Cloud Computing in Free Route Airspace Research

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Abstract: We use technical documentation, data structures, data, and algorithms in our research. These objects support our work, but we cannot offer a unique citation for each object. This paper proposes a method (for citation and reference management) to cite such supportive resources using Cloud Computing. According to the method, the publication cites only one source in the Cloud, and this source contains the Cloud schema, which describes the Cloud infrastructure. When we make a citation using the Cloud schema, we can pinpoint a cited object exactly. The proposed method supports open research; all research—Cloud items—is freely available. To illustrate the method, we applied it in the case of free route airspace (FRA) modelling. FRA is a new concept of Air Traffic Management and it is also the subject of our research.

Keywords: Research Cloud; Cloud infrastructure; airspace network; open research

1. Introduction

We are living in the time of the fourth industrial revolution. The technologies such as Internet of Things, Cloud Computing, and Big Data are defining technological progress. These technologies have become as much a part of our daily lives as the personal computer or the mobile phone. The main objectives/research problems of this paper are to present and describe our research results and to describe a general application of Cloud Computing technology, a method to reference research sources.

Cloud Computing is an interdisciplinary field that has been exponentially growing in recent years. This technology gives users access to storage, files, software, and servers through internet-connected devices; in other words, it means having the ability to store and access data and programs over the internet instead of on a hard drive. There are many Cloud Computing services that the users can take advantage of, ranging from the basic data storage and networking services to natural language processing and artificial intelligence, as well as standard office applications.

While we were working on our FRA research, we encountered a problem of how to cite the references properly. In scientific papers, it is not appropriate to include separate references to extensive documentation, data structures, data, and algorithms. All these references are of different nature and might need to be cited differently. To cite each reference separately might lead to a lengthy list of references and confusion for the readers. Moreover, the links to the online documents might change with time and, consequently, do not work properly. Therefore, we proposed a method that provides a citation only to one supporting source, which is located in the Cloud together with one special Cloud schema file describing the Cloud infrastructure. In our paper, we will present an application of this method and provide the advantages we encountered. In such an application, the data are placed in the Cloud off-line. In the context of Internet of Things technology, online data can also be generated. This technology is mainly based on the application of sensors that put the measured data into the Cloud via the internet. Supporting an Internet of Things project, this publication has been created. In the project, special sensors are used to create...
a monitoring system to protect isolated and at-risk populations from the spread of viral diseases. The sensors are used to write data to the Cloud via the internet. Data evaluation will be the next part of the project. The common point between the free route airspace (FRA) and the monitoring system are the significant points. These points describe the areas of investigation or the location of the sensors.

All Cloud applications are difficult to list; some applications can be found in publications [1–3]. These works deal with Cloud applications for software solutions [3], for scientometry and scientific literature [1], and for the application of technology in companies of various sizes [2].

The reason that we chose to use Cloud Computing and apply it in our research citations is because of the many benefits. It allowed us to create a virtual data repository to give us the flexibility of connecting to our documentation anywhere and at any time. This virtual data repository also reduces the effort required for citations (instead of citing multiple sources, we can use one Cloud reference). With the increasing number of web-enabled devices used in today’s business environment (e.g., smartphones, tablets), accessing our data is much easier.

Our Cloud Computing method can be used as a scientific publication reference management and resource management for any research area that does not rely on sensitive data. We use the Free Route Airspace (FRA), FRA mathematical modelling objects, and data structures together with the algorithms and the related documentation to demonstrate our method. A simple application of our research is shown in Figure 1.

![Cloud Computing](image)

**Figure 1.** Research Cloud application.

Research-related publications can cite only one object—the FRA Research Cloud [4]. At the same time, this Cloud can be used to manage research resources. The diagram was created based on the publication [5] as an insight into Cloud applications from a research perspective.

