Sectors co-operation in Air Traffic Management
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Abstract: Congestion in the air traffic network is a problem with an increasing relevance for airlines costs as well as for airspace safety. One of the major issue is the limited capacity of the air network, that is the limited maximum number of aircraft that can coexist on some points of the network. This value can also vary during the day for safety constraints (weather and visibility). In this work an Autonomous Agent approach is proposed to solve in real time the problem of air traffic congestion. The air traffic network is divided in different sectors each one modeled with a graph. Each sector has its own control decision agent managing the air traffic involved in it. When a congestion occurs in a sector the control decision agent has to reschedule and/or reroute the flights with the aim of respecting capacity constraints and of limiting delays.

In this paper rerouting solutions are obtained by applying an iterative procedure based on a generalized Dijkstra algorithm on the graph. We test the effects of different levels of cooperation between agents controlling adjacent sectors while solving the congestion problem.

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Keywords: Air traffic control, autonomous agent control, air traffic congestion, graph model, k-best path.

1. INTRODUCTION

Congestion problems are becoming increasingly evident in many European and American airports and air sectors since air traffic in Europe and the USA has registered a relevant growth during the last years (more than 50% in the last 10 years according to recent estimations) and a 50% traffic increase is expected by 2018 (1). Moreover the increasing demand of air traffic would imply an increase of the air traffic networks but the infrastructures capacities have not grown accordingly. To protect Air Traffic Control (ATC) from overload a planning activity called Air Traffic Flow Management (ATFM) tries to anticipate and prevent overload and limit resulting delays which imply additional onerous costs for airlines. When the traffic expects to exceed the airport capacities or the air sector capacity a congestion occurs and consequently flights are delayed.

Literature in this field is huge and analyze several distinct aspects of the problem of terminal and sector congestion. Simple models usually consider only terminal congestion and do not take into account air sector congestion. The reason is that the most efforts in this research line was done in USA where concrete problems arise only at ground level. In such cases, air traffic management systems propose alternative solutions considering technical, operational, economic, and environmental issues. European scenario is different since the overloading of air sectors is more frequent and in certain cases leads to the collapse of parts of the network. Congestion are due to the lack of coordination among sectors controllers. In order to solve these problems and avoid the deterioration of the situation, an European organization has been set up that is the European Central Flow Management Unit (CFMU) which depends by EUROCONTROL. Different approaches are proposed to minimize this undesirable crucial aspect.

A Ground Holding Policy (GHP) sets up the amount of delay to be imposed on the ground to each flight to minimize the over cost of delays (on the ground and in the air) in the network (see (3),(4),(5)). Many airlines in the USA been complaining about the GHP and support the concept of Free Flight. They ask to the FAA only for an arrival time slot, and they are free of selecting the departure time, route and speed, as long as the flights are able to arrive by the assigned slot (see (6),(8),(9)). In this context the route assignment problem aiming at global flight plain optimization has already become a key issue to face the growth of air traffic. Recent research has produced stochastic optimization models for adjusting traffic flow in response to predicted congestion in the en route airspace. These models simultaneously consider set of options for each flight that includes both the possibility of ground delay and rerouting (see (10),(11),(12),(13),(14),(15),(16),(17)).

In this paper we deal with the problem of congestion both in the air space and on the ground network and propose a solution approach based on the autonomous agents theory. In this case the autonomous agents are the aircraft and the different Control Sector Agents (CSAs), each one managing air traffic in a specific air sector with the responsibility of supervising the safety rules respect and with the aim of limiting delays. When the air traffic leads to a violation of the infrastructures capacity a congestion is detected and predicted and the CSA of the sector involved in the congestion has to solve it by delaying and/or rerouting and rescheduling the aircraft. A graph model of the air network partitioned into sectors is proposed and a heuristic procedure based on a generalization of the Dijkstra algorithm has been implemented to evaluate the performance and the effects of several rerouting solutions. Different levels of
coordination among the autonomous agents are analyzed. The paper is organized as follows: in section 2 a brief introduction to the autonomous agents theory is presented; in section 3 the air traffic congestion problem is described and modeled; in section 4 the generalized Dijkstra algorithm for the resolution of the air traffic congestion in a single sector is proposed, while in section 5 the problem solution is extended to different sectors. Finally in section 6 some preliminary computational results are reported.

