CONSTRAINT PROPAGATION THROUGH ELECTROMAGNETIC INTERACTION TOPOLOGIES

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INTRODUCTION

The effects of electromagnetic interactions in electrical systems are of concern because of the increased pollution of the environment with electromagnetic emissions and because of the increasing susceptibility of system components. The term electrical system is used herein in the general sense to include more than just networks of electronic components. Systems containing biological and/or mechanical components of varying complexity are also included when reference to the term electrical systems is made. Electromagnetic emissions from components within the electrical system, and also disturbances originating external to it, can be classified as deriving from intentional as well as non-intentional sources.The interaction effects on the susceptible components within these systems range from minor to catastrophic; they cannot always be predicted nor are they always understood. Study and control of this problem is very desirable and has involved the efforts of many persons from varying fields.

Non-algorithmic or heuristic methods are used daily by engineers to solve electromagnetic interaction problems. An approximate symbolic knowledge representation of a *single* emitter/path/susceptor problem has been described by LoVetri *et al* [1]. The many emitter/path/susceptor interactions possible in a complex system can be better understood by constructing the systems electromagnetic interaction topology (see Baum [2]). Useful heuristic information about possible interaction problems can be derived solely from topology information (see Tesche [3]). The structure of an expert system capable of reasoning about electromagnetic topology characteristics has been proposed by Messier [4].

In this paper the approximate single emitter/path/susceptor attributes described in [1] are distributed throughout the electromagnetic topology of a complex system. A constraint-based approach for the modelling of the electromagnetic interactions in the system is then described. The approach taken here subdivides the modelling task into: a) the definition of the related physical topology; b) constraining topological nodes with specific electromagnetic attributes and c) the propagation of the electromagnetic constraints to determine the probability of failure.

ELECTROMAGNETIC TOPOLOGY

The electromagnetic topology consists of a description of the electromagnetically distinct volumes and their associated surfaces (see Baum [2], Tesche [3], and Messier [4]). The distinct volumes are used to define the *electromagnetic components* which are involved in the interaction. The interaction sequence diagram keeps track of the *interaction paths* throughout the system. The interaction sequence diagram, represented as bipartite graph, can be derived from a given electromagnetic topology. Variations on the labelling of these graphs and topology have been investigated by Noss [5]. This turns out to be unimportant as considered herein since each volume and surface node will be labelled with a physically meaningful name in the software implementation. Below, in figure 1, is an example of a topological decomposition of a computer system with its equivalent *bipartite graph representation* (see Bondy *et al* [6]) of the interaction sequence diagram.