**Brief Introduction to Free Route Airspace (FRA)**

FRA is one of the key Air Traffic Management (ATM) functionalities to be implemented as part of the European Air Traffic Management Master Plan. The other ATM functionalities are described and available in the work [6]. FRA is a new concept of operations created to modernize the airspace and contribute to the reduction of ATM costs, of air transport’s impact on the environment, fuel consumption, production of emissions, and, last but not least, it improves the efficiency of flights. FRA is defined as a specified volume of airspace in which the airspace users can freely plan a route by using the FRA Significant Points [4, Documentation Section]. FRA Significant Points are specific points described (using the
standard ICAO format) by geographical coordinates or by bearing and distance. They are published in the national States’ Aeronautical Information Publications (AIP). The FRA topic has been already subject to several authors’ publications. For example, a study of FRA can be found in work [7]. This work is from 2011; therefore, some information concerning the FRA implementation in given countries is already outdated. Nevertheless, this work provides a good baseline to understand the principles of FRA. Similarly, we have also an FRA-related article published back in 2018 [8]. As the situation in Slovak airspace has changed since then, some information might be outdated. However, it gives a good overview of how the FRA has been evolving over the years. Another work was conducted to assess the Northern Europe Free Route Airspace deployment, where two Single European Sky Airspace Research programme (SESAR) solutions were combined, i.e., the Free Route Airspace and the Functional Airspace Blocks. This assessment was produced using fast-time simulations and based on aircrafts’ separation and airspace complexity [9]. All the FRA-related works have in common the FRA topic, but each of them is presenting it from a different angle. For example, one work is focused more on the FRA implementation in a specific country and the safety risk analysis of this implementation [6], while another work focuses on the flight planning in the FRA area [10]. Each work is specific as it addresses a certain area of research. The uniqueness of our work (when comparing it to all others) is in modelling the FRA airspace, using graph theory for this, and optimizing the flights in FRA—work that has not been done so far. In our work, the FRA system is a simplified representation network. In this network, the graph vertices represent the individual airspaces where FRA is implemented, and the edges represent connections!between these airspaces. Further operations performed in this network allow the modelling of the FRA graph and the creation of the algorithms for calculating the most effective flight in this system; see ([4], Algorithms Section).

In the next sections, we will present the outcomes of our research.

2. FRA Mathematical Models—Graphs and Networks

The complex concept of FRA will be modelled by using graph theory—more precisely, using the networks. First, we define some basic concepts of graph theory.

A graph is a pair \( G = (V, E) \), where \( V \) is a set of vertices (nodes), and \( E \) is a set of edges (arcs), connecting some pairs of vertices (nodes). Two vertices \( u \) and \( v \) of a graph are adjacent if they are connected by an edge \( r = (u, v) \). For our purposes, we will consider no multiple edges (several edges are called multiple if they connect the same pair of vertices) and loops (edges beginning and ending at the same vertex). A graph is said to be simple if it contains no loops or multiple edges. The adjacency matrix \( M \) of a simple graph \( G(V, E) \) is a \( 0–1 \) matrix (a matrix with elements 0 or 1) defined by \( M(i, j) = 1 \iff (i, j) \in E \) and \( M(i, j) = 0 \iff (i, j) \notin E \) for each \( i, j \in V \). An adjacency list is a set of all edges of a simple graph (we can enter graphs in the computer program using the adjacency list).

A directed graph or digraph is a pair \( D = (V, E) \), where \( V \) is a finite set of vertices, and \( E \) is a relation on \( V \). Elements of the set \( E \) are called directed edges or arcs. A simple digraph contains no loops or multiple arcs. A path \( p = (v_0, v_1, \ldots, v_n) \) of length \( n \) in a digraph \( D = (V, E) \) is a sequence of various vertices \( v_0, v_1, \ldots, v_n \in V \), each pair \((v_{i−1}, v_i) \in E (i = 1, \ldots, n)\) of which forms an arc.

A weighted graph is a graph in which a number (the weight) is assigned to each edge. Such weights might represent, for example, costs, lengths, or capacities, depending on the problem.

Further definitions and characteristics of graphs can be found in publication [11].

