

TOWARDS UNIVERSAL BEACON CODE ASSIGNMENT

Spatial and Temporal Analysis of Enroute Traffic in NAS

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Abstract— Beacon codes are a set of very limited National Airspace System (NAS) resource. Currently, the beacon code allocation process is based upon the concept of discreet beacon code assignment to each ARTCC. Due to the mismatch between the limited number of beacon code subsets available and the volume of traffic, duplicate beacon code assignment is unavoidable under the current scheme.

In this paper, the spatial and temporal structure of enroute NAS traffic is analyzed. This analysis provides the foundation of exploiting the inherent structure of NAS traffic to enable a more efficient beacon code assignment, i.e. with fewer beacon code changes per flight.

Keywords – Beacon Code, Squawk Code, ATCRBS, En-route traffic, NAS, Air Traffic Controller workload.

I. MOTIVATION AND BACKGROUND

The catastrophic 1960 collision between United DC-8 and TWA super constellation called for major technological overhauling of the existing Air Traffic Management system. Even though the collision was attributed to the fault of pilots, it was also partially blamed on the lack of secondary surveillance radar, which, if present, could have helped alert the controllers detect impending collision and alert the pilots. In 1961, President Kennedy ordered FAA to begin to “conduct a scientific, engineering overview of our aviation facilities and related research and development”. As a result of this order, “Project Beacon” committee was formed to investigate the deficiencies in the air traffic control system and propose alternate solutions. This resulted in the development and installation of ATCRBS (Air Traffic Control Radar Beacon System) as a new air traffic control technology.

ATCRBS is an acronym for Air Traffic Control Radar Beacon System. It is a system used in ATC to enhance surveillance radar monitoring and separation of aircraft (1,6,8).

Parts of the ATCRBS system

ATCRBS consists of transponders (in aircraft) and Secondary Surveillance Radar (SSR) which is co-located with the Primary Surveillance Radar (PSR) on the ground. The SSR located at the ATC site, transmits interrogations and listens for replies. Transponders located on the aircraft receive interrogations, decode it and respond with requested

information (mode 1,2,3/A,C). Note: Mode 4 and mode S are not part of the ATCRBS system even though they use the same transmit and receive hardware.

ATCRBS Operation

ATCRBS interrogator at the ATC facility on ground periodically interrogates aircraft on a frequency of 1030 MHz. Aircraft receiving this interrogation reply with the requested information (altitude and/or identification) after a 3 micro second delay. The interrogator then decodes the reply and identifies the aircraft.



Figure 1: Representation of 500 flight tracks in CONUS on 18th July 2007 in Google Earth.

When an aircraft receives a mode 3/A interrogation, the reply expected is a Beacon/Squawk code. Current mode 3/A transponders installed on aircraft are designed to transmit four octal digits, resulting in a total of $8^4 = 4096$ possible beacon codes. Many of the codes are reserved for special uses such as military operations, which further reduces the number of codes available for use by civilian aviation. The National Beacon Code Allocation Plan (NBCAP) established by DoT/FAA order 7110.66C (5) permanently allocates the remaining beacon codes to the ARTCC's. The controller uses the beacon code as the unique identifier for flights within a center boundary. In order for the controller to uniquely identify and address each aircraft it is necessary to ensure that all aircraft flying within the area of responsibility of that controller are

uniquely identifiable, i.e. each aircraft within that center has a unique beacon code.

Beacon Code Allotment process

A flight is assigned its first beacon code by the Host Computer System (HCS) of the departure center. Ideally, flights could fly from their origin to their destination using the same code for the duration of their flights. However, because there are more flights in need of codes at any point in time than there are codes available, and traffic levels are growing, each code has to be assigned to more than one flight (while still ensuring unique code assignment within a center). Due to this shortage of available codes, when aircraft cross center boundaries along its route, there is a strong possibility that the code it is using is already in use by some other flight in the facility it is approaching. The HCS in this case must reassign the flight entering the center a new beacon code. This process is known as code reassignment. This process requires voice communication to request the new transponder setting. As a result, these actions lead to increased workload of air traffic controllers and pilots (in addition to other tasks to be completed as part of a standard hand-off procedure). Therefore, code reassignments are undesirable and should be avoided as much as possible.

