Evolutionary Telecommunications: A Summary

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1 INTRODUCTION

This paper provides an early summary of aspects of a nearly-exhaustive survey of evolutionary telecommunications, *i.e.* the application of evolutionary computation (EC) to the telecommunications problem domain. To the best of the author's knowledge, there has been no prior publication of a thorough survey in this area. It is hoped that the full summary, when published, will correct this omission.

In considering the scope of the survey, it was decided to restrict it to the application of purely evolutionary approaches to problems that are unique (or nearly unique) to telecommunications, such as network design. As a result, not only other modern heuristic methods, such as simulated annealing and tabu search, but also other natural algorithms were excluded including *e.g.* ant colony optimisation. Limiting the problem domain to applications unique to telecommunications also removed many papers. Examples include areas as diverse as signal processing, groundwater monitoring network design, distributed computing and distributed databases. Furthermore, it was decided to focus exclusively on published papers, rather than include project reports, theses or technical reports. These are not necessarily of the same standard as published material, and where they are, this is best demonstrated by subsequent peer-reviewed publication. A final limitation is that there are some papers, of which the author is aware, that could not be located in the timescales and with the means available; as a result, these too have been omitted. In total, 112 papers are currently judged within the scope of the survey.

Fig. 1 shows the chronological distribution of the papers. From the earliest in 1987, there has been a long-term pattern of steady growth, overlaid by the two-year cycle of important conferences for the area, particularly the ICGA series. The slightly depressed total in 1998 is believed to be partially due to this latter effect, as well as to the relative difficulty of locating recent conference papers.

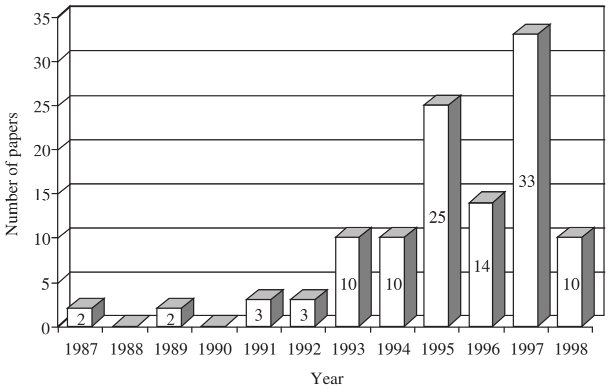

Figure 1: Number of Evolutionary Telecommunications Papers by Year

2 APPLICATIONS

In this summary, as well as only mentioning a subset of papers, the focus is primarily on application areas. In the full survey, consideration will also be given to solution representation, population dynamics, selection methods and genetic operators (including their adaptation). Table 1 records the classification of papers into application groups. While papers have usually only been included in one column (application area), they have been counted in as many rows (problem elements) as necessary. Although there is reasonable overall coverage, with every feasible 'cell' containing some papers, some applications have resulted in more publications than others. For example, while there are many similarities between wavelength allocation in optical networks and frequency assignment in radio networks, the latter has almost four times the number of papers. Such imbalances may well indicate areas with potential for further research.

Table 1: Number of Evolutionary Telecommunications Papers by Application Groups

PROBLEM ELEMENT	APPLICATION AREA GENERAL NETWORKS	OPTICAL NETWORKS	RADIO NETWORKS	COMPUTER NETWORKS
Dimensioning	11	6	4	10
Node location	9	3	7	2
Topology	15	5	—	9
Trees	19	2	—	2
Routing, restoration & call admission	20	4	3	9
Wavelength allocation & frequency assignment	—	4	15	—

Fully 27 papers consider *dimensioning* of telecommunications networks, although usually alongside another aspect of network design, such as node location, topology or routing. Some of the earliest evolutionary telecommunications papers address this area including Coombs & Davis (1987), Davis & Coombs (1989) and Potter *et al.* (1992). In their papers, Davis & Coombs select link capacities for wide-area packet switched networks using a hybrid genetic algorithm (GA) with both an integer representation and several problem-specific operators. They also apply efficient approaches to incorporate their numerous design constraints. Potter *et al.* combine both a hybrid GA and a bit-string GA for the design of military networks, including network element selection, dimensioning and battlefield location.

Network *node location* is tackled by 17 papers. As well as the early work by Potter *et al.*, Routen (1994) considered the concentrator assignment, terminal layout and concentrator location problems in local access network design. His GAs use integer representation and some problem-specific operators. More recently, Webb *et al.* (1998) employed a bit-string GA with heuristic repair for backbone node selection in a ring-star transport network. They contrasted topologies resulting from both distance- and tariff-based cost models.

