CONSIDERATIONS REGARDING A RADIO PLANNING PROCEDURE FOR THE GSM-R NETWORK COVERING THE BUCURESTI – CONSTANTA RAILWAY CORRIDOR

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Lucrarea descrie în detaliu o procedură de planificare radio special adaptată pentru proiectarea unei reţele de radiocomunicaţii mobile dedicată utilizării în cadrul infrastructurii feroviare, bazată pe standardul ETSI GSM-R şi conformă cu specificaţiile elaborate de Uniunea Internaţională a Căilor Ferate (UIC). Procedura de planificare radio propusă este practică şi originală prin ea însăşi, începând cu indicaţiile clare asupra scopului şi modalităţilor de manipulare a setului cartografic digital pentru reprezentarea cât mai fidelă a infrastructurii feroviare şi terminând cu furnizarea tuturor livrabilelor necesare dimensionării corecte a unei reţele GSM-R care să asigure servicii de comunicaţii mobile pe magistrala feroviară Bucureşti – Constanţa (225 km).

The paper describes in detail a radio planning procedure for the design of a railway radio communications network based on the ETSI GSM standard (GSM-R), compliant with all the mandatory requirements specified by the International Union of Railways (UIC). The approach of the proposed radio planning procedure is highly practical and original in itself, starting with clear indications on why and how to manipulate the digital cartography dataset to accurately represent the railway infrastructure, and eventually providing all the cell and frequency planning deliverables required to dimension a GSM-R network that covers the Bucuresti – Constanţa railway corridor (225 km).

Keywords: ITU; Land mobile radio cellular systems; Land mobile radio propagation factors; Land mobile radio interference

1. Introduction

An accurate radio planning is essential anywhere in the implementation process of an EIRENE (European Integrated Railway Radio Enhanced Network) network, starting with the preliminary planning phase, meant to correctly assess the system dimensioning and to fundament the equipment and services acquisition, and ending with the optimization phase, which ensures that the

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required parameters for the quality of services offered by the system are met. An EIRENE network provides the radio bearer for the train signaling systems (ERTMS – European Rail Traffic Management System and ETCS – European Train Control System), hence the railway safety relies on transmission link between train-borne and trackside ERTMS/ETCS applications, the EIRENE System Requirements Specification [1] are much more restrictive than those for commercial GSM networks.

The radio planning tool used throughout the radio planning procedure was ICS Telecom, produced by ATDI SA (www.atdi.com).

2. Radio planning assumptions and reasoning

A. Digital cartography

From the radio planning perspective, the digital cartography representation, integrated within the radio planning tool, is essential in order to ensure the desired radio planning accuracy. Regardless the types of propagation models used for the radio planning purposes, the representation of terrain and man–made features in the digital cartography set is one of the major inputs, if not the essential one, for the accurate simulation of radio propagation conditions. All the relevant radio propagation mechanisms at VHF and UHF frequency ranges – distance, reflection, scattering, refraction, diffraction, absorption – are decisively influenced by the environmental data stored in the digital cartography set, which, integrated within the radio planning tool, is further referred to as the *Geographic Information System (GIS) Functionality.*

The GIS Functionality used throughout the radio planning procedure includes the following data types, whose significance was largely detailed in [2]:
- Terrain elevation data (raster format 16 bits): DTED2 – 25 meters resolution Digital Terrain Model (medium resolution) – used in radio planning for calculation of point-to-point propagation losses (diffraction losses);
- Radio clutter data (raster format 8 bits): map of terrain occupancy – 25 meters resolution (original 50 meters resolution – resampled) – used in radio planning for calculation of point-to-point propagation losses (diffraction losses and absorption losses), and also for propagation model tuning;
- Image data (raster format 8 bits): scanned and geographically referenced paper maps – photographic images of the service area – no actual relevance in radio planning, useful for terrain orientation and landmarks identification;
- Vector data (VMAP2, SHP or other standard format): digitization of railway infrastructure, represented as vector lines and polygons – highly relevant in the prospective radio planning, as shown in the paragraph below.

