average traffic density of 1 mErlangs per $100\ m^2$. As the resolution of the digital terrain database is accurate to $100 \times 100\ m^2$, computer prediction of the signal level for the best server region will be quantized into elemental areas of the same size. This is shown in Figure I.1 c). Finally, also assume weighting factors for the traffic load in relationship to the geographical features as represented in Table I.1.

I.2 By mapping the best server region to the traffic elemental areas, the traffic demand for each cell can be calculated. Applying the weighting to the geographic area as shown in Figure I.1 b), a weighting map as shown in Figure I.1 d) can be obtained. Summing the total weights in the service area and knowing the total traffic, the traffic for each individual bin can be apportioned as shown in Figure I.1 e). Finally, mapping the best server region to the traffic map, the traffic prediction for each cell can be obtained, Figure I.1 f).

To show the importance of using the weighting factors, consider the demanded traffic of Cell 1. Without the weighting factor, a traffic load of 3.3 Erlangs would be predicted. However, with the weighting, a traffic load of 4.2 Erlangs (30% higher) can be anticipated.

It should be noted that the weighting factors shown in this example are indicative and for real applications more calibrations are necessary to ensure satisfactory accuracy.

Table I.1/E.760 – Weighting factors for the traffic demand in relationship to the geographical features (indicative values)

Feature	Weight
Road	2
Open space	1
Water	0
Road and building	3
Open space and road	2
Open space and building	3
Open space and water	1

