NEW GENETIC OPTIMIZATION STRATEGIES IN EFFICIENT OFF-LINE TRAFFIC ENGINEERING FOR SIMULATING MULTI-SERVICE UMTS CELLULAR NETWORKS

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ABSTRACT
This paper presents new strategies for offline traffic engineering, when designing multiservice-UMTS networks, based on an efficient modification of basic genetic optimization techniques. More specifically, the problem setup includes Mobile Internet access as the most emergent trade in the telecommunications industry due to the advancement of cellular smartphones, tablets, notebooks and netbooks based computing and communicating technologies. In this real world set-up, the integration of deployed wireless networks with the Internet and the transparent interworking among different wireless technologies, namely EDGE/GPRS/ CDMA2000 cellular and Wireless LAN (WLAN), appears to be a demanding objective for mobile communications service providers. The mixture and convergence of mobile and fixed infrastructures related services make it urgent to tackle quality of service and traffic engineering for mobile networks at the fundamental transport level with regards to OSI network analysis. A good solution to address such issues is the Multi-Protocol Label Switching (MPLS) technology providing a fused control instrument with connectionless multiprotocol capabilities, functioning over different communication media while supporting traffic engineering and quality of service (QoS) offering smooth traffic over the complex network of mobile and fixed communication infrastructures. Therefore, the MPLS architecture offers the required capacity to integrate different services over wired and wireless infrastructures in a unified convergent approach. Based on these concepts, this research proposal investigates traffic engineering solutions in MPLS involved wireless cellular networks. In this paper, two new methods for the solution of the off-line Traffic Engineering (TE) problem in multi-service wireless networks based on a certain efficient modification of basic genetic optimisation are presented. In the first method the off-line TE problem is formulated as an optimisation model with linear constraints and then solved using a new modified version of the Genetic Algorithm for Numerical Optimisation for Constraint Problems (GENOCOP). Besides, a hybrid method for the solution of the aforementioned problem involving modified GENOCOP and a heuristic TE algorithm is also provided. The performance of the above methods against a standard LP-based optimisation method is examined in terms of two different network topologies mixing both wireless and wired links and numerical test results are provided.

1 INTRODUCTION

Recent years have witnessed a tremendous increase in the carried traffic volume and the need for high bit rates UMTS networks. The trend is towards the development of hybrid *multi-service* wireless networks capable of handling together voice, video and data traffic with different *Quality of Service* (QoS) and survivability requirements. These networks should be seamlessly integrated with fixed infrastructure wired networks or we could have hybrid networks involving wired and wireless links. Both the increasing number of users as well as their escalating demands for various mobile wireless data services such as wireless Internet, multimedia MMS messages, video on demand, video telephony, etc., involving the up-and-coming WLAN technologies (such us Bluetooth, 802.11g etc.) and 2.5G and 3G mobile communication technologies (more specifically GPRS, UMTS, CDMA2000 and W-CDMA) result in the development and deployment of huge and complex hybrid networks (Rita Girao-Silva, et al. , 2013).

The critical issue for the 3G and extended WLAN network technologies administrators would be to provide a steady and scalable user-to-user QoS architecture to offer flawless multimedia content to the mobile users without unnecessary delay. A second issue involves how to develop optimal traffic engineering strategies for the converged IP transport network in order to deal with the heavy traffic expansion and grasp the great changeability in the stream distribution generated from the increasing number of mobile users. However, providing such a solution is complex, and this would be as effective as the slowest link in the network. Moreover, since the number of mobile users and terminals connected to the present wireless systems would be very huge, the scalability of

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the QoS and traffic engineering solution and clearly of the whole backbone is of immense concern. To address this challenge, the MPLS protocol can give us very stretchy and shining likelihood to dynamically and efficiently route the data streams on a traffic engineering and resource allocation basis, and to configure the protection paths for any resource failures. MPLS indeed presents the main player delivering QoS and traffic engineering features in IP fixed networks and can be regarded a hopeful technology to enhance the ability of the network administrators in controlling the network behavior to provide high quality mobile IP services to users.

In such networks, Traffic Engineering (TE) mechanisms can be applied for the efficient utilisation of the existing network resources (e.g. link capacity). TE basically combines together traffic admission control and routing. Applying TE mechanisms, appropriate paths for routing network traffic demands, with either QoS guarantees or not, can be established, which essentially satisfy the QoS prerequisites (if any) of the traffic demands. The QoS prerequisites may refer to minimum end-to-end path delay, minimum delay jitter, minimum guaranteed link bandwidth along the path, packet loss etc. However, with TE, the required paths are created in such a way that the network traffic is evenly distributed among the links, load balancing is achieved and congestion (leading to unwanted packet losses and traffic blocking) is avoided. As a result the network resource (link) utilisation is more reasonable; no overloaded or under-utilised links are normally anticipated in the network. Multiple protection (backup) paths can also be established. Nevertheless, protection is not considered in this paper.