B. Accurate representation of the railway infrastructure, the foundation of the radio planning procedure for the GSM–R network. Digital cartography manipulation

The radio access part of a GSM-R network consists of Base Transceiver Stations (BTS) and Terminal Stations, all of them being located along the railway routes, for obvious reasons [3]. The whole idea behind the GSM-R radio planning procedure herein is to generate subscribers along railway routes (accurately represented as vector lines and regions), and then to search, in the regions immediately adjacent to the same railway routes, the best locations for the placement of BTSs, in order to optimally provide radio coverage for the whole service area of the GSM–R network, leaving no portion uncovered, in accordance with the EIRENE SRS coverage requirements [1]. Having both the locations of the Terminal Stations and of the BTSs precisely determined, analytical point-to-point radio propagation models can then be used for the detailed radio design of the GSM-R network.

For this purpose, railway routes were firstly modeled using vector data achieved from high precision VMAP2 data, available from military sources (digitized from 1:50000 paper maps). Terminal stations were generated along railway routes, using the ICS Telecom function "Generate subscribers along vector line…", with exactly the desired density within the whole service area of the GSM–R network (i.e. one terminal stations on every 25 meters of railway track), and most importantly nowhere outside the service area.

The candidate areas for the placement of GSM-R BTSs were modeled as a dedicated railway clutter (raster format), starting from the same railway vector lines, which were subjected to a process called "rasterization", by means of the ICS Telecom function "Modify clutter along vector line".

This procedure ensured a perfect coherence between the vector and clutter files representing the railway infrastructure, that is all the subscribers used for the prospective radio planning are positioned on the railway clutter, which effectively "cuts" through other clutters represented on the map, giving the radio planner the possibility to deploy GSM–R base stations, in order to optimally provide radio coverage for the whole service area of the GSM–R network, leaving no portion uncovered.

C. Radio coverage requirements for GSM-R networks. Downlink and uplink link budgets

The radio coverage for a GSM-R network has to comply with the values specified in EIRENE System Requirements Specifications §3.2 [1], as follows:
- For network planning, the coverage level is defined as the field strength at the antenna on the roof of a train (nominally a height of 4 m above the track). An isotropic antenna with a gain of 0 dBi is assumed. The following minimum

values is recommended: coverage probability of 95% based on a coverage level of 41.5 dBμV/m (-95 dBm) on lines with ETCS levels 2/3 for speeds lower than or equal to 220km/h

- The specified coverage probability means that with a probability value of at least 95% in each location interval (length: 100m), the measured coverage level shall be greater than or equal to the figures stated above. The coverage levels specified above consider a maximum loss of 3 dB between antenna and receiver and an additional margin of 3 dB for other factors such as ageing.

For the mobile cab radio (8W transmit power) the maximum permissible pathlosses in the uplink and the downlink are almost equal (around 152 dB). This helps to ensure that there is good balance between the qualities of reception, at either end of the call [4].

Each of the BTS and Mobile Station features listed above are represented in the ICS Telecom software, through the radio stations and subscriber parameters configuration windows. The BTS antenna used throughout the simulation is Kathrein 739623 (65 degrees horizontal HPBW – half power beam width, 17 dBi gain, cross–polarized). The subscriber antenna was assumed to be the isotropic antenna, as recommended by EIRENE SRS.

3. Propagation models used within the radio planning procedure, in detail

Given the resolution of the available digital cartography (see §2.A), and the fact that the positions of the transmitters and receivers can be accurately determined through adequate digital cartography manipulation (see §2.B), we can conclude that *the path between the transmitters and receivers can be explicitly described in all cases, throughout the radio planning procedure* described in Chapter 4. *Thus, the highest accuracy of the radio propagation prediction (in terms of mean prediction error and standard deviation of prediction error) can be obtained through the use of deterministic (analytical) point-to-point propagation models*, as follows:

- ITU–R P.525 for free space attenuation [5];
- ITU–R P.526 §4.4.2 (Deygout) for diffraction geometry [6]
- ITU-R P.526 Appendix 2 to Annex 1 for subpath attenuation corrections [6];
- Rain attenuation (ITU–R P.838);
- Link reliability calculations (ITU–R P.530).

