AN AGENT BASED APPROACH TO THE REAL TIME AIR TRAFFIC CONTROL

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Abstract: Congestion in the air traffic network is a problem with an increasing relevance for airlines costs as well as airspace safety. One of the major factors is the limited operative capacity of the air network. In this work an agent based approach to the real time air traffic control is proposed. The air network is considered partitioned in different sectors. Each sector has its own decision agent devoted to the air traffic control involved in. In each of these sectors, in order to guarantee the respect of both delay and capacity constraints, a real time scheduling of the flights is obtained by an iterative procedure based on a specific graph model.

Keywords: Air Traffic Control, Scheduling, Routing, Air Traffic Flow management.

1. INTRODUCTION

The management of the evolution of the air traffic management (ATM) systems involves a careful evaluation of alternative scenarios, from a various perspectives involving technical, operational, economic, and environmental issues.
This assessment is often carried out through experimentation, in which analytical modelling and simulation contribute significantly, by reducing the turn around time between the design and the implementation of advanced operational concepts. In the context of the Air Traffic Control (ATC), one of the challenge facing the decision makers is to increase the air traffic capacity while providing safety improvements.
The flight route assignment problem, aiming at global flight plan optimization, has already become a key issue owing to the growth of air traffic. In this paper we present an optimization based, long range, conflict resolution procedure, in which flights interact through a simple coordination protocol. In particular, it allows to smooth traffic peaks and reduce the criticality of the short term conflict resolution activity, as well as to avoid low capacity areas and waiting times in holding patterns. The problem consists of finding a routing for the planned flights assigning planes to feasible slots in such a way that (i) the capacity constraints are satisfied (ii) the number of assigned flights is maximized. In order to guarantee the safety, the maximum number of movements in a sector is bounded in each slot. This number is called capacity of the facility in the slot.
The coordination mechanisms among different aircrafts are derived on the ground of a set of different models.

The complexity of the basic decision models will be analyzed; such basic models are useful to point out effective management procedures, but many facets of real environments are not suitably represented. An real-time slot allocation procedure based on simple coordination mechanisms among flights is proposed.

2. DIFFERENT APPROACHES TO ATFM

The increasing demand of air traffic in the last years had to a heavier use of Air Traffic networks , it is constituted of airports, airways and sectors. While Air Traffic networks have been used more and more every year, their capacities have not grown accordingly. The main effect is the congestion of the Air Traffic network. Different approaches are proposed to minimize this undesirable crucial aspect.

2.1 Ground Holding policies

A Ground Holding (GH) policy imposes on selected aircraft a ground-holding prior to their departures, so that congestion during peak periods of time may be smoothed away. The usefulness of these policies stems from the following facts. First, air delays are much costlier than ground delays. Second, the capacity of an airport is affected by weather conditions. Third, if pilots were free to depart at will the situation could get completely out of control (i.e. too many flights in a certain part of the air traffic network) and the air traffic controllers would not be able to provide any instructions, with serious safety risks. Cost and safety are sufficient to justify the study of methods for managing air traffic in unstable weather conditions. These policies rely on the fact that costs are lower when delays are imposed on the ground rather than on the air.
The ground-holding problem (GHP) consists of determining the amount of delay to be imposed on the ground on each flight, in order to minimize the over cost of delays (in the ground and in the air) in the network.
Optimization (both exact and heuristic) models and algorithms for the ground-holding problem in a network of airports were presented in literature (Vranas et al. 1994).
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2.2 Free flight policies

Many airlines in the USA been complaining about the GH policies, and have been complaining about the GH policies, and have been pushing toward the new concept of “free flight”. They are asking the FAA to provide them only with an arrival time slot, leaving them freedom of selecting, for each flight, its departure time, route and speed , as long as they are able to arrive at the assigned time slot. More rigorously, free flight is a safe and efficient flight operating capability under instrument flight rule in which the operators have the freedom to select their path their speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through special use airspace, and to ensure safety of flight.