TE is a major issue in the emerging multi-service wireless networks supporting the *Multi-Protocol Label Switching* (MPLS) protocol as well as in DiffServ / non-DiffServ supporting *Internet Protocol* (IP) and *frame relay* networks (Rita Girao-Silva, et al., 2013). This paper concentrates in MPLS-based and DiffServ-supported IP wireless networks. In these networks, traffic flows (demands) with the same source-destination address having the same QoS requirements are aggregated forming what is called a *traffic trunk* in IP networks or a *Label Switched Path* (LSP) in MPLS networks. To the rest of the paper aggregated flows will be referred to as traffic trunks. Besides, in these networks, traffic corresponding to a specific trunk demand can be divided into more than one paths (traffic bifurcation) thus enabling better load balancing.

One of the main problems in TE is how to map traffic trunks in the wireless network, while satisfying the QoS requirements of the trunks. In order to solve this problem a number of on-line (J. C. N. Clımaco, et al. 2007),(Casas, P., Fillatre,et al. 2008) and off-line (Rita Girao-Silva, et al., 2013), (Elwalid, A., et al. , 2001), (Karasan, E., et al., 2002) TE approaches have been already developed. In the on-line approaches, traffic trunks are mapped onto the wireless network one at a time as soon as a new demand for a trunk emerges. On-line TE is state-dependent and applies on a short timescale. The main objective of the on-line approaches is to allow the wireless network to respond rapidly to any changes in traffic load or network topology. However, routing randomly emerging demands one at a time may cause an unfair utilisation of network resources. On the other hand off-line TE aims at establishing well-defined routes for trunks in such a way that the utilisation of network resources is globally optimised. Specifically, instead of focusing on instantaneous network states and individual connections, the latter mechanism considers statistical behavior of traffic trunks. Combining this information with a centralised view of wireless network topology and link capacities, off-line TE selects the topology of routes for traffic trunks and provisions resources (e.g. link capacities) on the selected routes for carrying trunk traffic in an optimal manner using special optimisation models (usually based on mathematical programming) and algorithms. In fact, the output of each off-line TE method is a set of paths that can be used for effectively routing all potential traffic trunks, while efficiently satisfying their QoS requirements (if any) and also normally enabling load balancing in the network. This paper concentrates on off-line TE, which essentially offers much greater potential for high bit rates wireless network resource utilisation optimisation than on-line TE.

Genetic Algorithms (GA) are based on the idea of natural selection. It is suggested that an individual’s strength to survive in the world is determined by its gene structure and that over many generations only “good” genes prevail, whereas “bad” ones are rejected. Furthermore, it is expected that bringing together individuals with good gene combinations produces again good or even better ones. The GAs were firstly introduced by John Holland (Jäntschi, L. , 2010) in early seventies and are primarily “search procedures” based on principles derived from dynamics of natural population genetics. They have been successfully applied to numerous large space problems known to be NP-complete.

The problems to be solved using GAs should be formulated as one-dimensional or multi-dimensional structures, representing a search point in the overall search space. This means that the problem should be encoded, that is to find a pattern to represent each solution, called *chromosome*, as a chain of characters taken in a finite alphabet. The GAs operate on chromosomes grouped into a set called *population*. Successive populations are called *generations*. Each chromosome is evaluated by the *fitness function*, which reflects its merit and its chances to survive in the next generation. The study included in this paper uses the *Genetic Algorithm for Numerical Optimisation for Constraint Problems* (GENOCOP) (Xiao Yuan,et al., 2012) based on the floating-point representation. It is concerned with optimising a linear/non-linear function subject to a set of linear constraints.