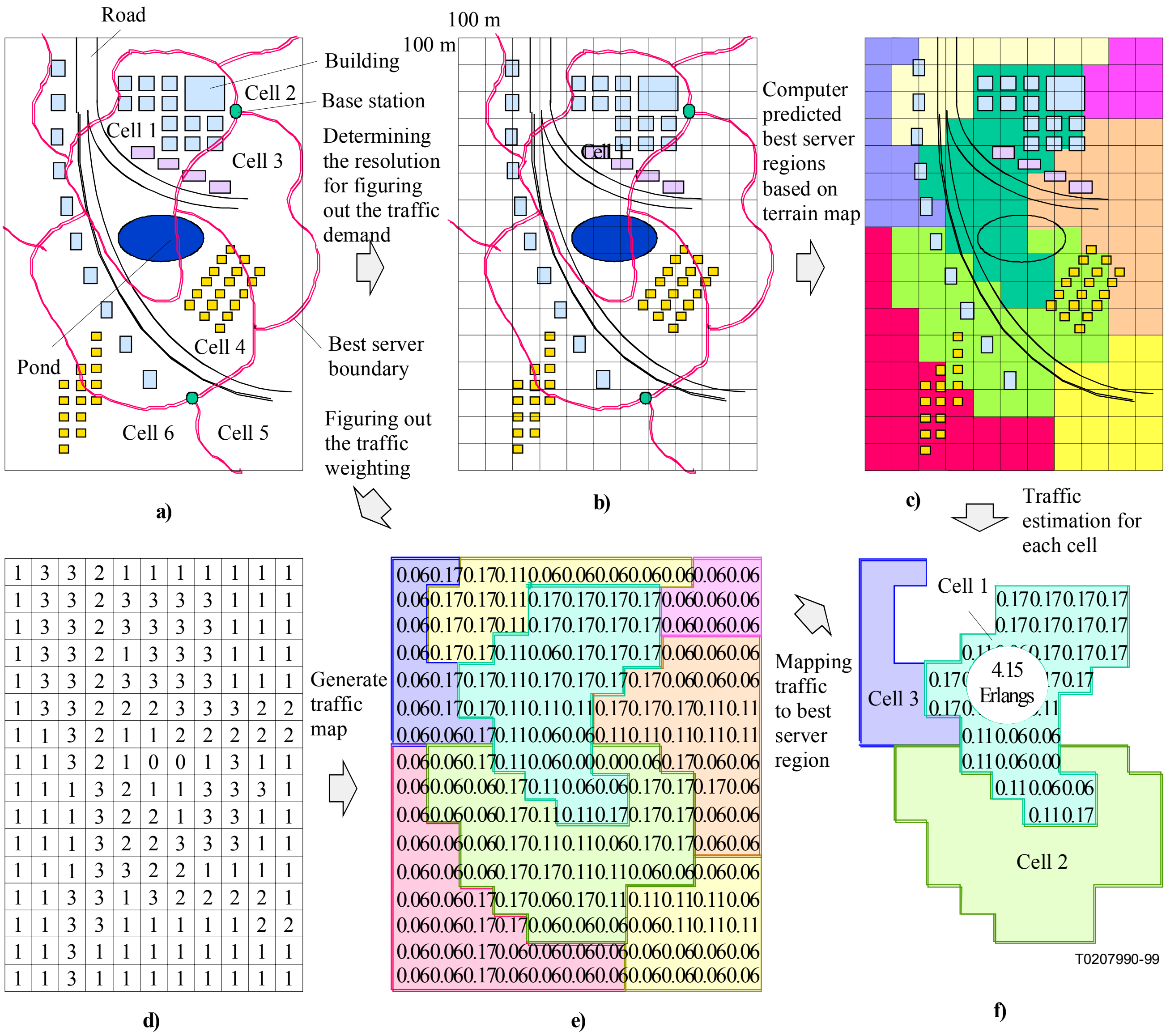

Figure I.1/E.760 – Estimating traffic demand from population distribution, service area layout and radio coverage arrangement

APPENDIX II

An example methodology for modelling the handover rate between cells in cellular, terrestrial-based mobile systems

II.1 Prediction of the handover rate in a cellular system has some common features with the prediction of the traffic demand, but it has also some very distinct features. For a given cell, the traffic demand depends on the user density in the whole cell, while the handover rate depends on the user density only in the border of the cell[3]. The in-call user mobility has only a second order impact on the traffic demand, while it has a fundamental impact on the handover rate. The mobility degree or speed of the users has to be considered, as it is necessary to distinguish between indoor and outdoor users, and for outdoor users, between pedestrians and cars.

The handover rate in cell is the rate of in-call users crossing the cell border. Given the overlapping between cells as a first approximation, the border of the cell can be taken as the border of "best server" region of its base station. To assume that the handover rate is equal to the in-call crossing rate of the border of the "best server" region leads to a safe-side estimation of the handover rate, since the system introduces a certain hysteresis before performing a handover[4].

II.2 Referring to a cell, distinction has to be made between outgoing handover rate (rate of in-call users moving out the cell) and incoming handover rate (moving into the cell). Both of them are estimated in a similar way. Obviously, an incoming handover in a cell is an outgoing handover of an adjacent cell. Thus we will refer here to the outgoing handover rate bearing in mind that the same could be said on the incoming handover rate.

Let a cell be characterized by:

- A density of in-call users at every point, given by the function $\sigma = \sigma(x, y)$.
- An average value of the component in the normal outside direction of the speed of each in-call user being in a point (x, y) of the contour, given by the function: $v_n = v_n(x, y)$.
- This average value is obtained considering the above-mentioned component equal to zero when it is negative (i.e. when the user goes in the inside direction).
- A border/contour L.

Thus, the number of in-call users crossing out the cell border per time unit, h, is:

$$h = \int_L \sigma \, v_n \, d\,l \qquad \text{(II-1)}$$

Two different approaches, apart from a mixed one, may be followed to integrate this expression. If the cell is in a rural area crossed by few roads and without any town in the border (see Figure II.1), the density σ can be considered zero in all the points of the border, except in the roads. The simplest way of evaluating the outgoing crossing rate is as the sum of the outgoing crossing rate by each one of the roads crossing the border:

[3] Only handovers due to the user's mobility, i.e. user crossing the border between adjacent cells, are considered here. Other types of handovers (e.g. those due to excessive co-channel interference or to traffic balancing between cells) are not considered in the proposed model.

[4] The case of hierarchical cellular layout with macrocells overlaid to microcells, resulting in more sophisticated rules for performing handovers, is for further study.