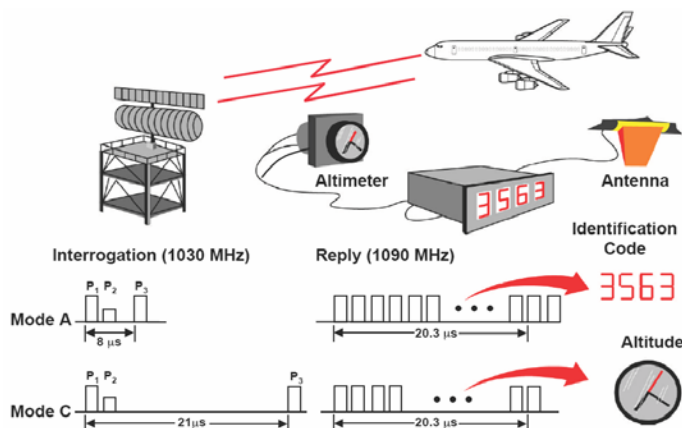


Figure 2: ATCRBS system working. Ref: Surveillance Tools for Distributed Air/Ground Traffic Management (Steven R. Bussolari, MIT, Lincoln Labs)

NBCAP (National Beacon Code Allocation Plan) – Primary Goal and Concept⁵

The primary goal is to efficiently manage the beacon code set as a limited National Airspace System (NAS) resource. The NBCAP is based upon the concept of discrete beacon code assignments to each ARTCC so that codes can be adapted and assigned by a computer to a flight plan according to a specific procedure. Ideally, each ARTCC should be allocated enough exclusive code blocks so that each aircraft could be given a computer assigned unique discrete code which would not be duplicated anywhere in the NAS. The intent would thereby, allow all aircraft to proceed from departure to destination using the same discrete code. Unfortunately, duplicate computer code assignments are unavoidable because of the limited number of code subsets available, the number of ARTCC's, and the

volume of traffic. To minimize the impact of duplicate computer assignments, careful analysis of code utilization statistics is required to ensure appropriate facility assignments. Therefore, ARTCC facility assignments are managed from the national level.

The objective of this research is to analyze historical data to extract spatial and temporal pattern(s). This analysis would help in understanding the beacon code assignment problem complexity at different levels (entire NAS, small geographic or time concentration).

This paper is organized as follows: Section II describes the previous work in this field. Section III describes the source of data and the relevant fields. Section IV describes the method of analysis and the results. Section V discusses the implications of these results.

II. PREVIOUS WORK

The most prominent previous work on beacon code allocation was done by Lucic et al at CSSI (12). This research focused on the optimization of beacon code allocations based on a new geographic scheme. When assigning a code to a flight, the current beacon code assignment procedure does not consider the flight parameters or the decisions of the other Host Computer Systems in the NAS. Consequently, a code assigned to a flight in one center may end up being used in other centers in the NAS. The current (baseline) code allocation scheme works well when each center has a unique set of allocated codes. However, the limited number of initially available beacon codes combined with growing traffic requires each code to be allocated to more and more centers. Beacon codes allocated to multiple centers and high traffic levels increase the number of code reassignments and consequently further increase demand for code allocations. To solve the problem, a geographic beacon code allocation scheme was proposed. It considers the destination region of a flight while the beacon code to be assigned to the flight is being selected. This further allows the allocation of beacon codes to centers in a way to be used for assignment to flights heading toward specific destination regions. The code allocation was developed based on multiple days of ETMS data. The data were initially used to estimate code demand and to determine the interference between center-regions. Since the code allocation to center-regions consists of primary and secondary blocks of codes, two optimization problems were defined. The primary code allocation is a set of codes to be assigned to the traffic with the highest priority, it was determined for all center-regions first. The center-regions' primary code allocation optimization is aimed to allocate the available codes proportionally to center-regions' code demands while allowing small or no interference between center-regions sharing the code allocation. Since each center-region needs a specific number of codes to support the traffic, the difference between the required number of codes and size of primary allocation is allocated in the secondary block of codes in a way that minimizes code sharing between center-regions with high interference.