Several studies make use of GAs based techniques to solve network problems. GAs are especially used for the solution of non-linear problems. The motivation behind the use of GAs in nonlinear function optimisation problems is that the problem can be expressed as such that natural evolution, as reported, can provide an attractive paradigm for implementing general nonlinear searches (Xiao Yuan,et al., 2012), (Fogel, D.B.,2007). Due to the broad applicability of GA techniques, a broad application domain exists in solving telecommunication network problems (Pedrycz, W., et al., 2000). (Elbaum et. al., 1996) use a GA to design the topology of *Local Area Networks* (LAN) and (Ko et. al., 1997) to design *Mesh Networks*. (Shimamoto et. al., 1993) consider call blocking probability as a network constraint and apply GAs for network routing. (Pan and Wang, 1991) code the traffic distribution to represent each chromosome, and use the average delay, derived from an M/M/1 queuing model, as an optimisation constraint to maximise bandwidth allocation. (Taterdtid et. al. 1997a, 1997b) address the network configuration problem (i.e. obtain best path for each origin-destination pair), based on the VP concept. They use an M/M/1/K queuing model to derive the blocking probability and the total average packet delay as constraints to maximise total network throughput. (Swaminathan et al., 1999) use GAs to predict the bandwidth-demand patterns to enable better VP management. (Medhi and Tipper at al. 1996) utilize a GA to solve the capacity assignment problem in multi-hour broadband networks, while at (Walkowiak et al., 1999) a GA for backup path planning in ATM networks is presented. (Konak and Smith, 1999) as well as (El-Sayed M. El-Alfy, et al. , 2013) illustrate hybrid GAs for backbone network design and traffic engineering in MPLS networks. (Riedl et al., 2002) uses a hybrid GA for routing optimisation. (Ericsson et. al. , 2002) present a method for *Open Shortest Path Setting* (OSPF) weight setting based on a GA, while (Pitsillides et al., 2002) solve the *Aggregated Bandwidth Allocation* problem in ATM networks using GENOCOP, but considering only small networks.

In this paper, genetic optimisation is used for the solution of the off-line TE problem in multi-service high bit rates wireless networks. Precisely, the basic off-line TE problem is formulated as an optimisation model with linear constraints, called TEM, and it is solved using GENOCOP. This procedure is referred to as GENOCOP *Method* (GM) to the rest of this paper. To the best of our knowledge, GENOCOP and more generally numerical constrained optimisation methods based on genetic algorithms have not been previously used for the solution of off-line TE problems in large high bit rates wireless networks, where large numbers of constraints and variables are involved. In addition, a hybrid method for the solution of the aforementioned problem is presented. It is called GHM and it combines GM with heuristic TE algorithms. The remaining of the paper is organised as follows: in Section 2 TEM is presented, while in Section 3 the two genetic optimisation-based methods are described; the simulation results concerning the efficiency of GM over standard *Linear Programming* (LP) techniques and the comparison between the off-line TE methods are illustrated in Section 4; finally Section 5 concludes the paper.

2 THE OPTIMISATION MODEL FOR MULTISERVICE WIRELESS UMTS NETWORKS

Consider a weighted undirected graph G = (N, L) where N denotes the set of nodes and L denotes the set of edges (links). The graph is 2-connected, i.e. even if one link or node fails a path between each source-destination pair can still be found. Each link $l \in L$ has capacity C_l, propagation and processing delay D_l, length L_l and cost K_l.

In this paper the link cost K_l is defined based on the expected utilisation of the corresponding link. Specifically, first a special algorithm called *Path Finding Algorithm* (PFA) is applied in order to find the set of candidate admissible routes for all trunks. Then for each link the number J_l of candidate paths traversing this link is calculated. Next J_l is divided by the total number of candidate paths in the wireless network, thus providing the new link cost K_l. Note that the defined link cost is big when a large number of candidate paths uses the corresponding link. So it is most probable that this link will be over-utilised in operating conditions. On the other hand, small link costs indicate links that it is most probable to be less or even under-utilised.

Let Σ denotes the traffic trunk set and Tqos the set of service classes. Specifically, four service (priority) classes based on QoS requirements (e.g. end-to-end delay) are defined in this paper: the *High* class with the greater priority and stringest QoS constraints (e.g. voice traffic); the *Medium* class with less strict QoS requirements involving *Virtual Private Network* (VPN) traffic, the *Low* class (e.g. *World-Wide-Web* - WWW traffic) and the *Best-Effort* (BE) class with the lowest priority and no QoS requirements. Note that four traffic trunks for each source-destination pair are defined, typically one for each service class. For brevity to the rest of this section High, Medium and Low class trunks will be referred to as QoS trunks.

Also, let $T_{\sigma t}$ be the bandwidth demand (traffic) of the trunk $\sigma \in \Sigma$, which belongs to service class $t \in$ Tqos, with weight $Z_{\sigma t}$, and S be the set of the normal operating state and the failure states of the wireless network, corresponding to node and link failures. Note that $Z_{\sigma t}$ actually indicates the priority that trunk $\sigma \in \Sigma$ of class $t \in$ Tqos has as regards admissibility/routing into the network. $Z_{\sigma t}$ can be determined based on either *Service Level Agreements* (SLA) and/or user profile information, or administrative criteria. Note that considering the QoS framework, trunk traffic belonging to service classes with stringent QoS (e.g. max end-to-end delay), must have greater priority than other traffic. However, $Z_{\sigma t}$ differentiates traffic belonging to the same service (priority) class from each other, as regards the corresponding trunk. Also let $U_{\sigma t}$ be the admitted demand of the trunk $\sigma \in \Sigma$, belonging to class $t \in$ Tqos. Wp_t indicates the nominal admission priority of trunks belonging to the class $t \in$ Tqos.