Network *topology* design is the focus of some 29 papers. Two of the earliest are by Michalewicz (1991) and Kumar *et al.* (1992). Michalewicz uses a two-dimensional binary adjacency matrix representation, and problem-specific versions of mutation and crossover, to evolve minimum-spanning-tree topologies for computer networks. Kumar *et al.* tackle three constrained computer network topology problems, aiming for maximum reliability, minimum network diameter or minimum average hop count. Their GA is bit-string, but uses problem-specific crossover, as well as a repair operator to correct for redundancy in their network representation. More recently, Sinclair has worked on multi-wavelength all-optical transport networks, applying a simple bit-string GA (1995), a hybrid GA (1997) and, with Aiyarak & Saket, three different genetic programming (GP) approaches (1997). Both Paul *et al.* (1996) and Brittain *et al.* (1997) address constrained minimum-cost passive optical network (PON) topology design for local access. However, while problem-specific representations are used by both, only Paul *et al.* employ problem-specific genetic operators. Other recent work includes papers by Dengiz *et al.* on a hybrid GA for maximum all-terminal network reliability (1997) and Pierre & Legault, who employ a bit-string GA for computer mesh network design (1998).

Network *trees* are the focus of 23 papers. Several authors have addressed minimum Steiner trees, including early papers by Hesser *et al.* (1989) and Kapsalis *et al.* (1993). Although they use a simple bit-string GA for arbitrary Steiner point locations, Hesser *et al.* apply several heuristics during decoding. In contrast, while Kapsalis *et al.* also used a bit-string GA, their focus was on the more limited problem of selecting Steiner nodes from a given graph. Abuali *et al.* have published several papers on trees, including one (1995) applying a tree encoding based on determinant factorisation to the probabilistic minimum spanning tree problem. Others focusing on encoding include Palmer & Kershenbaum (1995), whose GA applies node cost biases to a standard minimum spanning tree heuristic.

Some 36 papers address telecommunications *routing, restoration and call admission.* Three of the earliest are by Cox *et al.* (1991), Pan & Wang (1991) and Sinclair (1993). Cox *et al.* use a permutation-based GA for the bandwidth-packing component of an heuristic for dynamic-anticipatory routing in circuit-switched networks. Pan & Wang employ a GA for minimum-delay bandwidth allocation, *i.e.* link capacity assignment and routing, in an ATM network. Their GA encodes individuals as a string of indices into a combined look-up table of both link capacities and routes. Sinclair applies a bit-string based encoding of static-routing tables in an unreliable circuit-switched network, employing a penalty function to eliminate infinite-routing loops, and aiming for minimum network grade-of-service. More recent work includes that of Bentall *et al.* (1997), who use a GA with a two-dimensional order-based representation to obtain restoration paths for a heavily-loaded network. Their aim was not so much to apply the GA to real-time restoration, but rather for the results obtained to serve as a benchmark in assessing rapid heuristic algorithms with only local knowledge. Shami *et al.*(1997), apply GP to obtain both primary and restoration paths in a network subject to single-link failures. Munetomo *et al.*(1997), describe a real-time dynamic-routing algorithm that employs path-based genetic operators to create alternative routes in a packet-switched network, thereby balancing link loads and reducing delay. Yener & Rose (1997) apply a bit-string GA to evolve local call admission policies for cellular radio networks using only partial state information. Finally, Zhu *et al.*(1998) employ a permutation-based GA on the point-to-multipoint routing problem, *i.e.* routing a set of circuit-switched connection requests, each of which has a single source and one or more destinations.

Only four papers consider *wavelength allocation* in optical networks. The earliest, by Tan & Sinclair (1995), describes several GA-based solution approaches for multi-wavelength all-optical transport networks. The most successful of these combines a bit-string GA for route selection with an heuristic for wavelength and fibre allocation. Sinclair (1998) subsequently developed a hybrid GA for routing, fibre choice and wavelength allocation using both an object-oriented representation and problem-specific operators.

Frequency assignment in radio networks is the topic of 15 papers. Crompton *et al.* (1993), the earliest of these, applies a parallel GA to the air-ground-air problem using an integer representation. More recent work includes Crisan & Mühlenbein (1998), who apply a breeder GA to digital cellular networks. Their frequency assignments are represented as integers and several heuristic operators employed in evolving a minimum-interference solution. Ngo & Li (1998) use a compact bit-string representation and apply problem-specific operators to avoid constraint violation in obtaining a feasible assignment. Finally, Valenzuela *et al.* (1998) employ a permutation encoding to initialise a sequential assignment algorithm while searching for a minimum frequency span solution.

3 CITATIONS

One important observation is that papers in evolutionary telecommunications rarely cite earlier work in the field. Indeed, if citations of each author's own prior papers are discounted, remarkably few remain. Examination of the individual papers reveals that many are 'first entries' into the evolutionary telecommunications domain. A typical paper will thus cite earlier research on the specific problem tackled, make reference to one or more books on EC, such as those by Goldberg (1989) or Davis (1991), before describing the particular algorithm used and reporting results. Little reference, if any, is made to any earlier work in applying EC to this or similar problems. Clearly, given that there is now more than ten years of research reported in over 100 papers, such an approach fails to develop on the experience of previous researchers. However, this is not an uncommon omission in EC in general, as Fogel has observed (1998): "Evolutionary computation has a long history. Unfortunately, this history is virtually unknown to many practitioners in the field." Indeed, it is only as researchers break this practice and begin to build on earlier work, that evolutionary telecommunications will begin to mature as a field.

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