In a basic definition, a network is defined as a collection of points joined together in pairs by lines. The points are referred to as vertices or nodes, and the lines are referred to as edges or arcs. Any system that is composed of individual parts or components linked together in some way can be called a network. It can be, for example, the internet, a collection of computers linked by data connections or human societies, collections of people linked by social interactions, or flights in air transport [12].
2.1. Encoding of the GFRA Graph Vertices and Edges

In this section, we define a graph for FRA. This graph is labeled as GFRA. Using the graph GFRA, we can define a complex network \([13]([4], A[1]—Free Route Airspace a Complex Network)\). Let \(GFRA = (V, E)\) be a graph, where individual FRA areas create the set of vertices \(V\). One can see this graph in Figure 2; it displays the situation with FRA evolution in 2021. For better visualization, the red-highlighted vertex \(V_1\) displays the SEE FRA (South East Europe Free Route Airspace) area, which consists of the airspace of Slovakia, Hungary, Romania, and Bulgaria. We can load the adjacency matrix of GFRA from the database \([4], D[2]—FRA adjacency matrix\).

Let \(E\) be the set of edges, and \((i, j) \in E\) if and only if the vertices \(V_i\) and \(V_j\) are adjacent. The vertices are adjacent if there is a transition from \(V_i\) to \(V_j\).

![Free Route Airspace Graph and SEE FRA, 2021](image)

**Figure 2.** Graph Free Route Airspace, 2021.

2.2. The FRA Significant Points

Each FRA is defined by FRA significant points. The significant point is defined by GPS coordinates, names, and other attributes; see ([4], Data and Data Structure section, and [14]). The FRA significant points are divided as follows:

1. FRA Horizontal Entry Point (E)—It is a published significant point located on the horizontal boundary of FRA from which the FRA operations are allowed. It should be located exactly on the boundary of the relevant FRA area.
2. FRA Horizontal Exit Point (X)—It is a published significant point located on the horizontal boundary of FRA to which the FRA operations are allowed. It should be located exactly on the boundary of the relevant FRA area.
3. Combined FRA Horizontal Entry and Exit Point (EX)—It is a published significant point located on the horizontal boundary of FRA from which and to which the FRA operations are allowed. In some exceptional cases, the above-described points can be located inside or outside the relevant FRA (instead of being located at the horizontal border). This has to be within certain limits and after coordination with the EUROCONTROL Network Manager (NM). Note: For more details, see EUROCONTROL FRA Design Guidelines ([4], Documentation section).
4. FRA Arrival Connecting Point (A)—It is a published significant point to which FRA operations are allowed for arriving traffic to specific aerodromes. In a vertical dimension, this point could be also considered as an exit point (X) as any arriving traffic exits the FRA area through this point but it is not marked as (X).
5. FRA Departure Connecting Point (D)—It is a published significant point from which FRA operations are allowed for departing traffic from specific aerodromes. In a vertical dimension, this point could be also considered as an entry point (E) as any departing traffic enter the FRA area through this point but it is not marked as (E).

6. Combined FRA Arrival Connecting and FRA Departure Connecting Points (AD)—It is a published significant point to/from which the FRA operations are allowed for arriving/departing traffic to/from specific aerodromes. In a vertical dimension, this point could be considered as a combined FRA entry and exit (EX) point as any arriving/departing flight exits/enters vertically the FRA area but this point is not marked as such (EX).

The points in bullet 3–6 are referenced to the FRA area/State to which they are located but they can be also defined with reference to an aerodrome located in an adjacent FRA or non-FRA area.

7. FRA Intermediate Points (I)—It is a published or unpublished point defined by geographical coordinates or by bearing and distance via which FRA operations are allowed. This point is located inside the FRA area.

3. FRA Data Structures and Algorithms

This section presents parts of our research on FRA. In the next sub-section, we will present the objects that we work with. They do not fall under the ISO 690:2021 citation standard and that is why we decided to group them together and cite them all as only one source. Data structures arise after data analysis of input and proposed output objects. The input objects were documentation and input databases; see ([4], Data and Data Structures, Documentation).

3.1. NFRA Network and Significant Points

By using the graph GFRA, we define a complex network. In this network, each vertex of the graph GFRA is defined by FRA significant points (see Figure 3 and [4], Algorithms section). We define the FRA network as an object that contains the pairs $[V, P_V]$, where $V \in V(GFRA)$, $P_V = \{[LatP, LonP]; [LatP, LonP] \in V\}$ is a set of the FRA significant points, and $[LatP, LonP]$ are GPS coordinates of the given point. We do not mention the edges of the network here. We assume that each vertex (significant point) can be connected to every vertex (significant point) within the area FRA. This network is called the Free Route Airspace Network and is denoted by NFRA; see ([4], A[2]—The Vertex SEE FRA). In Figure 3, the interior airspace points are indicated by a dot, and the Entry, Entry and Exit points by a triangle.