Also, let $Rs(t,\sigma)$ be the set of all candidate routes for the trunk $\sigma \in \Sigma$, which belongs to service class $t \in$ Tqos, containing only operating links (links interconnecting operating nodes), at the network state $s \in S$. Let Kp_i be the additive cost of the candidate route $i \in Rs(t,\sigma)$ for $\sigma \in \Sigma$ of class $t \in$ Tqos. Specifically, in this paper it is assumed that the cost of each candidate route for a QoS trunk equals the sum of link costs K_l along the route, while for each BE trunk the candidate route cost is one, i.e. $Kp_i = 1$. B and H are the QoS (e.g. max end-to-end delay) and the max hop bound for routes respectively. Also the link utilisation bound at state s ∈ S is denoted by cb_s.

The decision variable is denoted by X_{rs}. X_{rs} is the flow or carried bandwidth on route r ∈ Rs(t,σ), belonging to the trunk σ ∈ Σ of class t ∈ Tqos at state s ∈ S. Note that X_{rs} is always greater than or equal to zero (data bandwidth can not be a negative number) and so it is: $X_{rs} \geq 0$.

The objective function of TEM attempts to minimise the routing cost for the QoS trunks without minimising total QoS throughput, and maximise BE throughput, while considering trunk priorities. The objective function is shown next.

$$F = Max:\left(\sum_{t\in Tqos}\sum_{\sigma\in\Sigma}\sum_{r\in Rs(t,\sigma)} Wp_t \bullet \frac{Z_{\sigma t}}{Kp_r} \bullet X_{rs}\right) \qquad (1)$$

The following constraint indicates that the total carried bandwidth of trunk σ ∈ Σ, which belongs to class t ∈ Tqos, must be at most equal to $T_{\sigma t}$.

$$\sum_{r\in Rs(t,\sigma)} X_{rs} \leq T_{\sigma t}, \forall \sigma \in \Sigma, \forall t \in Tqos, s \in S \qquad (2)$$

The next constraint is the link capacity constraint.

$$\sum_{t\in Tqos}\sum_{\sigma\in\Sigma}\sum_{r\in Rs(t,\sigma):l\in r} X_{rs} \leq cb_s \bullet C_l, \forall l \in L, s \in S \qquad (3)$$

The TEM model can optimally be solved using LP techniques. In fact TEM can be formulated as a standard LP optimisation problem and solved using a mathematical LP solver such as *lp_solve 5.5* (M. Berkelaar et al., 2013), which is a freely available solver. The output of TEM is the set of paths that will be used for routing all traffic trunks with either QoS prerequisites or not. Traffic of a trunk σ ∈ Σ, belonging to service class t ∈ Tqos, may go through more than one routes r ∈ Rs(t,σ).

To the rest of this paper, the LP problem involving TEM will be referred to as *LP model* and the related off-line TE method *LP-based method*. Note that the mathematical algorithm that solves TEM is deterministic. The deterministic algorithms have the advantage of always delivering the optimal solution if there is one.

PFA finds a set of candidate admissible routes with/without QoS guarantees for each traffic trunk. It is a step-by-step procedure based on the iterative execution of a modified version of the *Floyd-Warshall* (FW) *all-pairs shortest path algorithm* (Paolo D'Alberto, et al., 2007). FW finds the shortest path between each source and destination in an wireless network. PFA is described below.

1. Execute FW to the initial high bit rates wireless network topology.
2. Exclude a node or a link from the standard topology (as if it has failed) and execute the FW algorithm for the new topology.
3. Store the established source-destination paths by the FW algorithm.
4. Compare the established paths with the paths already included to the current set of candidate paths (if any exists).
5. The paths not previously established are included to the set of candidate paths.
6. Repeat steps 2 to 5, each time excluding a different node or link from the wireless network, for a specified number of iterations.

FW estimates the total path delay summing together the link propagation delays along the path or equivalently the total path length, summing together the link lengths along the path, since basically link length accounts for link propagation delay. It also estimates the number of intermediate hops a candidate path has. Each hop is associated with a node and consequently with additional processing delay and variable delay (jitter). Therefore the smaller the number of hops of a path is, the less jitter and delay the traffic trunk(s) that use this path will experience. Besides, using a smaller number of hops increases the transmission reliability of the traffic trunks, since the probability of a failure on the path decreases.