The following paragraphs in this chapter describe in detail, for reference, the selected propagation models (entirely documented by ITU-R recommendations P.525/526), showing how the propagation losses can be entirely determined by the geometry of the path between the transmitter and the receiver.

The accuracy of the deterministic propagation models can be significantly improved by model tuning. The propagation model tuning has been performed

using iterative modification of the terrain factors, i.e. *clutter attenuations*, as recommended by ICS Telecom user documentation [7], the coverage prediction results being correlated to actual drive test samples (52046 samples measured for five different GSM based stations, covering rural areas, comparable to railway environment). The objective of the propagation model tuning is to achieve a negative mean prediction error of less than 2 dB, and a standard deviation of prediction error not exceeding 5 dB, in other words, the simulation results should be slightly pessimistic when compared with the measurement results (drive tests).

A. ITU-R P.525 – Free space attenuation [5]

With a point-to-point link it is preferable to calculate the free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: L_{bf} or A_0), as follows:

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \qquad \text{dB} \qquad (1)$$

where:

f: frequency (MHz)

d: distance (km).

B. ITU-R P.526 - Propagation by diffraction [6]

A general guide for the evaluation of diffraction loss corresponding to § 3 and 4 of ITU-R P.526 is given in §7 of the same reference. In our case, given the resolution of the available digital cartography set, the procedure of choice is *Multiple knife edge*, as described in ITU-R P.526 § 4.4.2, whose main concepts are detailed below.

1) Fresnel ellipsoids and Fresnel zones

In studying radiowave propagation between two points A and B, the intervening space can be subdivided by a family of ellipsoids, known as Fresnel ellipsoids, all having their focal points at A and B such that any point M on one ellipsoid satisfies the relation:

$$\text{AM} + \text{MB} = \text{AB} + n \frac{\lambda}{2} \qquad (2)$$

where n is a whole number characterizing the ellipsoid and $n = 1$ corresponds to the first Fresnel ellipsoid, etc., and λ is the wavelength.

The radius of an ellipsoid at a point between the transmitter and the receiver can be approximated in self-consistent units by:

$$R_n = \sqrt{\frac{n \lambda d_1 d_2}{d_1 + d_2}} \qquad (3)$$

where λ is the wavelength, d_1 and d_2 are the distances between transmitter and receiver at the point where the ellipsoid radius is calculated.

2) Fresnel integrals

The complex Fresnel integral is given by:

$$F_c(v) = \int_0^v \exp\left(j\frac{\pi s^2}{2} \right) \, ds = C(v) + jS(v) \tag{4}$$

where j is the complex operator equal to $\sqrt{-1}$, and $C(v)$ and $S(v)$ are the Fresnel cosine and sine integrals defined by:

$$C(v) = \int_0^v \cos\left(\frac{\pi s^2}{2} \right) ds, \; S(v) = \int_0^v \sin\left(\frac{\pi s^2}{2} \right) ds \tag{5}$$

3) Single knife-edge obstacle

In this extremely idealized case, all the geometrical parameters are combined together in a single dimensionless parameter, normally denoted by **v**, which may assume a variety of equivalent forms according to the geometrical parameters represented in Fig. 1(a,b) below.
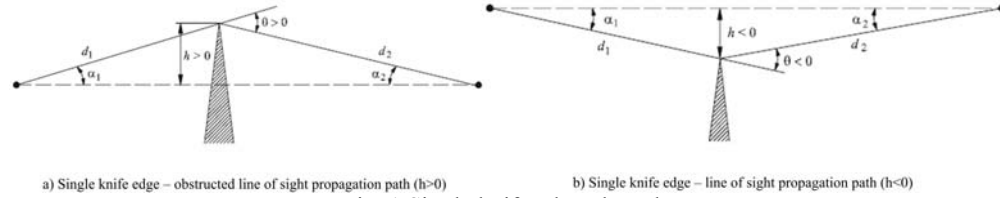

a) Single knife edge – obstructed line of sight propagation path (h>0)   b) Single knife edge – line of sight propagation path (h<0)
Fig. 1 Single knife edge obstacle