![Figure 3. SEE FRA significant points.](image-url)
We can calculate optimal flights between any travel destinations for this feature.

where \( P_i \) are the significant points with GPS coordinates \((\text{lat} P_i, \text{lon} P_i)\) of the significant points. These values are required for calculating the distance \( d(P_i, P_i+1) \) between points \( P_i, P_i+1 \) for \( i = 1, 2, \ldots, n-1 \). The value

\[
I(p) = \sum_{i=1}^{n-1} d(P_i, P_i+1)
\]

is the length of flight \( p \). The departure point \( P_1 \) belongs to the airspace \( V = V_1 (P_1 \in V_1) \) and the arrival point \( P_n \) belongs to the airspace \( V = V_k (P_n \in V_k) \). Therefore, we can assign an airspace sequence

\[
A_p = (V_1, V_2, \ldots, V_k)
\]

to the flight \( p \), where \( P_i \in V_j \) for each \( j = 1, 2, \ldots, k \) and \( i = 1, 2, \ldots, n \). Note that, according to system rules, \( V_i \neq V_i \) if and only if \( i \neq j \) (it is possible to enter and exit each area only once during one flight). The term air transport optimization will represent the optimization of each flight within the airspace. Therefore, it is sufficient to deal with only one flight optimization.

In the NFRA network, we can define the set of all permissible flights. This is similar to the set of all admissible solutions for optimization problems. In this sense, we can also view the FRA system as an optimization model. However, we still need to define an objective function.

### 3.3. Objective Function

For flight route planning, the departure point \( P_1 \) and the arrival point \( P_n \) (\( P_1 \in V, P_n \in V \) and \( V, V \in V(\text{GFRA}) \)) represent the input of the flight. We are looking for a flight route \( p = (P_1, P_2, \ldots, P_n) \), a path in network NFRA \( (P_i \in \text{NFRA} \text{ for } i = 1, 2, \ldots, n) \) in our optimization model. To completely enter the optimization model, we need to define the conditions that the path \( p \) should meet. These conditions are defined using an objective or target function defined by

\[
f(p, c, w) = \frac{1}{100} \sqrt{\sum_{i=1}^{n-1} d(P_i, P_i+1) \times c(P_i, P_i+1)}
\]

where \( d(P_i, P_i+1) \) is the distance, \( c(P_i, P_i+1) \) is the en-route charge between points \( P_i \) and \( P_i+1 \), for \( i = 1, 2, \ldots, n-1 \), and \( w \) is the weight of a plane (MTOW); see ([4], D[5]—List of airliners by maximum takeoff weight) and ([4], D[4]—The list of unit rates for each country). The exact description of the target function can be found in the publication [15]. The target function is determined by three elements: distance factor, aircraft weight factor, and unit rate of charge.

Our goal is to minimize the value of \( f \), which expresses the minimal cost of the flight. We can calculate optimal flights between any travel destinations for this feature.
3.4. FRA Optimization Task

The mathematical notation of the flight planning optimization task in FRA has the following characteristics:

The target function is defined by Equation (4).

Constrains, inputs:

P, departure point, P, arrival point of a flight in NFRA. We are looking for such a flight for which the target function has an optimal value between the departure and arrival point. The decision variables are flights, paths in a network NFRA from point P and to point P. Therefore, we need to take into account the distance factor and unit rate of charge for any points Q, R ∈ NFRA. In addition, we must consider the aircraft weight factor.

c(Q, R)—en-route charge function between points Q, R ∈ NFRA we can load from a database ([4], D[4]—The list of unit rates for each country);

d(Q, R)—distance function between points Q, R ∈ NFRA (can be calculated by point coordinates of Q and R);

w—(MTOW) weight of the plane.