3 MODIFIED GENETIC OPTIMIZATION STRATEGIES DEFINITION

3.1 MODIFIED GENOCOP Method (GM)

GM is implemented as follows (consider the terminology found in Section 2):

1. PFA (see Section 2) finds a set of candidate admissible routes with/without QoS guarantees for each traffic trunk.
2. A total of Σ x T_{qos} real valued chromosomes $U_{\sigma t}$ are initialised, where:

$$U_{\sigma t} = \sum_{r\in Rs(t,\sigma)} X_{rs}, \ \sigma \in \Sigma, \ t \in Tqos \qquad \textbf{(4)}$$

Each chromosome corresponds to the total maximum possible traffic flow (demand) $T_{\sigma t}$ of the trunk σ ∈ Σ, which belongs to service class t ∈ Tqos. This trunk traffic flow may essentially go through more than one routes r ∈ Rs(t,σ). All traffic classes T_{qos} are considered.
3. All chromosomes, $U_{\sigma t}$, are evaluated with respect to the fitness function F shown in equation (1) - see Section 2. Note that each chromosome must not violate the typical traffic demand and link capacity constraints (2) and (3) found in Section 2.
4. Some chromosomes of the population (the 'winners') reproduce, while others (the 'losers') die, but with a probability, so that, even some of the "losing" chro-

mosomes exist. That is, there is a small probability P_{loser_exist} per generation , allowing "losers" to co-exist with winners. In our experiments this is fixed to 0.08. This is the new modification of the basic GENOCOP method

5. Genetic operators are applied on 'winners' and the small percentage of 'losers' and a new generation is produced to replace members that died. The genetic operators are based on floating point representation.
6. During reproduction, randomly selected genetic operators are applied on random 'winner' and allowed 'loser' chromosomes, one or two each time depending on operator, until all members that died are replaced.
7. Go to step 2 for a predetermined number of generations.

The output of GM is the set of paths that will be used for routing all traffic trunks with either QoS prerequisites or not. For more details on the basic GENOCOP see (Xiao Yuan,et al., 2012) , (Michalewicz, Z., et al., 1995).

3.2 Hybrid GM - Heuristic TE Algorithms Method (GHM)

GHM is a hybrid off-line TE algorithm combining the GM method (see Section 3.1) and heuristic TE algorithms for establishing QoS and BE trunk routes. Actually, in GHM, the GM method is initially applied providing a set of QoS and BE trunk routes. Nevertheless, if the problem solution (provided by GM) does not provide all the required routes for the QoS traffic trunks then an attempt is made to find the routes for the unsatisfied trunk demands using a special QoS routing algorithm, called *TE Algorithm_1* (TEA_1). Besides, if GM does not provide all the required routes for the BE trunks, another routing algorithm called TEA_2 is used.

Both the TEA_1 and TEA_2 algorithms are based on the *Dijkstra shortest path algorithm* (Jing-Chao Chen, 2003). TEA_1 is used for admission control/routing of QoS traffic trunks. It involves the following steps (consider the terminology found in Section 2):

1. Sort the QoS traffic trunks in decreasing order according to their priority, i.e. the higher priority trunks are placed first. The sorting takes place in two phases. Specifically, at the first phase, considering the priority classes previously defined, the trunks belonging to the High service class are put first followed by the trunks belonging to the Medium class, etc. Then at the second phase the trunks of each class are re-arranged according to the their earnings rates, that is the trunks with the higher earnings rates are placed first followed by the trunks with the lower earnings rates. When two or more trunks have the same earnings rate then these trunks are placed in decreasing order of bandwidth demand, that is the trunks with the higher bandwidth demand are placed first followed by the trunks with the lower bandwidth demand.
2. Consider first the higher priority trunk with demand $T_{\sigma t.}$
3. Create a sub-graph G′ where all the links with residual bandwidth less than the traffic demand $T_{\sigma t}$ are removed. This ensures that all the remaining links have bandwidth greater than or equal to $T_{\sigma t}$.
4. To sub-graph G′ use Dijkstra's algorithm to determine the minimum link weight path between the source and the destination of the trunk, considering special link weights based on the metrics presented in (Fortz, B., et al., 2002)
5. If a path exists and the number of intermediate hops along the path is less than the max hop bound H then establish the path and deduct the resources (e.g. link capacity) used by the path.
6. For each of the next trunks, placed in descending order of priority, repeat steps 3 to 5.

