CAST: A SOFTWARE PACKAGE FOR THE DESIGN OF RADIO RELAY NETWORKS

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Abstract: CAST ("Coverage Advance Software Tool") is a network planning tool, developed at SIAE Microelettronica, specifically intended for the design of digital fixed radio relay networks for LoS access and infrastructure application. The paper, in its first part, describes the general architecture and the structure of CAST by showing the main tool components. The second part of the paper describes the most important features implemented in CAST giving examples of the most recent designing requirements and features. Finally, an on going extension for application to "nomadic applications of forthcoming WiMAX equipment is briefly introduced.

1. INTRODUCTION

The usage of software tools for the analysis and the design of communication systems has been a common practice in many scientific fields. This is of utmost importance for the wireless community where the need for a preliminary analysis of radio links is a mandatory requirement. For this reason, the market, offers several simulation packages suitable for the analysis and the design of various wireless networks (e.g. mobile, satellite, fixed radio). However, each network has its own peculiarity and has many substantial differences from the others. As an example, mobile network analysis is primary oriented to the coverage prediction and interference management. As a consequence, software packages for mobile network design have been developed by implementing sophisticated algorithms for the field strength prediction (e.g. ray tracing) with ad-hoc (non line of sight) propagation models. In addition, in the various wireless networks, the radio equipments could differ both in terms of physical layer, being they deployed in frequency bands with different characteristics, as well as in terms of DLC layer.

Taking into account these considerations, SIAE Microelettronica has developed CAST (Coverage Advance Software Tool), a specific software package for the analysis of fixed radio networks. This specific development has allowed the insertion of dedicated features for the design of fixed networks such as the propagation models published by ITU-R for line of sight radio links. In addition, CAST has offered, over the years (since its first development), a high degree of flexibility for the introduction of new features that were becoming fundamental for improving and speeding up the network designing process.

In this paper the basic CAST's characteristics will be presented with some basic theory upon which the tool is based. Finally, the latest features introduced into CAST will be presented.

2. SOFTWARE STRUCTURE

CAST can work in Microsoft Windows © environment. The software structure of the tool is shown in figure 1. The graphical interface is written in Visual Basic 6.0. It is a user friendly tool that allows the designer to easily perform the network design task. In particular, through the graphical interface it is possible to insert the input data (radio site coordinates, link parameters, antenna and radio equipment selection, etc.) as well as to show the output results (graphical layout of the radio network, path profile, link budget, etc.). All input parameters are stored into a Microsoft Access network database. This network database is connected with standard SQL interface to the graphical interface.

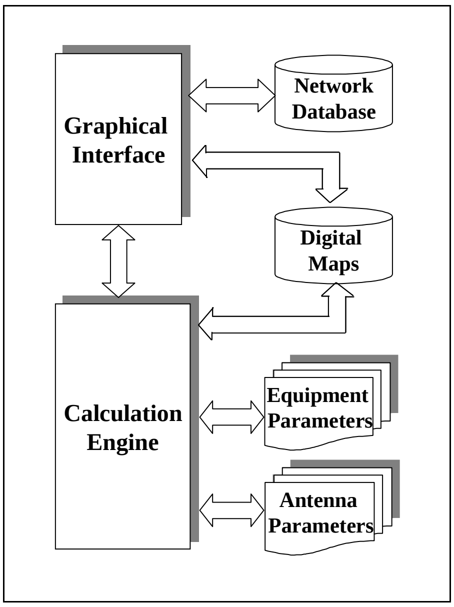

Figure 1 - CAST Software structure

The equipment parameters are stored in very simple text files that provide all the necessary information for the designing task. In addition to the most common parameters (capacity, modulation, operative frequency range, output power, BER thresholds, signature curves, etc.) the equipment files include the threshold degradation curves as a function of the C/I (Carrier over Interference ratio) and the NFD (Net Filter Discrimination) curves. These latter parameters are very important for the interference management of the radio network. In fact, as soon as a new link is set up, CAST calculates the interference between the new link and the other links already present into the network. All interference level is scaled by the proper NFD factor and stored into the network database. In order to perform the link budgets (whichever is needed, wanted or interfering) it is necessary to use the antenna RPEs (Radiation Pattern Envelope). These patterns are stored into four text files that represent the two co-polar (VV and HH) and the two cross-polar (VH and HV) radiation pattern envelopes. The digital terrain maps represent the third source of input data. The tool makes use of two types of digital maps:

- Lower resolution raster maps
- High-resolution urban maps

Basically, digital maps are files containing information on the orography of the terrain (elevation) and, for the high-resolution maps, information about the height and the shape of the buildings. For low-resolution maps, the terrain is divided in square pixels. Into each map are stored 600x400 integers representing the elevation above sea level of each pixel. In addition, each maps contains the UTM co-ordinates of the upper left corner of the covered area. Depending on the map resolution (200x200, 100x100, 50x50 or 20x20 m^2) the area covered by each map can vary from 120x80 to 12x8 km^2. High-resolution maps are used only for urban area and the resolution can vary frrm 1x1 to 5x5 m^2. In addition, for this kind of maps, beside to the elevation file, it is necessary to use a vectorial file containing the shape of each building. The vectorial file includes a list of UTM co-ordinates that represent the position of the vertexes of each building covered by the map.

The calculation engine represents the most important part of the software tool. It has been developed in standard C language and is stored into ".dll" libraries. The calculation engine receives input data from the graphical interface (as user's direct input as well as from the network database) and from the three main input data sources (equipment parameters files, antenna files and digital maps). By using the input parameters it performs all calculation required by the user (path profile calculation, coverage estimation, link budget calculation, etc.). The output results are then transferred to the graphical interface for a proper representation.

3. THEORETICAL BACKGROUD

CAST, as all software packages for the design of radio networks, is based on a large theoretical background that comes from the wide available bibliography, field trials and R&D studies carried out up to today. The basic know-how on the propagation theory has been integrated by the large amount of publications made available by the international standardisation bodies such as ETSI (European Telecommunication Standard Institute) and ITU-R (International Telecommunication Union-Radiocommunication Sector). In particular, ETSI Technical Reports represent a precious source of information and know-how on the newest available technology and on their usage. In the same way, ITU-R publishes a large number of recommendations that have been taken as the basic reference during CAST development. In particular, ITU-R F. series of recommendations provides, with CEPT/ECC recommendations, the essential information on channelization for all frequency band allocated for fixed radio applications. However, the most important source of propagation know-how is represented by the ITU-R Recommendations and Reports of the P. series. In fact, these recommendations represent a valuable work that has been carrier out during years on a large number of topics specifically oriented to the propagation issue. The most important of these recommendations, that in it self represents the base of the propagation know-how implemented into CAST, is the ITU-R P.530. The contents of this recommendation, evolved along the time through many releases, can be summarised as follows:

a) Flat fading model for multipath occurrence factor estimation
b) Flat fading outage estimation method
c) Selective fading outage estimation method
d) XPIC (Cross Polar Interference Canceller) outage estimation method
e) Diversity configurations outage estimation method

The most important of these items is represented by bullet (a). In fact, the basic parameter for outage estimation in terrestrial radio link is represented by multipath occurrence factor p_0. The recommendation ITU-R 530 provides a set of algorithms for the estimation of the p_0 factor that are the results of a valuable on-field experience and are recognised all around the world. CAST implements the most used of these algorithms providing a wide choice for the estimation of the multipath occurrence factor.

In the same way, CAST takes reference from all the most important ITU recommendations regarding quality and unavailability objectives for terrestrial radio links. In particular, ITU-T recommendations G.821, G.826 and G.828 have been considered during CAST implementation as a reference due to their popularisation around the scientific community.

4. BASIC CHARACTERISTICS

The calculation options, presently available into CAST, can be subdivided in two main categories:

- Options for general radio network analysis
- Options for link-by-link analysis

The first category includes those features that allow a preliminary network analysis to be carried out in advance before introducing any radio connection. The second category includes those features that specifically deal with the designing of radio links both in terms of link budget as well as in terms of frequency management.
The general network analysis includes all activities that are oriented to the definition of the network layout and can be used both for PMP (Point-to-MultiPoint) and PP (Point-to-Point) networks. In particular, for a general PMP analysis several coverage prediction options are available. In this case, during the designing process, the user's premises are not known. In addition, also the base station sites might not be known and many candidates could be available. So a preliminary study is necessary in order to select the best ones. In the same way, a channel frequency assignment for each sector shall be done in order to guarantee their coexistence in a way that should be as much as possible independent from the user's links that will be actually deployed in the network. The main CAST calculation options that can be categorised as general analysis options are as follows:

- **Path profile.** This feature allows drawing, by using the available digital maps, the path profile between two radio sites.
- **Cross visibility.** This feature, given a set of the radio sites, allows showing the visibility between all sites. In figure 2 it is shown an example of cross visibility
- **PMP coverage.** This feature allows showing the coverage of a PMP sector. The output result can be either visibility coverage or field strength coverage.
- **PMP C/I calculation.** This feature allows showing the C/I (Carrier over Interference) ratio among a set of PMP sectors. Fig. 3 shown an example with two sectors: the victim and the interfering ones.
- **Sector analyser.** This feature allows showing the areas over which it is possible to install peripheral units. In particular, the area covered by each sector is drawn with different colours in order to highlight the areas over which there is an insufficient filed strength or an unacceptable interference level
- **Union coverage.** This feature allows showing the coverage of a set of PMP sectors. The output result is the union of the coverage of each single sector either as visibility, field strength or sector analyser.

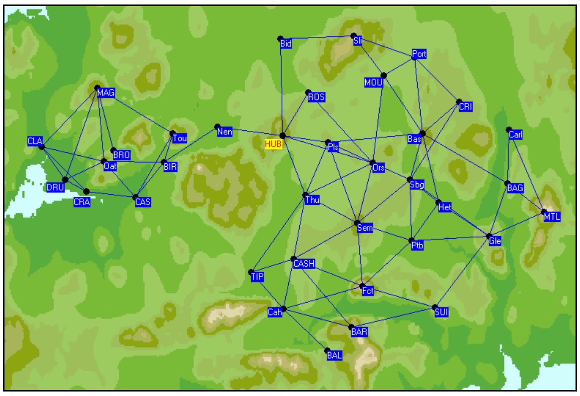

Figure 2 - CAST: cross visibility example

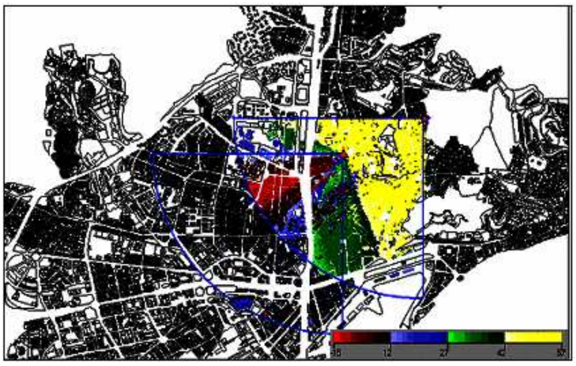

Figure 3 - CAST: PMP C/I calculation

The options for a link-by-link analysis include those used for the final designing task. In particular, in this category can be listed the following calculation options:

- **Obstacle editor.** This feature allows a deep analysis of the radio path profile allowing the insertion of a new obstacle or the removal of an obstacle due to orography.
- **PP and PMP link management.** This feature allows the management of each PP (Point-to-Point) or PMP (Point-to-MultiPoint) radio links both in terms of link budget, quality and unavailability objectives calculation and interference management. The tool allows showing a window for link budget summary. In addition, a summary window is used to details the quality and unavailability objectives achieved by the link. Finally, a summary is available for frequency management purposes showing the interference levels coming from all the links in the network.
- **Network computing.** This feature allows performing a test on all links present into the network by showing those links that are/are not compliant with the required quality and unavailability objectives.
- **Ray tracing.** This feature allows performing a deep analysis on a single link with 2-D ray tracing in order to find out the presence of anomalous propagation conditions. In figure 4 is shown an example of ray tracing output.

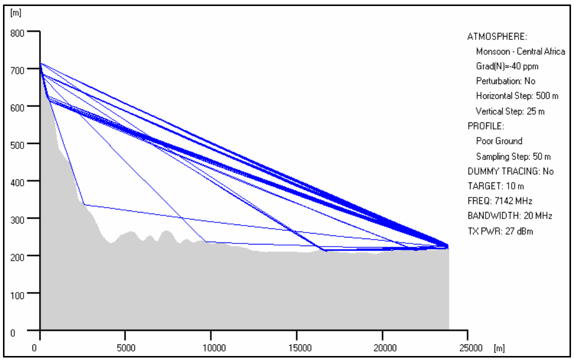

Figure 4 – 2-D ray tracing

5. NEW CALCULATION OPTIONS

In order to make faster the network designing task, new calculation options have been implemented into CAST. In this chapter we will present these new options.