The proposed allocation was tested using the beacon code assignment simulation. A total of 31 days of ETMS data were included in the simulation testing. Test samples were taken

from different years and months to capture traffic variations. The test results show that the proposed allocation reduces the total number of reassignments by approximately 60% with standard deviation of approximately 2%.

III. DATA SOURCES

The data used in this study was obtained from ETMS (Enhanced Traffic Management System). The data extracted spans over a period of 24 hours starting from 4 AM EDT on 18th July, 2007 to 4 AM EDT on 19th July 2007. A snapshot of the data is shown in Figure 3 below.

FID	Time	ACID	AcType	Ori	Dest	Lat	Lon	Alt
547236635	28893	AAL256	B752	ORD	EINN	2906	3674	370
547236635	28953	AAL256	B752	ORD	EINN	2909	3662	370
547236635	29013	AAL256	B752	ORD	EINN	2912	3648	370
547236635	29073	AAL256	B752	ORD	EINN	2915	3634	370
547236635	29133	AAL256	B752	ORD	EINN	2918	3621	370
547236635	29193	AAL256	B752	ORD	EINN	2921	3609	370
547238499	30582	AAL900	B772	SAEZ	MIA	1427	4703	400
547238499	30642	AAL900	B772	SAEZ	MIA	1435	4706	400
547238499	31422	AAL900	B772	SAEZ	MIA	1515	4776	179
547238499	31482	AAL900	B772	SAEZ	MIA	1520	4781	158
547238499	31542	AAL900	B772	SAEZ	MIA	1525	4786	138
547238499	31602	AAL900	B772	SAEZ	MIA	1529	4791	138
547238499	31662	AAL900	B772	SAEZ	MIA	1533	4797	106
547238499	31722	AAL900	B772	SAEZ	MIA	1536	4802	101
547238499	31782	AAL900	B772	SAEZ	MIA	1538	4807	90
547238499	31842	AAL900	B772	SAEZ	MIA	1541	4811	81
547238499	31902	AAL900	B772	SAEZ	MIA	1542	4815	75
547238823	29100	COA30	B762	SBGR	EWR	1550	3936	360
547238823	29700	COA30	B762	SBGR	EWR	1626	3971	360
547238823	29820	COA30	B762	SBGR	EWR	1634	3974	360
547238823	30360	COA30	B762	SBGR	EWR	1699	4005	360

Figure 3: Snapshot of enroute ETMS data for 18th July 2007.

The data has 48966 tracks (each track is one flight leg). It also includes international and cargo flights. Military flights are not included in this data as they have their own reserved set of beacon codes. The following fields were used:

1. FID – this field is the unique identifier for a flight leg.
2. Time – Time in seconds from 12 AM GMT on 17th July, 2007. So 8 AM GMT (4 AM EDT) on 17th July would have a value of $8*60*60 = 28800$.
3. ACID – Airline assigned aircraft ID. Eg: AAL900
4. AcType – Aircraft Type. Eg: B752
5. Ori – 3 or 4 letter ICAO code for origin airport. Eg: ORD
6. Dest – 3 or 4 letter ICAO code for destination airport.
7. Lat – Latitude of the aircraft at the corresponding time in minutes. Eg: 2906 represents $2906/60 \sim 48.43$ degree North
8. Lon – Longitude of the aircraft at the corresponding time in minutes. Eg: 3674 represents $3674/60 \sim 61.23$ degrees West.
9. Alt – Represents the flight altitude level. Eg: 370 means the aircraft was at 370000 feet above MSL(mean sea level).

As this analysis is focused on CONUS (Continental US), all points outside an artificially constructed imaginary boundary (15 N 50 N && 60 W 128 W) were excluded. This boundary is shown in Figure 1 in red.