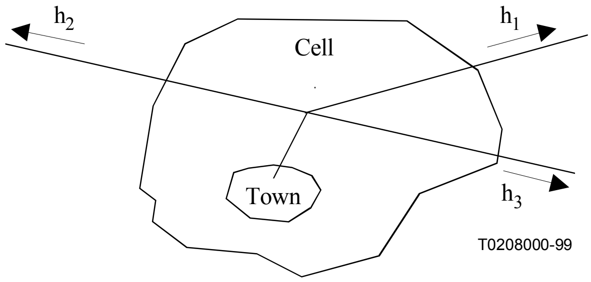

Figure II.1/E.760 – Typical rural area

$$h = \sum_j h_j \qquad \text{(II-2)}$$

where h_j is the number of in-call users passing by road i in the outside direction per time unit. Note that the existence of a town inside the cell, as in Figure II.1, is not explicitly considered in Formula II-2. h_j may be estimated from published road traffic information. The number of cars passing by each road per time unit must be multiplied by the service penetration factor and by the average traffic per user. If the cell border is close to a town, the number of pedestrians (with mobile set and in conversation) crossing the border by each of the roads must also be considered.

This approach, which is quite simple in a rural area with few roads, becomes tedious when the number of roads crossing the cell is large and even more in an urban area with a high number of streets. [1] shows that when the number of roads or streets crossing the cell is in the order of 10 or higher, a good approximation is to assume that the mobiles follow a random uniformly distributed direction with a same average modular speed in all the directions. If v is the average modular speed of the in-call users, then:

$$v_n = \frac{v}{\pi} \qquad \text{(II-3)}$$

and Formula (II-1) becomes:

$$h = \int_L \frac{\sigma v}{\pi} d\, l \qquad \text{(II-4)}$$

If both σ and v can be considered constant along the contour, the outgoing crossing rate is:

$$h = \frac{\sigma v}{\pi} p \qquad \text{(II-5)}$$

where p is the perimeter of the cell.

If σ can be considered constant in all the internal points of the cell:

$$h = a \frac{v p}{\pi S} \qquad \text{(II-6)}$$

where a is the (originating plus terminating) traffic demand in the cell and S is the surface of the cell.

Formula (II-5) and even more Formula (II-6) can be used in most cases only as a first approximation since the assumptions on which they are based are not usually satisfied. Thus, a more appropriate way of evaluating (II-4) is by overlaying a grid on the area as explained in Appendix I. Figure II.2 shows a 100 × 100 m^2 grid overlay on a cell. The border of the cell passes through 14 bins of the grid.

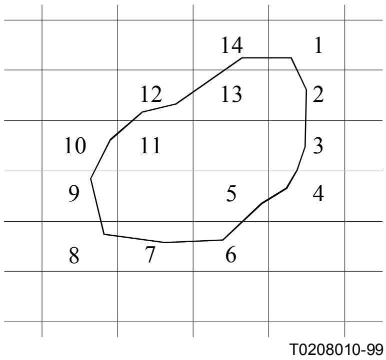

Figure II.2/E.760 – Use of a grid to estimate handover rate

For each bin i of the grid, the traffic demand a_i, the average speed v_i and the length p_i of the cell border within the bin can be estimated, and then Formula (II-4) becomes:

$$h = \frac{1}{\pi \cdot s} \sum_i a_i \, v_i \, p_i \qquad \text{(II-7)}$$

where s is the surface of a bin (10 000 m^2 in the case considered).

For estimating the product $a_i \, v_i$ in each bin, it may be useful to distinguish three types of users with very different mobility characteristics:

- Indoor users, characterized by a traffic demand a_{di} and an average speed v_{di}.
- Outdoor pedestrian users, characterized by a traffic demand a_{pi} and average speed v_{pi} [5].
- Users in cars, characterized by a traffic demand a_{ci} and an average speed v_{ci}.

Thus Formula (II-7) could be written as:

$$h = \frac{1}{\pi \cdot s} \sum_i \left(a_{di} \, v_{di} \, a_{pi} \, v_{pi} \; + a_{ci} \; v_{ci} \right) p_i \qquad \text{(II-8)}$$

a_{di}, a_{pi} and a_{ci} can be estimated by a procedure similar to that explained in Appendix I: to estimate the traffic demand of the group of users in the whole area and to apportion it among the bins by assigning a weighting factor to each bin. For estimating the average speed a_{di}, a_{pi} or a_{ci}, the fraction of users in movement during a call can be estimated, and multiplied by an estimation of their average speed.