TEA_2 is used for admission control/routing of BE trunks only. It involves the same basic procedure and the same number of steps as TEA_1. However, at step 1, the BE traffic trunks are sorted in decreasing order according to their earnings rates, i.e. the trunks with the higher earnings rates are placed first. When two or more BE trunks have the same earnings rate then these trunks are situated in decreasing order of bandwidth demand. Furthermore, at step 4, Dijkstra's algorithm determines the minimum hop path between the source and the destination of the considered trunk. In step 5 no hop count test is made.

Note that in both TEA_1 and TEA_2 the complexity of step 3 is O(L) and the complexity of step 4 is $O(N^2)$. Since connected networks are considered it is $L \leq N^2$. So, the overall complexity of the steps 3 and 4 is $O(N^2)$.

4 SIMULATIONS AND NUMERICAL RESULTS

For the simulations the *NetLab* software package (Papademetriou, R.C, et al., 2003) was used. It was developed using the *Tcl/Tk* scripting language. NetLab is used for network topological design and simulation. In the context of the tests, modified GENOCOP was implemented in NetLab. The experiments were run on a PC equipped with an *Intel Pentium* 3.2 GHz processor and 4 Gb RAM. Note that the solution of the off-line TE methods is both CPU and memory intensive.

Two network topologies are used for the tests. The first one (Wireless/Wired links Network A) is the 15-node 30-link topology shown in Figure 1. Wired and Wireless links were considered at random with each wireless link providing capacity equal to 2 Mbps (normal to UMTS) and each wired link providing capacity equal to 10 Gbps. The second one (Network B) is the 9-node 18-link topology shown in Figure 2. Each wired link of B was assigned a capacity equal to 8 Gbps, while each wireless link was assigned a capacity equal to 2.5 Mbps..

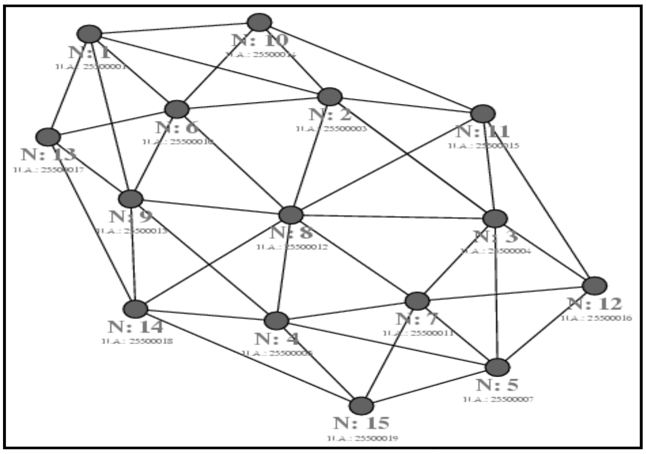

Fig. 1. Base stations and trunks topology in network A mixing wired and wireless links.

Three sets of tests took place. The first set involved Network A only. In this set of tests, GM was solved for 1000, 2000 and 3000 generations and the obtained solutions from these three tests were compared with the results taken from the solution of the equivalent LP model. The LP model was solved using the lp_solve 5.5 software. The goal of this set of four (4) tests was to evaluate the performance of GENOCOP as regards the solution of optimisation problems. For this purpose blocking ratios were considered. Specifically, for each method the ratio of the number of admitted routes to the number of expected routes for the trunks of each class was calculated based on the obtained results. The same traffic matrix was used to all tests. For trunks belonging to the High and Medium classes candidate paths with H = 7 were considered and for trunks belonging to the other classes, candidate paths with H = 15 were considered. In addition, the basic parameters of TEM were assigned the following values: $Z_{\sigma t}$ = 5, 3, 2, 1 for each High, Medium, Low and BE class trunk bandwidth demand respectively; Wp_t = 7, 5, 3, 1 for the High, Medium, Low and BE class trunk traffic respectively and cb_s = 0.95. PFA found totally 578 candidate admissible paths for all trunks. For GM the population size was 100 and the cumulative probability was 0.3.

The second and third set of tests involved Network B solely. The objective of these sets of tests was to compare the performance of the two off-line TE methods, analysed in Section 3, with the performance of the equivalent LP model, solved using the lp_solve 5.5 solver. For this purpose blocking ratios were also considered. Specifically, as in the previous set of tests, for each method the ratio of the number of admitted routes to the number of expected routes for the trunks of each class was calculated. Each set involved 30 tests. In each test a different traffic trunk set/traffic matrix was used with 288 traffic trunks each, but with randomly chosen bandwidth demands in the range 200 - 2400 kbps for the wireless links and 500 – 6500 Kbps for the wired links. However, for the tests of the second set the priorities of the trunks of each class were randomly chosen but for the tests of the third set fixed priorities were used ($Z_{\sigma t}$ = 5, 3, 2, 1 for each High, Medium, Low and BE class trunk bandwidth demand respectively). For the trunks belonging to the High and Medium classes, candidate paths with H = 5 were considered and for trunks belonging to the other classes, candidate paths with H = 11 were considered. Besides, the next values were assigned to the basic parameters of TEM: Wp_t = 7 for the High class trunk traffic, Wp_t = 5 for the Medium class trunk traffic, Wp_t = 2 for the Low class trunk traffic and Wp_t = 1 for the BE class trunk traffic. Also it is cb_s = 0.9. PFA found totally 187 candidate admissible routes for all trunks. For GM the population size was 100 and the cumulative probability was 0.3. The number of generations used in GM in both the second and third set of tests was 3000.