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2} \right)} \tag{6}$$

where:

h : height of the top of the obstacle above the straight line joining the two ends of the path (line of sight). If the height is below this line, h is negative

λ : wavelength

d_1 and d_2: distances of the two ends of the path from the top of the obstacle

d : length of the path

θ : angle of diffraction (rad); its sign is the same as that of h. The angle θ is assumed to be less than about 0.2 radians, or roughly 12°

α_1 and α_2: angles between the top of the obstacle and one end as seen from the other end. α_1 and α_2 are of the sign of h in the above equations.

NOTE – h, d, d_1, d_2 and λ should be expressed in self-consistent units.

From equations (3) and (6) it can be demonstrated that v can also be expressed in more easily computable terms as:

$$v = \sqrt{2}\,\frac{h}{R_1} \tag{7}$$

where:

R_1 : radius of the first Fresnel ellipsoid calculated at the coordinates of the obstacle top

The terms used in equation (7) are graphically represented in Fig. 2. The ratio h/R_1, between the obstacle height over the line of sight (positive upward), and the radius of the first Fresnel ellipsoid at distance d from the transmitter is commonly referred to as the *clearance ratio*.
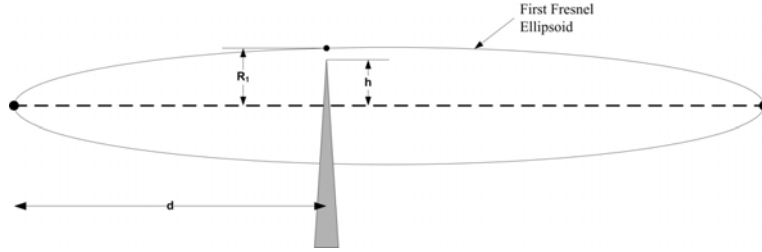

Fig. 2 Single knife edge diffraction as a function of the clearance ratio

Diffraction loss for a single knife edge obstacle, $J(v)$, is expressed through the complex Fresnel integrals as follows:

$$J(v) = -20 \, \log \left(\frac{\sqrt{[1 - C(v) - S(v)]^2 + [C(v) - S(v)]^2}}{2} \right) \quad \text{dB} \quad (8)$$

where $C(v)$ and $S(v)$ are the real and imaginary parts respectively of the complex Fresnel integral $F(v)$ defined above.

For v greater than –0.78 an approximate value can be obtained from the expression:

$$J(v) = 6.9 + 20 \log \left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1 \right) \quad \text{dB} \quad (9)$$

Fig. 3 below represents the diffraction loss $J(v)$ (dB), as a function of v.
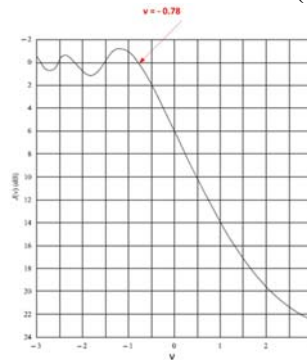

Fig. 3 Single knife edge diffraction loss

NOTE – the "no diffraction loss" value of ν (-0.78) corresponds to a clearance factor value of about -0.6, hence the widely spread rule of thumb, that if the first Fresnel ellipsoid is 60% clear, the diffraction loss is negligible.

4) Cascaded knife edge method

The procedure below, recommended through ITU-R P.526-11 §4.4.2, is based on the Deygout method limited to a maximum of 3 edges.