2.2 Autonomous Agents approach

Autonomous agents (AA) are becoming increasingly popular in different fields related to computer applications, although often disguised by different concepts. In manufacturing, telecommunications, medicine and public administration different entities such as intermediate providers, departments, wards or even final users may have sufficient freedom to organize their own activity within a general framework, without depending on external influences.
In all these cases, the concept is that a project or a process should be regarded as the result of the interaction of several different subjects, rather than of a single centralized decision maker. Each individual acts in order to pursue his/her/its own objectives, which may be sometimes expressed by means of a mathematical objective function.
Generally speaking, for the individuals to carry out their tasks in a feasible and profitable way for the overall system, they will have to cooperate and negotiate to some extent. Cooperation means that two individuals may realize that taking a common action may turn out to be convenient for both of them. Negotiation refers to the fact that one individual may accept losing something in exchange for something else.

With respect to centralized decision making, autonomous agents typically offer such advantages as management simplicity, flexibility, modularity, ease of monitoring and more.
Transportation is a natural setting in which the autonomous agents’ concept may yield considerable payoffs. In the organization of the transportation system, it is natural to identify the agents with the elements having a certain amount of behavioural autonomy, be it a vector, a station, a booking centre, a single passenger or a vehicle.

In AAS the focus is on the coordination and the negotiation among intelligent autonomous agents. When several agents (sub-systems or resources) are able to execute the same tasks or operations, a negotiation mechanism is needed to establish relationships between a seller agent and a buyer agent.
In the implementation of the autonomous agents concept there are at least two trades-offs which must be carefully addressed.

A trade-off is between the amount and the detail of the information available to the agent and the quality of its decisions. In fact, in principle each agent can be fed with a large amount of information concerning the status of the overall system, but this may be physically infeasible. Actually, conveying too detailed information to each agent may be impossible, because of communication and computational overhead. This is in fact a major problem in many centralized architectures. On the other hand, a careful choice of the actually relevant pieces of information may point out that the agents can still work satisfactorily, even without a full knowledge of the whole system.

In our model we have considered two different types of Autonomous Agents, the sector control agent (CSA) and aircraft agent (AA) (Adacher et al 2002). The sector control agents can take the decision on the air traffic flow in the sector, and the aircraft agents give only their necessary information for the decision of the sector controller.

3. AN AGENT BASED DYNAMIC FLIGHT SCHEDULING

The considered problem can be seen as a multi-period (dynamic) problem where the time dimension is an essential ingredient to consider when constructing flight plans (see Ma et al 2003). This dynamic problem can be transformed into a static one by using standard technique based on the time-expansion of the underlying network.

Several assumptions are necessary to set the topology of the airspace network. The main idea is to re-model the existing network We consider the airspace partitioned into a set of sub-spaces called sectors. Related to each sector there is a control agent (CSA), that can decide the schedule of the flights for each node belonging in its sector, taking into account different constraints.

We focalize our attention on the constraints related to the delay of flights and the capacity of the different points within a sector. At this aim, each sector is represented by a network in which the nodes represent fixed points (in the ground and in the air) characterized by different capacities; the existence of an airway between two nodes is represented by an edge.
During different time slots the network may change its structure, i.e., the nodes capacities and the edges. The capacity of each node represents the maximum number of aircrafts controlled by the sector controller to guarantee the safety of the sector. In practice, a CSA controls different networks one for each time slot (assumed of 15 minutes each); it is because for each time slot the capacity constraints and the flights associated to the nodes may change.

3. THE NETWORK MODEL

The assumptions allows us to set the structure of the airspace network following the main idea of re-modeling the original network. Airspace is made of routes that cross each other.

The network starts off with a number of initial nodes, corresponding to beacons, and a set of fixed links corresponding to the probable used links. This can be realized simply by deducing the used links from a given air traffic situation, where all flight plans are given, and preferred routes are already known.

In the graph corresponding to the initial network, potential conflicts can be seen as the overload of some nodes, identified as potential conflict area. Also the airports are represented like nodes with their capacity, but in this node it is possible apply the ground holding policy.

Let us first fix some hypothesis which will help us to build our model:

1. aircraft are in constant motion;
2. a number of aircrafts may be placed in the same air segment, and conflicts are resolved using appropriate method, i.e. there is no capacity imposed on links;
3. the different flight levels are collapsed in a single one.