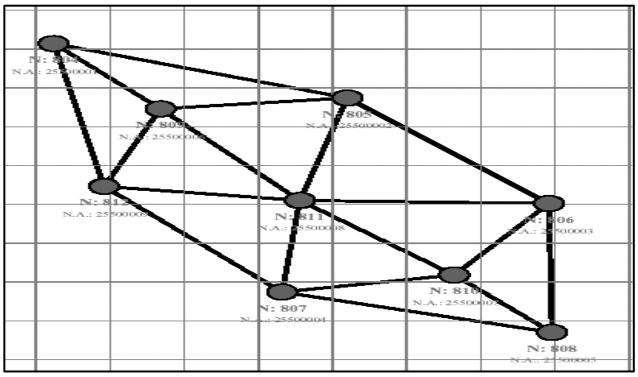

Fig. 2. Base stations and trunks topology in network B mixing wired and wireless links..

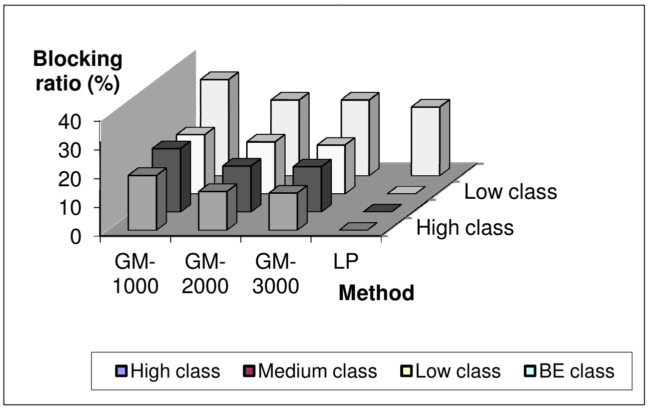

Fig. 3. Results from the first set of tests.

The obtained results from the first set of tests are presented to the graph in Figure 3. As regards the GM method the traffic blocking ratios for all classes reduces as the number of generations increases, but they are still much higher than the blocking ratios obtained from the solution of the LP-based method. However, in all cases the High class traffic had the lowest blocking ratio and the BE class traffic had the highest. Note that the blocking ratio of each QoS class for the LP-based method is zero. Considering all four tests, the average solution time for GM was significantly higher than the solution time for the LP-based method. Specifically, the solution time for GM-1000, GM-2000 and GM-3000 was 69:05, 168:20 and

282:12 minutes respectively, while for the LP-based method was only 0:25 minutes.

The acquired results from the second set of tests are presented to the graph in Figure 4. The blocking ratios of all classes for the LP-based method and the hybrid scheme were zero. However, when the GM method is applied blocking occurs.

Note that the blocking ratio of each class depends on the assigned priority to each trunk of the class. Consequently, the blocking ratio of each class ranges from test to test as it is observed on Figure 4 for GM. Nevertheless, the relative priority of the QoS traffic (High, Medium and Low class traffic) over the BE traffic was preserved, resulting in lower blocking ratios for the QoS traffic. The average solution time for the LP-based method was much