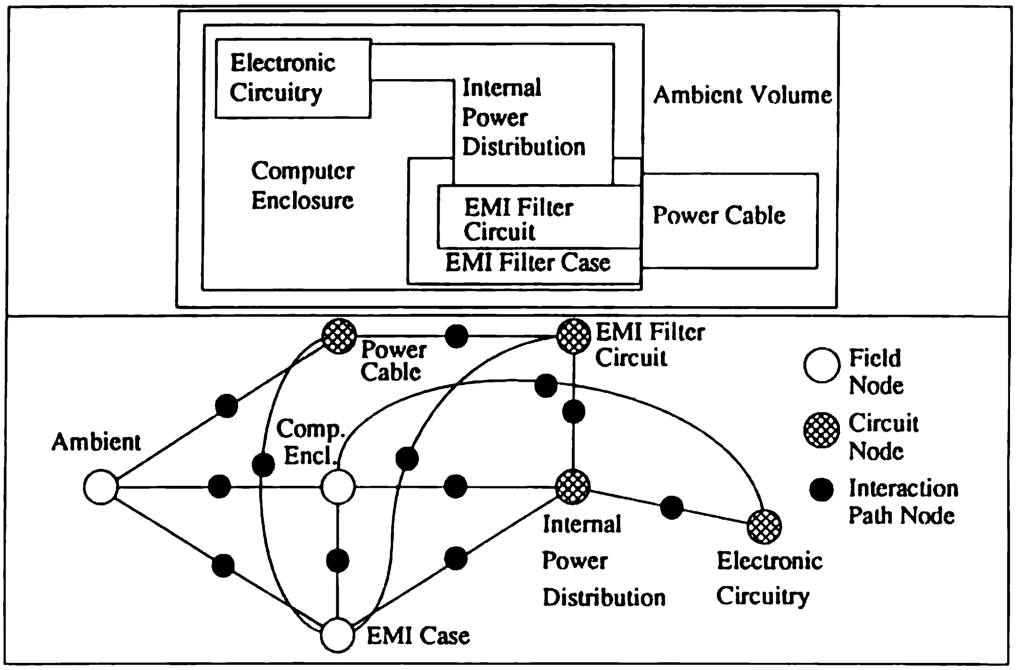

Figure 1: Example Topology with Equivalent Bipartite Graph

As depicted above in figure 1, volume nodes can be classified as two types: *Field Nodes*; and *Circuit Nodes*. This distinction determines the type of *units* which will be used for the node attributes. Thus, there exist four types of interaction path nodes: *ff-nodes*; *cc-nodes*; *fc-nodes*; and *cf-nodes*; where *f* represents an interaction to or from a field node, and *c* an interaction to or from a circuit node. For instance a cf-node indicates a path where circuit quantities such as voltage and current are transformed to field quantities such as electric and magnetic field.

NODE ATTRIBUTES

Nodal electromagnetic information is represented in an approximate way in that specific numerical data is not used (see LoVetri *et al* [1]). All the node attributes are specified over quantized *frequency ranges*. Each attribute does not need to be specified over the same frequency ranges since a normalization procedure is used to combine attributes specified over different frequency ranges.

Each component node in an electromagnetic topology may have an electromagnetic disturbance associated with it. This disturbance is denoted *AF* (*ambient field*) for all nodes. For field nodes the AF represents either the actual measured electromagnetic power density *emitted* by the component node or an approximation to this based on numerical and/or experimental data of similar components. For circuit nodes the AF represents power emitted by that node. For example, the AF of a circuit node may be instantiated as one of the qualitative levels shown in figure 2 for a specific frequency range.

extreme	if P is > 84 dBm/Hz (> 3.5 kV/Hz);
high	if P is 44-84 dBm/Hz (35 V/Hz - 3.5 kV/Hz);
medium	if P is 4-44 dBm/Hz (350 mV/Hz - 35 V/Hz);
low	if P is -36-4 dBm/Hz (3.5 mV/Hz - 350 mV/Hz);
very low	if P is < -36 dBm/Hz (< 3.5 mV/Hz);
nil	--> no disturbance;
unknown	(propagate as unknown throughout);

Figure 2: Example Disturbance Ranges for Circuit Nodes

Similarly, each node may contain susceptibility information denoted *SS* (system susceptibility). The SS value is also specified in a qualitative form as for the AF. Many AF's and SS's may be specified for a specific node. These are pulled out from a database of AF's and SS's for some typical electromagnetic components. Once all of the EM attributes for a specific node are entered a *frequency normalization* and *parallel addition* is performed on the AF and SS quantities in order to produce a *total* AF and SS for the node which is normalized to a chosen *global frequency range* (see figure 3 below).

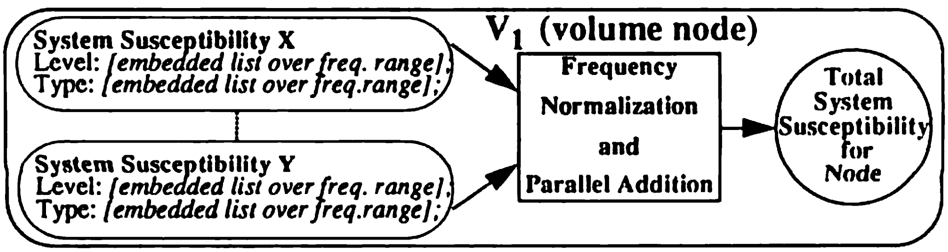

Figure 3: Susceptibility Attribute Structure for a Sample Node

The attribute values of the interaction path nodes may also be constrained to certain shielding effectiveness (SE) values. These are shown below in figure 4.

excellent	if SE > 100 dB;
good	if 80 < SE < 100 dB;
fair	if 60 < SE < 80 dB;
not good	if 40 < SE < 60 dB;
poor	if SE < 40 dB;
nil	--> no shielding; and
unknown	propagate as unknown throughout;

Figure 4: Shielding Effectiveness Ranges for Interaction Path Nodes

Parallel SE paths may also exist in a single interaction node as shown in figure 5 below. These are frequency normalized and added in parallel in a similar way to the AF and SS attributes.