Outputs:

path \( p = (P_1, P_2, \ldots, P_n) \), \( P_i \in \text{NFRA} \) for \( i = 1, 2, \ldots, n \), where object function \( f \) is optimal,

\[
    f(p, c, w) = \min \{f(r, c, w); r – \text{path from } P_1 \text{ to } P_n \text{ in NFRA} \} \tag{5}
\]

Note: We can assign an airspace sequence \( A_p = (V_1, V_2, \ldots, V_k) \) to every flight \( p = (P_1, P_2, \ldots, P_n) \), where \( P_i \in V_j \) and \( i \in \{1, 2, \ldots, n\} \), \( j \in \{1, 2, \ldots, k\} \).

3.5. FRA Optimization Algorithm

After defining the FRA optimization task, we have the input points \( P_1, P_n \in \text{NFRA} \).

Now, our task is to find the optimal flight from \( P_1 \) to \( P_n \). We proceed by finding the shortest path between vertices in the GRFA graph \( P_1, P_n \) and so we get the sequence \( A_p = (V_1, V_2, \ldots, V_k) \). Here, it is necessary to determine the entry and exit points for each airspace \( V_j \) and then we can solve the problem (5) in parallel in each space \( V_j \). When we find multiple shortest paths, we perform a calculation for each path and find the optimal flight. Within the airspace, we consider a flight to be optimal if we can make it along a line segment that has the minimum length.

FRA optimization algorithm diagram:

Input:

P, departure point, P, arrival point of flight in NFRA.

1. Suppose that \( P_1 \in V, P_n \in \overline{V} \).
2. Compute the shortest path from V to \( \overline{V} \) in graph GRFA (the shortest path contains the minimum amount of airspace).
3. If there are more shortest paths, find the optimal shortest path, and let it be the path \( A_p = (V_1, V_2, \ldots, V_k = \overline{V}) \) (optimal shortest path selection—according to the criterion of optimization).
4. Find entry–exit points \( P_{je}, P_{lx} \in V_j \subseteq \text{NFRA} \) for \( j = 1, 2, \ldots, k \). \( P_{xe} = P_1 \) \( P_{lx} = P_{(j+1)e} \) (the point \( P_{lx} = P_{(j+1)e} \in V_j \cap V_{j+1} \) can be selected as the point which lies at the smallest distance from the line \( P_lP_n \)).
5. Find the shortest path between points \( P_{je}, P_{lx} \in V_j \subseteq \text{NFRA} \) for \( j = 1, 2, \ldots, k \) (can be calculated in parallel).

The program code of algorithms can be found in the MATLAB File Exchange database. One such algorithm is here [13]. All research (project) algorithms are located in the Cloud ([4], Algorithms section).
4. The FRA Research Results Compilation into the FRA Research Cloud

The FRA documentation and the outcomes of our FRA research are very extensive; this is why decided to seek a way to simplify its citation, which we could also use in future publications. Before using a Cloud method, our list of references resembles the one in Figure 4. The citations displayed in Figure 4 are unnecessarily lengthy and might confuse the readers. In the research, it is important to offer proper citations to different objects. The objects, such as books, articles, software, electronic sources, etc., can be cited according to the ISO 690:2021 Standard: Information and documentation—Guidelines for bibliographic references and citations to information resources. However, in our research, we work with objects that are not a part of the citation standards, such as extensive documentation, data structures for research, simple algorithms for mathematical model development, etc. We decided to cite all these objects in a single and structured way and specify only one Cloud source for all of them. The citation of all documents takes place by using the Cloud schema. We registered our Cloud location as a Method in ResearchGate and obtained a DOI (Digital Object Identifier) from ResearchGate. We named this location FRA Research Cloud. DOI provides the information where our work can be found online, and it is a reliable link to our research—it is guaranteed to never change. Consequently, in the list of references, we use only one main link for citing all objects. By using this Cloud option, we can perform the resource management more easily and include all supporting documents. The advantage of such a system is that it can be used for any other projects, personal use, etc.

![Figure 4. Documentation, software, data, and data structures citation.](image-url)

The FRA Research Cloud [4] related to FRA Research is divided into the following parts:

1. FRA documentation. This folder contains the documents where all FRA concept elements are described.
2. FRA data structures and data. This folder contains the data structures that are used for model creation. By using the data structures when applying models, we are generating algorithms and processes.
3. FRA algorithms (references to the algorithms used). This folder contains the references to the algorithms that were used for the flight route planning.
4. Online FRA data.
5. Sensitive data.