IV. ANALYSIS AND RESULTS

A. National flight count

Figure 4 shows the count of active flights in the entire NAS for every 15 min time interval starting at 4 AM EDT on 18th July 2007. A flight is counted as active for all time periods between its actual gate push back (request beacon code) and gate in time (release of beacon code). If beacon codes are assigned centrally for the entire NAS, then this count of active flights on a national level for every 15 min time period would help ascertain the level of shortage of beacon codes, i.e. when do we run out of beacon codes for first time during the day?

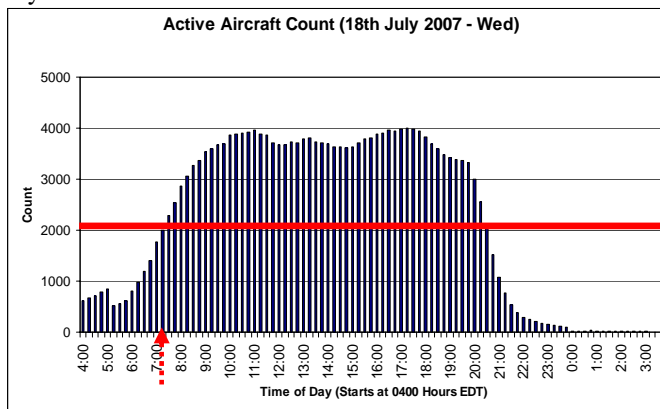


Figure 4: Active aircraft Count for Entire NAS

The active count of aircraft exceeds 2000 for the first time during the 7:00 – 7:15 AM (EDT) quarter of the day. This means that if we were to do a FCFS (First Come First Served) allotment of Beacon codes on a national level, then we would be out of codes by 7:00 AM EST. Clearly, this is not a feasible option.

B. Flight Count by geographical division

If the entire NAS is divided into 2 halves, namely Eastern and Western corridors, then these corridors could simultaneously use the same set of codes without causing any conflicts as the flights would be geographically wide apart. For simplicity, there are two divisions of longitude considered, namely 102° W and 92° W. 102° W is Kansas/Colorado border. Figure 5 A and B shows the count of Eastern, Western and trans-continental flights for these longitudinal divisions.

With the East-West dividing boundary set as 102° W, the active aircraft count for Eastern corridor exceeds 2000 for the first time during the 08:30-08:45 AM (EDT) quarter of the day. And for the Western corridor, the active aircraft count never exceeds 769. The implication of this result is that if 102° W is used as the dividing boundary, then 2000 codes would not be sufficient for the entire Eastern corridor by itself.

However, with the boundary set as 92° W, the active count in both the eastern and western divisions remain under 2000 at all times.

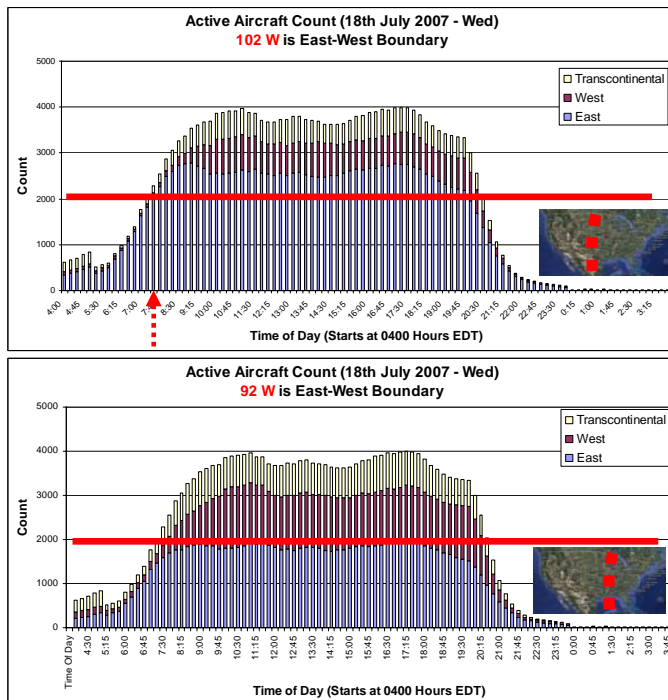


Figure 5: Active aircraft Count divided by geographical location of flight trajectory. Figure 5.a – Dividing Longitude is 102 W. Figure 5.b – Dividing Longitude is 92 W

C. Flight count by distance flown

Flights which travel smaller distances would relinquish their codes faster. This implies that if sufficient number of codes were reserved for short-distance flights then they could automatically be de-conflicted with the long-distance flights. To test this hypothesis, we first plot the histogram for the flight count by flight distance travelled.