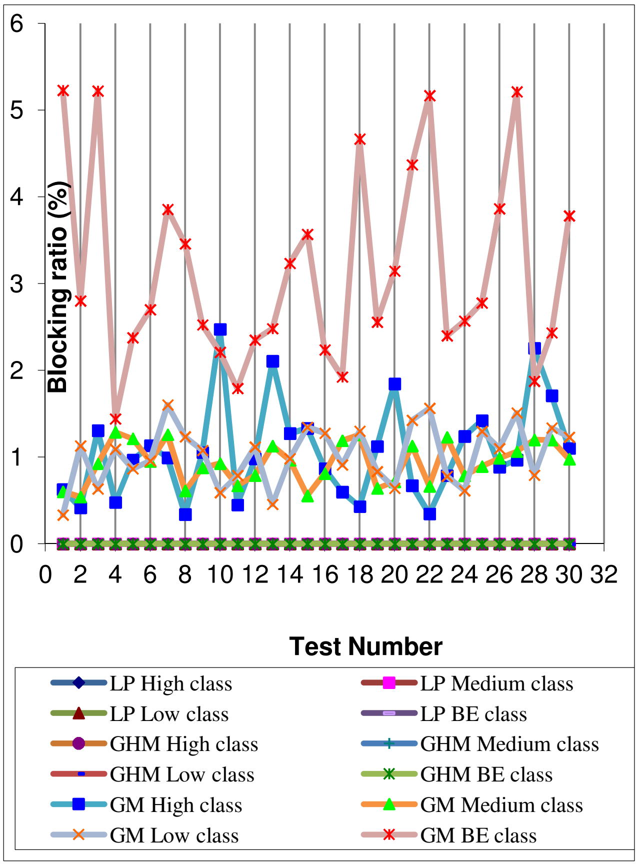

Fig. 4. Results from the second set of tests

shorter than the average solution time for the genetic-based methods. In particular, the solution time for GM alone was approximately 21 minutes, while for the LP-based method was only 1 second. The obtained results from the third set of tests are presented to the graph in Figure 5. The blocking ratios of all QoS classes for the LP-based method and the hybrid scheme were zero. As regards the BE class traffic the blocking ratio that appears when the LP-based method was applied was zero. Generally, the BE traffic blocking ratio for GHM was zero; only in two tests this blocking ratio was non-zero. On the other hand when the GM method was applied traffic blocking to all classes was introduced. However, in all tests the High class traffic had the lowest blocking ratio and the BE class traffic had the highest. As in the second set of tests the solution time for GM alone was approximately 21 minutes, while for the LP-based method was only 1 second.

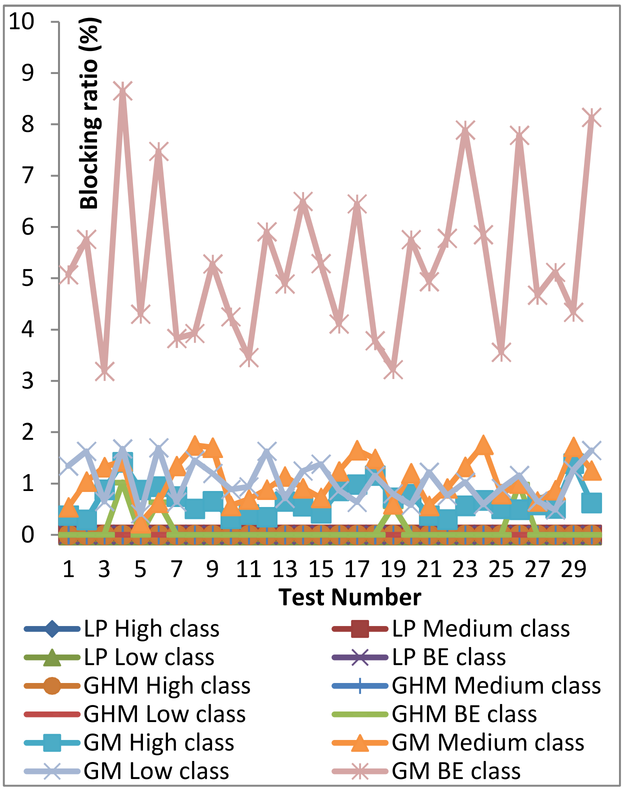

Fig. 5. Results from the third set of tests

5. CONCLUSIONS

This paper presents two novel off-line TE methods that utilise modified genetic optimisation. Both methods are based on a modified GENOCOP algorithm and can be applied in practical multi-service survivable high bit rates wireless networks.

The performance of the two methods as regards traffic blocking was compared with the performance of a LP-based optimisation method through a series of tests. The performance of GM was inferior to that of the LP-based and GHM methods. In fact, the performance of GHM was generally the same with the performance of the LP-based method, for which it is assumed that provides optimised results. Note that the total solution time for every genetic-based method was higher than the solution time for the LP-based method. However, all tests indicate that GENOCOP alone does not perform as well as the standard LP techniques in the solution of large optimisation problems with linear objective function and linear constraints. More improvements are required. Note that generally the relative class admission priorities were preserved in all methods when fixed trunk priorities were used, i.e. in terms of each method, the High class traffic had the lowest blocking ratio among all traffic, followed by the Medium and Low class traffic respectively.

Nevertheless, some characteristics of the methods, especially regarding load balancing, must be further studied. Also, genetic optimisation will be applied for the solution of new versions of the off-line TE optimisation model, which will include non-linear objective functions. However, survivability-supported off-line TE methods based on the presented work in this paper are already under study.

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