The method is based on a procedure which is used from 1 to 3 times depending on the path profile. The procedure consists of finding the point within a given section of the profile, with the highest value of the geometrical parameter ν, as described above. The section of the profile to be considered is defined from point index a to point index b ($a < b$). If $a + 1 = b$, there is no intermediate point and the diffraction loss for the section of the path being considered is zero. Otherwise, the construction is applied by evaluating v_n ($a < n < b$) and selecting the point with the highest value of ν. The value of ν for the n-th profile point is given by:

$$v_n = h\sqrt{2\frac{d_{ab}}{\lambda d_{an} d_{nb}}}, \; h = h_n + \frac{d_{an}d_{nb}}{2r_e} - \frac{h_a d_{nb} + h_b d_{an}}{d_{ab}} \qquad (10)$$

where:

h_a, h_b, h_n :   vertical heights as shown in Fig. 4

d_{an}, d_{nb}, d_{ab} :   horizontal distances as shown in Fig. 4

r_e :   effective Earth radius, as defined in ITU-R P.310 (8500 km for an atmosphere with a standard refractivity gradient)

λ :   wavelength

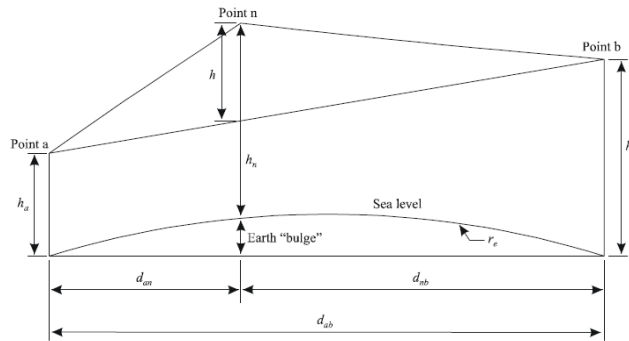and all h, d, r_e and λ are expressed in self-consistent units.

Fig. 4 Geometry for calculating ν for each point *n* along the propagation path

The diffraction loss is then given as the knife-edge loss $J(v)$ according to equation (9) for $v > -0.78$, and is otherwise zero.

Note that equation (10a) is derived directly from equation (6). The geometry of equation (10b) is illustrated in Fig. 4. The second term in equation

(10b) is a good approximation to the additional height at point n due to Earth curvature.

The above procedure is first applied to the entire profile from transmitter to receiver. The point with the highest value of v is termed the principal edge, p, and the corresponding loss is $J(v_p)$.

If $v_p > -0.78$, the procedure is applied twice more:
- from the transmitter to point p to obtain v_t and hence $J(v_t)$;
- from point p to the receiver to obtain v_r and hence $J(v_r)$.

The total diffraction loss for the path is then given by:

$$\text{L} = J(v_{\text{p}}) + T\left[J(v_t) + J(v_r) + C\right] \qquad \text{for } v_p > -0.78$$
$$\text{L} = 0 \qquad\qquad\qquad\qquad\qquad \text{for } v_p \leq -0.78$$

(11)

where:

C :   empirical correction, $C = 10.0 + 0.04D$ (12)
D :   total path length (km)

and

$$T = 1.0 - \exp(-J(v_p)/6.0)$$

(13)

5) Sub-path diffraction losses

The practical experience in using geometrical models with classical diffraction corrections, gained through comparisons with measurements, demonstrated that such models provided too optimistic field strength predictions, thus implying the need for additional geometric corrections. Appendix 2 to Annex 1 of ITU-R P.526 recommends a method to compute the additional sub-path diffraction loss, for a line-of-sight subsection of a diffraction path (see Fig. 5).
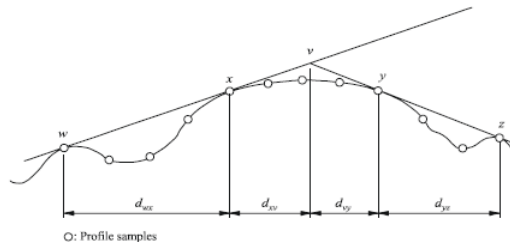

O: Profile samples
Fig. 5 Geometry for line-of-sight subsections of a diffraction path

The sub-path diffraction is to be calculated for each subsection of the overall path between points represented by w and x, or by y and z. The method can also be used for a line-of-sight path, with sub-path diffraction - the line-of-sight is clear of obstacles, but this is not the case for the entire zone defined by 60% of the first Fresnel ellipsoid. In such cases, the method below is applied to the entire path.