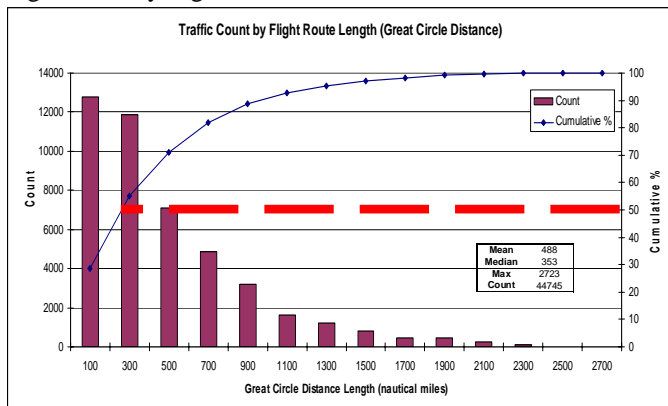


Figure 6: Distribution of Aircraft count by flight distance

Figure 6 shows the count of aircraft by distance travelled in miles. It can be seen that 50% of the flights travel 400 nautical

miles or less. Figure 7 shows the distribution of these short and long-haul flights throughout the day. The activity count of short-haul flights (<400 nautical miles) on the East and West corridors never exceeds 1480 and 483 respectively. Similarly, it is also observed that the activity count of long-haul flights (>400 nautical miles) on the East and West corridors never exceeds 1196 and 279 respectively.

This implies that if a set of beacon codes were reserved for short-haul flights on the Eastern corridor, then at least 1480 codes would be required to make sure there is no shortage of codes at the highest traffic level period. Also, at least 1196 codes would be required for the long-haul flights on the Eastern corridor. Together this adds up to 2676 codes, which is well over the 2000 available quota of beacon codes. Therefore distance based beacon code assignment is not a viable alternative in itself. However, it might be used in combination with other heuristic procedures. The feasibility of such assignment is yet to be determined and is part of the future research.

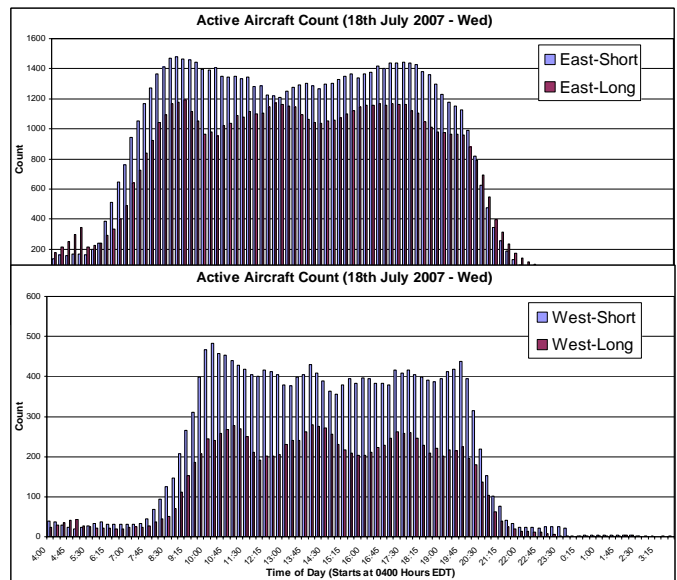


Figure 7: Distribution of Aircraft count by flight distance and geographical location (Short is defines as flight route < 400 nautical mile)

D. Sector traffic Intensity

Figure 8 shows the cumulative count of aircraft for each ARTCC for the entire 24 hour period. This data set has 11904 tracks (each track is one flight leg). ZDC with 8395 flights during the day is the ARTCC with highest cumulative traffic count, followed by ZTL and ZOB.