For evaluating p_i it has to be considered that cell borders inside buildings are in general more irregular than in open spaces, with incurred higher values for p_i. Moreover, in the case of high buildings upper floors are sensitive to line-of-sight effects between base station antennas and openings in the walls (windows, external doors, etc.) which may alter the relationship between receiving/transmitting devices and best station valid for lower floors. These effects usually result in sequences of smaller, interleaved cells and, ultimately, in higher p_i values. The quantification of the dependency of p_i on the above aspects is for further study.

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[5] Users in large indoor surfaces (as e.g. large shopping centres) could have a mobility behaviour more similar to outdoor pedestrian users than to users in small indoor sites. In this case, they should be characterized by v_{pi} instead of v_{di} and their traffic demand included in a_{pi} instead of in a_{di}.

In some areas, a mixed approach among those represented by Formulae (II-2) and (II-8) could be more appropriate, for example, in a city crossed by a few highways, as in Figure II.3 a), or a cell whose border is partially inside a city and partially outside it, as in Figure II.3 b).

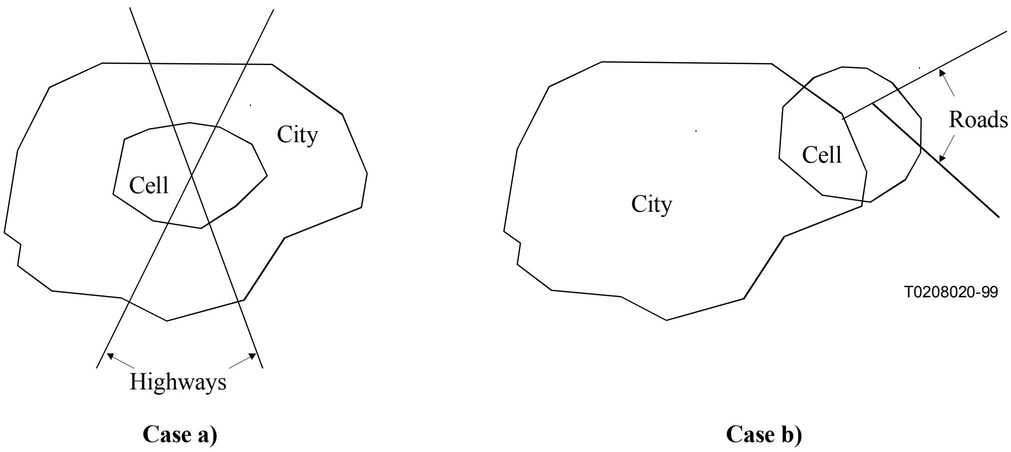

Figure II.3/E.760 – Examples in which a mixed approach is appropriate to estimate the handover rate

In these cases, a high fraction of the handovers may be produced by cars going by few roads or highways, but the number of handovers produced by other users (pedestrians or cars in streets or indoor users) may also be significant. It may be appropriate to estimate the rate of handovers produced by cars in the roads by means of Formula (II-2) and the rate of handovers produced by the other users by means of Formula (II-8). In this formula a_{ci} must not include the traffic produced by the cars in the roads.

APPENDIX III

An example methodology for modelling the location registration and location updating rate in cellular, terrestrial-based mobile systems

A location registration is produced when the user switches on the mobile set, and a location updating is produced when a switched-on mobile crosses the border of a location area.

The total location registration rate in a geographical area does not depend on the layout of location areas, while the location updating rate depends on it. For estimating the location registration rate, the operator must firstly estimate the number of users in the area and multiply it by the location registration rate per user, which can be estimated from the experience gained in geographical areas with similar characteristics. If the operator is interested in apportioning the total location registration rate into location registration rates for each cell, the same procedure explained in Appendix I for apportioning the traffic demand for each cell can be followed.

For estimating the location updating rate in a location area, the same methodology explained in Appendix II for estimating the handover rate may be followed. Formulas of Appendix II apply to this case by only changing:

- Cell by location area.
- Traffic demand by number of switched-on users.

This methodology may be appropriate for the first deployment of the network. Once the network has been deployed, statistics can be taken on the rate of handovers between each pair of adjacent cells. By assuming proportionality between the location updating rate and the handover rate between each pair of adjacent cells, the location updating rate for any other configuration of location areas can be estimated. It allows to choose the location area layout which minimizes the total location updating rate.

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