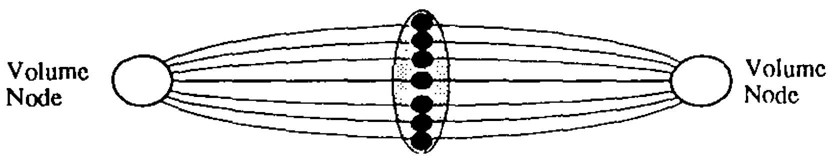

Figure 5: Interaction Path Composed of Many Parallel Paths

PROPAGATION OF CONSTRAINTS

The *probability of failure* (PF) of a component is determined by comparing its *total system susceptibility* to the *total ambient fields* received from all other components. In the topology representation of the physical system, the AF constraint value of one node must pass through various *shielding effectiveness* constraint values along its path to the node with SS constraint values. The methods by which an AF passes through an SE, combining multiple AF's received at a node, and comparing incoming AF's with the SS are all *propagation constraints* placed upon the system in the calculation of the PF.

In a typical highly connected, cyclical topology, an AF from one node has multiple paths and cycles to a susceptible node. A naive approach would be to determine all of the paths from all of the AF nodes to a given SS node, propagate the AF's through the SE's along these paths, and use the new AF values to determine the PF. To avoid this NP-complete search problem, a simple constraint heuristic is applied: in the calculation of the PF of one node due to another, only the weakest shielded path between the two nodes need be considered. Thus, in order to reduce search time *Dijkstra's algorithm* (see Bondy *et al* [6]) resulting in a minimal spanning tree for the single source problem is employed. The weights of the connections between nodes is the SE, which in turn are *summed* in series to determine the total SE of a path. For a given SS source node (root of the spanning tree), using such an algorithm is $O(n^2)$, where n is the number of nodes in the topology.

Searching can be further reduced by incorporating two other heuristics. First, instead of using Dijkstra's algorithm to find minimal paths from a given node to *all* other nodes, the search is stopped when all of the nodes with AF values have been considered, and the rest are ignored. Second, once the current total SE that is currently being considered has reached some maximum, the search is again stopped. This is permissible, since such a shielding may be considered so strong that no AF could pass through it.

As an AF passes through a series of SE's it is reduced proportionally by the amount of shielding. The reduction need not be linear. Also, since only the worst case scenario is considered, only the strongest AF of multiple AF's received as input to a susceptible node is used. This is the *parallelization* of multiple AF's (or similarly multiple SE's or SS's in parallel) by using the most conservative value. Finally, the calculation of PF is done by comparing the SS of a node to the parallelized incoming AF's using a non-linear table to arrive at a PF value.

Information is kept throughout the propagation of the constraint values and methods. This trace data is used to highlight the worst case (or *critical*) path. That is, the path of SE's between the SS node and AF nodes resulting in the highest PF. This tells the user, not only the cause of the PF but where changes in the topology might be made in order to reduce failure. A specific SE connection could be in a great number of the critical paths of the whole topology, suggesting an area for improvement. A ranking of worst to best case values during parallelization is also maintained. This information can be used for explanation and diagnostic purposes and help with finding alternate worst paths.

One of the problems encountered in using the scheme outlined above is how much of the search need be redone if the user changes the topology, and how the retained trace information can be used to further reduce search time. One technique already implemented is that of *grouping*. If a set of nodes and their attributes can be deemed fixed, the information they contained can be collected together. In a valid grouping, the *cut vertex* with respect to the remainder of the graph is determined and the AF and SS constraints from the grouped nodes are propagated through the SE paths to the cut vertex using the same procedures as described above. These values are then parallelized with the cut node's own AF an SS values to arrive at the group AF and SS constraints. Thus, whenever future searches are done on the entire topology, the paths within the grouped nodes need not be taken into account again, and only the group values are used. Grouping of nodes can also be done to simplify the interaction sequence diagram to obtain better understanding of the interactions. For example, components in a topology that make up a computer (such as a serial board, a CPU, etc.) may be grouped together by the user.

IMPLEMENTATION AND CONCLUSIONS

The scheme as outlined above has been implemented in *Quintus Prolog* on a *Sun Sparcstation*. The electromagnetic topology is represented in Prolog using an *object-oriented knowledge representation* methodology (see Stabler [7]). A graphical drawing tool is used to input the EM topology while the corresponding graph is automatically generated. A summary of the terminology for the different representations is shown in Table 1.

Table 1
Summary of Terminology

Physical System	Electromagnetic Component	Interaction Path or Mechanism
Electromagnetic Topology	Volume	Surface
Bipartite Digraph	Vertex or Node	Directed Node
Prolog Implementation	Object	Object

A small database containing some attributes of electromagnetic components found on the *Canadian NSA helicopter* was developed (see LoVetri *et al* [8]). A coarse topological decomposition of the helicopter was made and the attributes for the various components were entered. This tool was very useful in providing understanding of all the complex interaction paths existing in complex systems.

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