For a line-of-sight section of the profile between profile samples indexed by w and x (see Fig. 5), the first task is to identify the profile sample between but

excluding points w and x which obstruct the largest fraction of the first Fresnel zone for a ray travelling from w to x. To avoid selecting a point which is essentially part of one of the terrain obstacles already modeled when calculating the diffraction loss, the profile between w and x is restricted to a section between two additional indices p and q, which are set as follows:

- Set $p = w + 1$.
- If both $p < x$ and $h_p > h_{p+1}$, then increase p by 1 and repeat.
- Set $q = x - 1$.
- If both $q > w$ and $h_q > h_{q-1}$, then decrease q by 1 and repeat.

If $p = q$ then the sub-path obstruction loss is set to 0. Otherwise the calculation proceeds as follows.

It is now necessary to find the minimum value of the normalized clearance, C_F, given by h_z / F_1, where in self-consistent units:

h_z: height of ray above profile point
F_1:   radius of first Fresnel zone.

The minimum normalized clearance may be written:

$$C_F = \min_{i=p}^{q} \left[(h_z)_i / (F_1)_i \right] \tag{14}$$

where:

$$(h_z)_i = (h_r)_i - (h_t)_i \tag{15}$$

$$(F_1)_i = \sqrt{\frac{\lambda \cdot d_{wi} \cdot d_{ix}}{d_{wx}}} \tag{16}$$

$(h_r)_i$, the height of the ray above a straight line joining sea level at w and x at the i-th profile point is given by:

$$(h_r)_i = \frac{h_w d_{ix} + h_x d_{wi}}{d_{wx}} \tag{17}$$

$(h_t)_i$, the height of the terrain above a straight line joining sea level at w and x at the i-th profile point is given by:

$$(h_t)_i = h_i + \frac{d_{wi} \cdot d_{ix}}{2 r_e} \tag{18}$$

4. Description of the GSM-R prospective radio planning procedure. Nominal cell plan

The best BS locations are determined through a complex algorithm, implemented by the ICS Telecom function "Prospective planning from subscribers", which runs based on the following rules:

- BS locations are determined from the subscribers perspective – a BS is deployed only if its location is positioned on the allowed clutter selection (user configurable, i.e. clutter 11 – railway infrastructure) and has direct line-of-sight with a minimum number of subscribers (also user configurable); the subscriber database generated within the desired service area (see reasoning and procedure in Chapter 2) is incrementally parsed by the algorithm, which performs an intersection between the direct visibility areas, computed from each "orphan" subscriber location;
- Once a BS is deployed, the algorithm runs a downlink radio prediction from the determined BS location, through each of the "orphan" subscribers in the subscribers' database; all the subscribers which receive a signal level above an user configurable threshold (in our case -95 dBm), are parented to the new BS, and are no longer taken into account in the subsequent steps of the algorithm;
- The algorithm runs until one of the following conditions is met:
    - The percentage of "orphan" subscribers falls under a configurable threshold (e.g. <5%);
    - The distance between deployed base stations is lower than a configurable threshold (e.g. 10 km);
    - The density of remaining "orphan" subscribers is too low to allow the deployment of additional base stations.
- The final outcome of the GSM-R prospective radio planning procedure:
    - Nominal cell plan - 16 base station locations (sites), completely determined through geographic coordinates and nominal antenna heights;
    - 10166 subscribers parented out of the total 10258 generated subscribers (96.56%).