In the following $\underline{G}$ = (V,E) denotes the graph representing the airspace, where:

- V (the set of vertices) represents fixed points (in the ground and in the air) characterized by different capacities;
- E (the set of edges), each edges represents the existence of an airway between two nodes.

5. A DECENTRALIZED APPROACH TO THE AIR TRAFFIC FLOW MANAGEMENT

The airspace is partitioned into a set of sectors (Duong et al. 2003a). Related to an each sector there is a control agent, that can decide the schedule of the flights for each nodes of its sector, considering different constrains.
We focalize our attention on the delay and capacity constraints. At this aim, each sector is represented by a sub network G of the whole airspace $\underline{G}$. A sector

can be represented as in Fig.1; the nodes are fixed points, and the edges are the airways, the direction is not represented because it is a characteristic of the flight.

During different time slots the network may change its structure, i.e., the nodes capacities and the edges. The different flight-levels are collapsed on the nodes capacity (see also Duong et al. 2003b). The capacity of each node represents the maximum number of aircrafts controlled by sector controller to guarantee the safety of the sector.
In practice, a CSA control different networks one for each slot time; it is obvious because for each slot time the capacity constrains and the flights associated to the nodes can change.

The foreseen congestion in a node is signalized at the CSA by a different colors of a traffic light:

- *red* means that the capacity constraint is achieved;

- *yellow* means that the node can accept only another flight before the constraint is activated;

- the *green* color means that there are not capacity problems in that node.

For the objectives pursued by our model we have considered two different traffic lights for each node in a sector during a slot time. The most important is related to the safety constrains (i.e. maximum number flights that a CSA can control for a single node), the other is related to the delay for a flight.

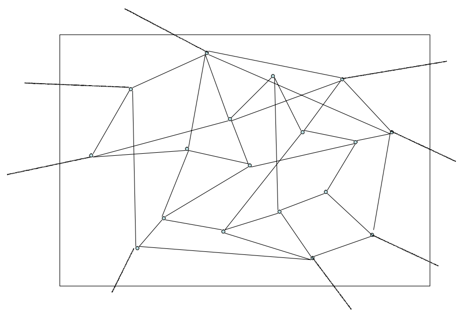

Fig. 1. An example of the sector.

When in a sector is presented a yellow or red signal in one of the nodes, the CSA must find another flights scheduling for the aircrafts associated to the congested node.
In general, not all the aircrafts associated to the congested node can change their route; only the flights those are not on an airway direct to the congested node. For each of those aircrafts, the CSA must resolve a re-routing problem. If the CSA find a new routing without introduce red signals, the new schedule is accepted; otherwise the only schedule admitted is a solution with red signal for the delay constraints.

When there is a forecast of congestion, the CSA resolve a routing problem on a set of partial sub-graphs, one for each flight associated to the congested node.
A partial sub-graph have a fixed pair of input/output points, that represent the intersection with the other sectors, with this hypothesis the cooperation between CSAs is not necessary at this level.

An example of the partial sub-graph is presented in Figure 2. The basic concept of our approach is the dynamic structure of the solution. It is possible that during the construction of the new solution the CSA introduce new congested nodes, at the end of this recursive algorithm the solution may be acceptable with all constrains respected, but some flights (more then one) have changed their routes.

Is important to underline that the partial sub-network is characterized by a single flight, but all the information connected to the nodes are related to the whole sector for a fixed time slot, then to re-solve a routing problem a CSA use global information about the sector (i.e. two different signal for each nodes) and information on the single Aircraft Agent.

5.1 The real time flight scheduling

When in a sector is presented a yellow or red signal the CSA must find another flights routing/scheduling for some aircrafts associated to the congested node.
Not all the aircrafts associated to the congested node can change their route; only the flights those are not on the airway direct to the congested node.
For each of those aircrafts, the CSA, in order to individuate an improved routing, solves a k-shortest path problem (KSP) on the dynamical network containing information about nodes and flights.

The KSP problem is defined as the problem of finding the k best alternatives in the case that we need more than one route to get from an origin to a destination.
This type of solution is especially meaningful in the Air Traffic Management context, in which a number of aircrafts has to be enrouted in order to satisfy capacity and time requirements.