5.1 Automatic network design

This new calculation option allows, given a cross visibility, to automatically find out a PP network solution. The option deploys a modified version of the Dijstra algorithm (see Dijstra, 1959) to find out the cheapest PP network that connect a main site to the other sites. The Dijstra algorithm can be described as follows. Let us suppose to have a graph *G* and a main source vertex *M* in *G*. Let us define as *S* the set of all vertices in the graph *G*. The vertices are connected through edges and each edge is provided by a non-negative cost. The algorithm works by searching, for each vertex in *S*, the cheapest path between the main vertex *M* towards all the other. The algorithm keeps two sets of vertices: *E* and *B*. The set *E* contains the vertices for which the cheapest path has been already found while the set *B* contains all the other vertices. At the beginning, the main vertex *M* cost is set to 0 while the cost for the other vertices is set to ∞. The vertex *M* is moved to set *E*. At the first step, the cost of each vertex directly connected to *M* is updated by the cost of the edge from *M*. The cheapest vertex is moved to set *E*. At the second step, starting from the vertices in set *E*, the paths cost towards the vertices in *B* is found by using the following strategy: if there is an edge from vertex s_i to a vertex s_j, the cost of the path reaching s_j can be found by taking the following cost:

$$C(s_j) = \min\big(C(s_j), C(s_i) + w(s_i, s_j)\big) \qquad (1)$$

The cost for reaching vertex s_j is the minimum between the current cost of the best path reaching s_j and the cost of the path reaching vertex s_i plus the cost of the edge between s_i and s_j. At the end of the second step, the vertex reached through the cheapest path is moved to *E*. The second step must be repeated until all vertexes have been reached. At the end of this procedure, for each vertex the cheapest path to reach it has been determined.

Referring to PP radio networks, many analogies can be found. The graph *G* is represented by the cross-visibility (see fig. 2) where an edge represents a radio link. The cost of the edge is the sum of the equipment plus antenna costs. In addition, mast fee and spectrum price must also be considered in order to correctly estimate the edge cost. The main difference between the original Dijstra algorithm is that, for PP radio networks, the edge costs can not be evaluated at the beginning but depend on the survivor paths selected by the algorithm. In fact, the cost of the equipment to connect a vertex s_i depends on how many edges are merging on it. For this reason and to keep limited the calculation time it is necessary to implement sub-obtimum versions of the Dijstra algorithm. In fig. 5 it is shown an example of PP network obtained by means of the automatic network design option starting form the cross-visibility in fig. 2.

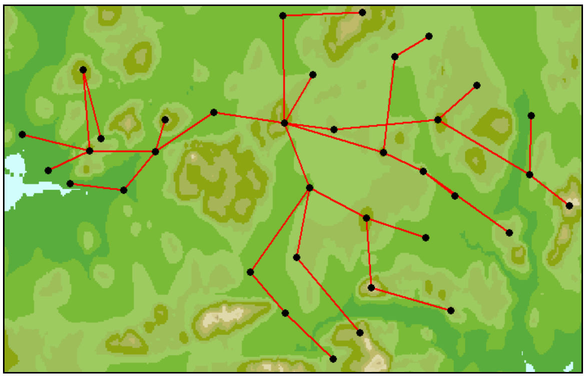

Figure 5 – Automatic PP network design

5.2 Automatic frequency allocation

After the automatic network design, CAST automatically assigns the carrier frequency to PP radio links. Let us define as *L* the set of all PP radio links with cardinality N_L. Let us also define as *F* the set of available frequency channels with cardinality N_F. The optimum methodology to find the best frequency allocation would imply checking exhaustively all the possible couple (L_i, f_i). However, this procedure could not be practical because the number of combinations is $N_F^{\,N_L}$. For this reason, CAST implements a sub-optimal procedure that, at the first step, chooses, in a random way, a PP link and assigns to it the first available frequency carrier. At the second step, another link is chosen and the same channel of the first link is assigned to it. If the coexistence between the two links is not guaranteed, another frequency carrier is assigned to the second link. The procedure is repeated until a sufficient degree of coexistence between links is achieved. Then, the second step is repeated until a frequency carrier is assigned to all the links. If the algorithm fails, the procedure is repeated by changing the choice of the link to be used in the first step and/or by increasing the number of available channels.