2. AUTONOMOUS AGENTS APPROACH

Autonomous agents are becoming increasingly popular in different fields such as manufacturing, telecommunications, medicine and public administration in which different entities may have sufficient freedom to organize their own activity within a general framework, without depending on external influences (see (21)-(23)). 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 system. Each entity is an agent and operates in order to pursue his/her/its own objectives, which may be sometimes expressed by a mathematical objective function. In practice the execution/implementation of the tasks in a feasible and profitable way leads the agents to cooperate and negotiate to some scopes. Cooperation means that two agents take a common action which results to be convenient for both of them. Negotiation means that an agent accepts losing something in exchange for something else.

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 behavioral autonomy. An adaptive, multiagent approach is an ideal fit to the distributed problem here addressed, where the complex interaction among the aircraft, airports and air traffic controllers makes a centralized solution substantially suboptimal at the first deviation from the expected plan. Though a truly distributed and adaptive solution (e.g., free flight where aircraft can choose almost any path) offers the most potential in terms of optimizing flow, it also provides the most radical gap from the current system. As agent methods are a natural tool to help automate existing air traffic systems, there has been significant research into other agent solutions as well (see (24)-(28)).

In this paper we explore a multiagent algorithm to solve air traffic congestion through local actions, considering collaborative actions. We present an optimization conflict resolution procedure, in which flights and CSAs interact through a simple coordination protocol. In particular, the procedure allows to smooth traffic peaks and reduce the critical issues of the short term conflict, as well as to avoid a low capacity in this areas and waiting times in the holding patterns.

The problem consists of rescheduling and/or rerouting the flights, assigning them to feasible slots so that (i) the capacity constraints are satisfied (ii) the delay is minimized. The coordination mechanisms among different aircraft are derived on the bases 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 aspects of real environments are not suitably represented. A real-time slot allocation procedure based on simple coordination mechanisms among sectors is proposed. In our model we have considered two different types of Autonomous Agents, the CSAs and aircraft agents (AAs). The CSAs can take the decision on air traffic flow in the sector, and the AAs only give the useful information for the control sector decision. In this contest the Autonomous Agent theory properly model the situation and, with respect to a centralized decision system, offers advantages such as management simplicity, flexibility, modularity and ease of monitoring.

3. THE PROBLEM AND THE MODEL

We consider the problem of air traffic control in case of congestion. The problem can be seen as a multiperiod (dynamic) problem and can be transformed into a static one by using standard technique based on the time extension.

We fix some hypothesis which will help us to build up our model:

(1) aircrafts move in constant speed;
(2) each aircraft has associated a nominal route;
(3) the different flight levels are collapsed into a single one;

Note that the nominal route of each aircraft is assigned in a strategic phase and it is often assumed to be the shortest path. We represent the space network as a directed graph $G = (V, E)$ where $V$ represents the set of nodes and $E$ represents the set of arcs, each arc is weighted with the time necessary to run the arc. We consider the network partitioned into a set of sub-spaces called sectors. A node is a fixed point on the ground or in the air. Nodes in the air can be positioned in the sector or on the frontier between two adjacent sectors, in the latter case the node is a crossing node. Each node is characterized by a node capacity, that is the maximum number of aircraft that can cross the node at the same time in a fixed slot. Such capacity is not fixed since it can change during the day for example due to the weather conditions or to the visibility. An arc represents a feasible route between two nodes. Each sector is controlled by CSA, that decides the schedule of the flights for each node belonging to its sector, taking into account the node capacity constraints and the resulting delays. We divide the time horizon into slots of 15 minutes each. Hence, in practice, a CSA controls different networks, one for each time slot, for the dynamic capacity constraints subject to the real traffic flow.

Conflicts arise when the capacity of one or more nodes is exceeded. Each aircraft has assigned a path composed by an ordered list of alternating nodes (control points) and edges (routes). Such route is divided in sub-routes, one for each sector that the aircraft crosses. The start/end nodes of each sub-route in the sector is called origin/destination of the aircraft in the sector. In Fig. 1 two adjacent sectors are represented. The green points represent the crossing points between the two sectors. The blue points are the air control points and the red ones are the ground control points (i.e. airports).
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