It may be that there is more than one possible route to take and that some routes may be more efficient when flown by a particular aircraft. Moreover, due to capacity limitations at some route, it may be beneficial to have alternative routes available in the event that one route becomes overly congested. In this context, it is useful to know several of the best routes to get from an origin point to a destination point.

The k-shortest path problem is largely studied and different solution methods are presented in the literature. The method we have adopted in this work is known as the double-sweep algorithm.
This algorithm was introduced in the seventies and recently has been revisited by Rink et al .(2000), which propose a new simplified version. This algorithm finds the k-shortest paths between a specified origin node and all other nodes in the dynamical network.

In our decision model, if the CSA find a new routing without introducing red signals, the new schedule is accepted; otherwise the only schedule admitted is a solution with red signal for the delay constraints.

A campaign of computational experiments based on a computer simulation, referring either on artificial and real instances, are conducted to evaluate the behavior of the proposed approach.

6. SIMULATION RESULTS

A campaign of computational experiments, based either on artificial and real instances, are conducted to evaluate the behavior of the proposed agent based approach.

To test our approach, we have simulated the Centre-North Italy airspace. We have considered like fixed points only the point where different airways crossed each other, naturally, only the principal airports (Milan, Rome, Genoa,…) are considered like nodes. To drown the network, we have reported all routes of the different flights during the day, and we have simulated the network during 12 ours from 6:00 a.m. until 18:00 p.m.

It is important to note that the edges represent the shortest paths between two nodes, and the flight time inside one sector is short one (i.e. 70 minutes), for these reasons to find a good re-routing or to recuperate a delay are not simple tasks.
Naturally capacity congestion can occur when there is a time delay for one or more flights.
To test our algorithm we generate different delay and degree of congestion on the network.
In order to consider the impacts of rerouting , some performance indicators and measures were examined, including:

- *Flight delay.*

It is the difference between the end delay and the start delay of an aircraft in the sector. When an aircraft cross a sector is characterized by its start delay (if it is in time the delay assumes the zero value) and when the aircraft leaves the sector or stops in an airport of the sector, it is characterized by the end delay.

- *Sector delay.*

It is the sum of the delays of the aircrafts that live or stop in the sector.

- *Conflicts.*

It is the number of nodes with problem of capacity.

- *Traffic node*

It is a index give us an idea of how long this node is saturated respect the total simulation time.

- *Traffic sector*

This index is the average on all traffic nodes in the sector.
The simulation has been conducted to cope with different levels of conflicts, and also different levels of start sector delays are tested.
The re-routing policy is applied in the majority of cases, otherwise when there is an high level of traffic in the airports the ground delay program is applied. In this last case, it is not simple find good solution, because it is not possible to find a re-routing without touch this critical airport; also when there is short time flight it is difficult to find a rerouting, and the find solution is based on the ground holding policy.
Also when the start condition are critical (start delay equal to 70% of the flight time), the results are satisfied, finding diminution of the initial delay.
Moreover, we also are working on a coordination mechanism between the CSAs of different sectors. In particular we consider the case in which the input and output points for each aircrafts in a sector con be established by a inter-sectorial negotiation process involving different CSA, while the path of a flight in a sector is decided by the CSA's intra-sectorial decision process.

The cooperation between the CSAs can be based on rules or negotiation schemes able to allow improvements in the global performance of the overall system and guarantee the respect of constraints imposed by the real-time context.

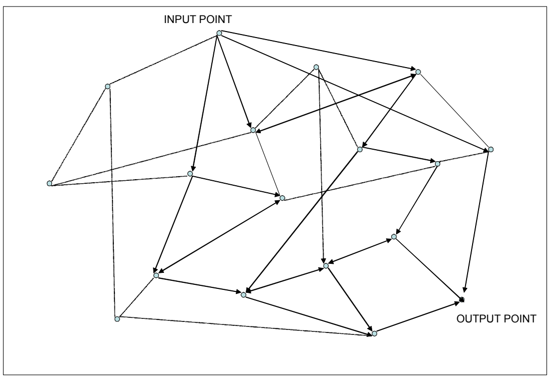

Fig. 2. An example of partial sub graph related a single Aircraft Agent

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