We list the online and sensitive data here for completeness only. Such data may be generated by the Internet of Things technologies, such as aircraft coordinates in FRA airspace at a given time. The Cloud structure with the exact content is described in the Cloud schema.

[9] P. Szabó and M. Ferencová. The list of FRA Areas with the latitudes, longitudes and unit rates URL: https://tinyurl.com/FRA-vertices. Cloud:DropBox, 2021. Data Structure.
[10] P. Szabó and M. Ferencová. The Vertex SEE FRA. URL: https://tinyurl.com/Vertex-SEE-FRA. MATLAB Central File Exchange, 2021. Software.
[11] P. Szabó, M. Ferencová, and R. Szabóčová. Free Route Airspace a Complex Network. URL: https://tinyurl.com/Complex-Network. MATLAB Central File Exchange, 2021. Software.
[12] xEUROCONTROL. European Route Network Improvement Plan, Part 1 URL: https://tinyurl.com/EControl-ENRIPI. 2017. FRA Documentation.
[13] xEUROCONTROL. Free Route Airspace Design Guidelines. URL: https://www.eurocontrol.int/publication/free-route-airspaces-fra-design-guidelines. 2017. FRA Documentation.
[14] xEUROCONTROL. Free Route Airspace Points List. URL: https://www.eurocontrol.int/publication/free-route-airspace-fra-points-list-cma-area. 2021. FRA Documentation.
[15] xEUROCONTROL. Free Route Airspace. URL: https://www.eurocontrol.int/concept/free-route-airspace, 2021. FRA Documentation.
4.1. Cloud Scheme and Object Citation

FRA Research Cloud can be simply cited as [4]. According to the Cloud schema, we also enter the location of the object and the names of the documents, data structures, or algorithms that are located in the Cloud.

4.2. Algorithm Citation

Algorithms that are licensed and have a URL can be cited using a URL link (this applies to any material with a URL link), such as [13]. In this way, it is possible to apply copyright in research. Algorithms and program codes that do not have an associated URL link can be cited using the Cloud and Cloud scheme as ([4]—Algorithms, A[n]—Title of the Algorithm), where n is the number of the cited algorithm. The algorithm A[n] is located in the Algorithms folder according to the Cloud scheme. The parameters—Algorithms, A[n]—Title of the Algorithm are optional.

4.3. Documentation, Data, and Data Structure Citation

Citation of documents, data, and data structures is similar to algorithms that do not have a URL link. This means that we will provide a link to the Cloud [4] and then provide the document number according to the Cloud scheme. In the case of the document—(Documentation, Doc[n]—Document Title), the document Doc[n] is located in the Documentation folder according to the Cloud scheme. The parameters—Documentation, Doc[n]—Document Titles—are optional. In the case of the Data, and Data Structure—(Data, and Data Structure, D[n]—Data, and Data Structure Title), the object D[n] is located in the Data, and Data Structure folder according to the Cloud scheme. The parameters—Data, and Data Structure, D[n]—Data, and Data Structure Titles—are optional.

5. Conclusions

In the publication, we describe a method for the citation of FRA research objects using Cloud Computing. It is convenient to apply this method when we have extensive technical documentation or supporting research objects that are not suitable for citation. It is necessary to obtain the reference (DOI) to the Cloud location of the supporting materials and develop the Cloud infrastructure. This infrastructure is written into the Cloud schema and used to reference individual supporting objects. One of the advantages of this method is that we have the whole project, documentation, models, programs, data structures, and data in one transparent Cloud. The Cloud scheme ensures clarity. FRA Research Cloud is a method for research and scientific publications’ reference management. Another essential role of such a Cloud is the precise management of research resources or research projects. We can apply such a Cloud multiple times, but we still have to state the time of updating documents, data, and algorithms. The method can be used in the vast majority of research projects. The proposed method supports open research, documentation, data, data structures, and algorithms being freely available. Therefore, it can also serve as study material on the issue.

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operational purposes. Our data are stored in the Cloud; see ([4]—Data and Data Structures). The main documentation of the FRA system can be found in references ([4]—Documentation).

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