5.3 *DCN design for supervision network*

This feature allows the user to design a DCN (Data Communication Network) for the remote supervision of SIAE radio networks.

This DCN is basically an IP (Internet Protocol) network over which SNMP (Simple Network Management Protocol) packets are carried. The supervision traffic is out–of–band and the following dedicated ports are available on each equipment:

- Ethernet Port, to connect two or more equipments deployed in the same site
- Radio port, to establish a connection with the remote radio terminal through a dedicated radio channel;
- Serial port (RS232 or USB) to connect a Local Craft Terminal (LCT) for commissioning and local management;
- Other serial connections (RS232, STM-1 DCC, E1 64kbs Time Slot, etc…) depending on the radio equipment type.

The internal controller of the equipment acts like a layer 3 router between these ports: it needs an IP address for each supervision port and uses a routing table to route traffic between them. This means that different sub-networks must be used in order to address all SIAE equipment.

The DCN Design feature is based on the following sub-programs: Network Layout Editor (see figure 6) and Site Layout Editor (see figure 7). The Network layout editor allows the user to specify how the network sites are interconnected from the DCN point of view and the IP sub-networks to be used into each site. Different type of connections can be specified (radio, RS-232, etc.). Existing Radio connections can be imported from a radio network already deployed within the same project. On the basis of these inputs, the DCN engine will calculate the parameters (IP addresses and routing tables) to be set into each radio equipment. The Site Layout Editor allows the user to design the DCN interconnections between the radio equipment into each site. As a final result, either Excel or Word formats report can be exported, containing all the IP parameters to be set into each equipment.

5.4 *WIMAX coverage*

Taking into account the large interest on the new emerging WIMAX standard, an extension of CAST is needed. Provided that WIMAX equipment has been thought to work also without LOS (Line Of Sight) and with nomadic/mobile terminal equipment, a new CAST SW release is under development for introducing a dedicated calculation option in order to allow the estimation of sector coverage. The basic concept comes from those implemented into the planning tools for mobile network and makes use of the ray tracing techniques. In fact, the present PMP coverage calculation options are based on the concept of rooftop coverage by implementing the diffraction algorithms published into ITU-R recommendation P.526 for the field strength prediction. .

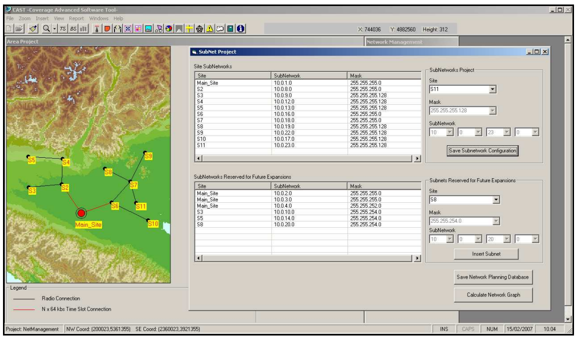

Figure 6 - Network Layout Editor

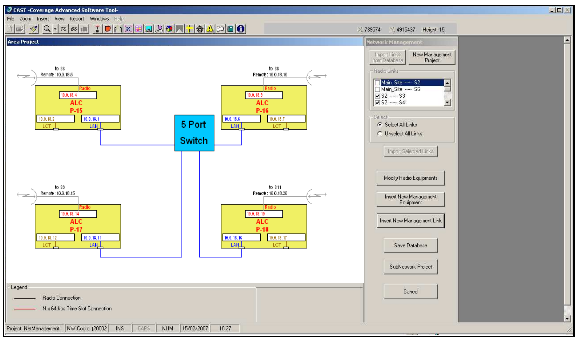

Figure 7 - Network Layout Editor

6. CONCLUSIONS

In this paper a description of the CAST planning tool has been presented. The tool has been developed in SIAE Microelettronica and allows the designing of PP and PMP radio network. In the present paper the main tool characteristics have been presented with particular emphasis to the newest ones.

7. ACKNOWLEDGMENT

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