Figure 9 shows the traffic count for every 15 min time bin for the top 7 ARTCC. Interestingly, even though ZDC has the highest cumulative traffic count for the entire day, it has the highest instantaneous traffic count (15 min bin) for only 22 of the 96 time periods. ZTL has the highest count for 42 time periods. ZAU has the third highest number of peaks with 12 time periods corresponding to highest instantaneous traffic count.

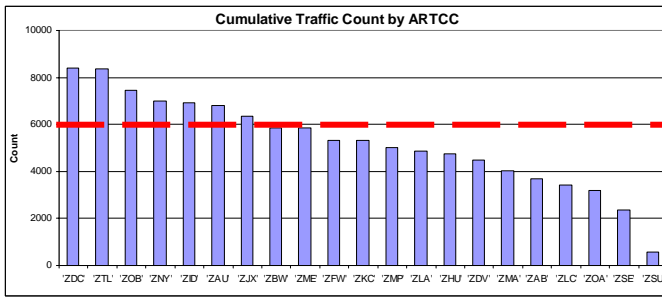


Figure 8: Cumulative count of aircraft for each ARTCC for the entire day

This implies that if mutually exclusive sets of beacon codes were assigned to ARTCC's based on the dynamic traffic intensity by time of day, then ZTL for example would need to be assigned atleast 537 codes for 23rd quarter of the day. It must be noted here that more data needs to be analyzed to take into account the effect of seasonality and traffic variations due to weather for example.

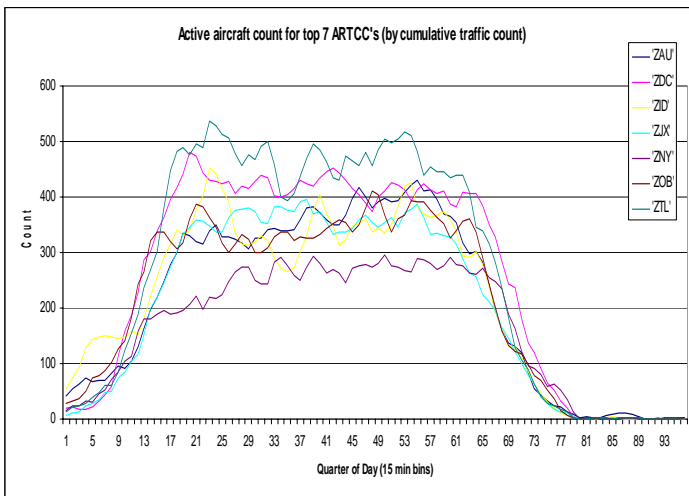


Figure 9: Cumulative count of aircraft for each ARTCC for the entire day

V. CONCLUSIONS AND FUTURE WORK

This paper presented a spatial and temporal analysis of a day's worth of 4-D trajectory data for the entire CONUS.

At the national level, the maximum active flight count during the day is ~4000. As the number of available beacon codes is about 2000, this statistic precludes the possibility of national beacon code assignment without any space and time considerations.

When the CONUS is divided into two halves along an imaginary longitudinal boundary (92 W), the maximum count of active flights in the east-only and west-only category is about 1980 and 1400 respectively. As these two regions are geographically independent, they could share the same beacon code sets without any conflicts. However, flights which cross this imaginary longitudinal boundary are not included in this

count and they would conflict with both the eastern and western halves.

When the flights are categorized based on distance flown and/or their geographical locations, the counts are as follows. At its peak traffic period, there are 1480 and 1196 short (<400 nautical miles) and long-haul flights on the Eastern corridor. This adds up to 2676, which is well over the 2000 available quota of beacon codes. This leads to the conclusion that distance based beacon code assignment is not a viable alternative in itself.

The beacon code assignment problem can be formulated as mixed binary integer optimization. One of the possible objectives of such a problem could be reducing the number of code reassignments for flights. Constraints would include:

Ensuring that every flight gets assigned exactly one beacon code for each time period during which it is active. Ensure that no two 'space-time adjacent' flights (flights present in the same sector at the same time period) share the same code.

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