5. GSM-R radio network detailed cell planning

The following steps were performed in order to produce the other deliverables of the GSM-R radio planning procedure, thus completing the nominal cell plan resulted from the prospective planning procedure.

A. Base station sectorization

Each base station was configured with two sectors, oriented back-to-back along railway tracks, configured with the chosen sector antennas (Kathrein 739623). The sector orientation was automatically optimized using the "Station azimuth optimizing…" function. Essentially, the function rotates each base station sector in the azimuth plane, until the maximum number of subscribers is parented by that respective sector. This ensured that each sector was optimally oriented to connect the largest number of subscribers in its service area, along the railway tracks.

B. GSM-R network radio coverage calculation

The radio coverage was calculated based on the same propagation models, and the same radio parameters of the base stations, that were used for the GSM-R prospective radio planning procedure, again in accordance with EIRENE SRS.

The radio coverage map is represented using a color palette for different signal level thresholds. Fig. 6 presents a detailed view of radio coverage, showing how the base station position and sector orientation were optimized to exactly cover the railway track, the desired service area.
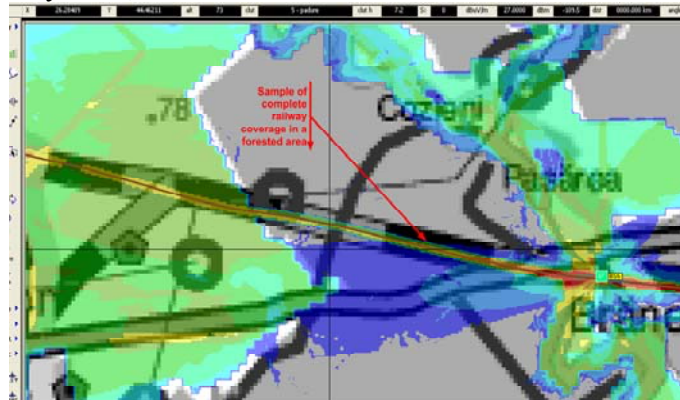

Fig. 6 Radio coverage – detailed view – railway track coverage in a forested area

The percentage covered from the desired service area (clutter 11 – railway tracks) is reported to be 98.21%. More sophisticated reports, for each point along railway tracks, can be generated using the "Vector layer→FS received on vector lines" function of ICS Telecom.

C. Frequency assignment

In accordance with EIRENE SRS, the UIC frequency band allocated for GSM-R is:
- 876 – 880 MHz (mobile station transmit); paired with
- 921 – 925 MHz (base station transmit).

The resulting frequency table contains a total of 19 channels (numbered 955 to 973), with 200 kHz bandwidth and 45 MHz duplex spacing.

For all stations along the rail track in rural areas and for other stations where the capacity demand is low, i.e. maximum 2 carrier units, there shall be one cell only. We should always try to configure with only one cell per station where this is possible from a frequency and capacity planning point of view. Also, at high speeds handover between cells on same site (intra-BTS handover) should be avoided, and this is another reason for not splitting cells in rural high-speed areas. The handover between BTSs is easier to perform since the signal strength of the serving and neighboring cells are more or less equal during a longer period of time.

The frequency allocation was done automatically, using the "Network assignment→Band assignment" function of ICS Telecom.

Channels 955, 971 and 973 were deliberately excluded from the attributable channels, in order to allow for further development and interference mitigation where need may impose that. The spare channels were chosen such that they can all be allocated in the same site.

Additional settings for the automatic frequency assignement:

- C/I mask (as for the GSM systems): $C/I_C > 12$ dB, $C/I_A > -6$ dB;
- Coverage threshold: -95 dBm;
- As we configured one cell per station, and each cell is distributed on two sectors facing oppositely along the rail tracks, we should not account for interferences between two sectors of the same cell. In ICS Telecom, this is achieved through setting the same "Network ID" for both sectors of the same cell, and allowing the allocation of the same frequencies for both sectors of the same cell.

D. Interference analysis

The interference analysis was carried out using the "Network interference →C/I mode" function ("Coverage" menu of the ICS Telecom main window). The interference analysis reports that 1.3% from the desired service area (railway clutter) is subject to interference, a fraction which is also negligible. A more detailed interference report is also available in tabular format, specifying the percentage of the service area interfered, for each base station and each radio channel. The highest interference percentage for one sector is 0.56%, again negligible from the radio planning perspective.

E. Handover map

Handover maps for each cell can be produced using the "Coverage→Handover" function. The result is available both in graphical and tabular formats, and indicates each base stations neighbors, and the surface of the handover area (see example in Fig. 7).
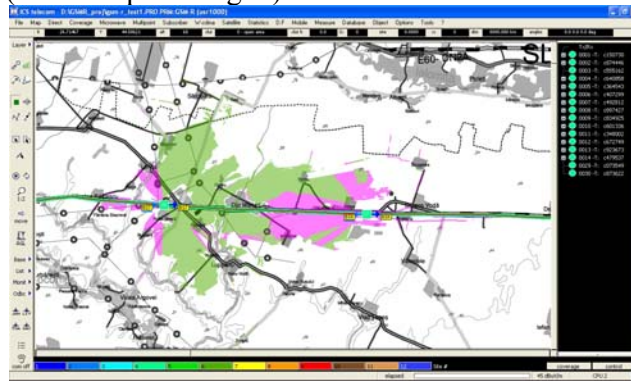

Fig. 7 Handover map – graphical representation

6. Conclusions

Radio planning for the GSM-R networks requires a much higher precision for the digital cartography set, than the one required for commercial GSM networks, mainly because of the extremely stringent radio coverage requirements specified by EIRENE SRS. The manipulation of the digital cartography to represent as exactly as possible the railway infrastructure, both as a set of vectors, and as a clutter layer, is described in detail in the paper herein, providing an original and easy to follow procedure and the solutions to generate the required geographic data.

Although the radio planning carried out throughout the paper is just a case study for the Bucureşti – Constanţa Railway Corridor, its results can be considered accurate enough at least to dimension an equipment and services acquisition for the implementation of such network. The radio planning deliverables are original by themselves, their accuracy being guaranteed by the use of deterministic propagation models, accurate cartography and a procedure that determines the best site locations/ sectors orientation, from the perspective of the exact area to be covered by the GSM-R network.

Future work is intended to refine the radio planning procedure in order to make it applicable to other railway corridors, running through mountainous terrain (e.g. Bucureşti-Braşov railway corridor), as well as to identify applicable radio planning procedures for railway tunnels environments.

R E F E R E N C E S

[1] *Union Internationale des Chemins de Fer, GSM-R Operators Group*, EIRENE System Requirements Specification, Version 15, 17 May 2006
[2] *L. Dobrică, T. Ionescu, L. Dobrică, S.E. Colesca*, Spatial Data Acquisition, Management and Visualization in Geographic Information Systems, UPB Scientific Bulletin, Series C, **Vol. 72**, No. 3, 2010, pp. 93-108
[3] *Compania Naţională de Căi Ferate CFR SA,* Proiect ERTMS Pilot Chitila-Crivina, pentru o aplicaţie ERTMS/ETCS de nivel 2, Document de licitaţie, **Vol. III**, Cerinţele angajatorului - GSM-R, Sistemul Electronic de Achiziţii Publice, Anunţ de participare nr. 112098/26.11.2010.
[4] *Union Internationale des Chemins de Fer,* GSM-R Procurement Guide, V. 5.0 – 01.02.2007, Paris, February 2007, pp. 111-115
[5] *International Telecommunications Union*, Recommendation ITU-R P.525-2: Calculation of free space attenuation, 1994
[6] *International Telecommunications Union*, Recommendation ITU-R P. 526-11: Propagation by diffraction, 2009
[7] *A. Graham, N. Kirkman*, P. Paul, Mobile Radio Network Design in the VHF and UHF Bands, John Wiley and Sons, Ltd, pp. 37-71, 2007