Identification of BDS Registers

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Abstract. The SSR Mode S technology is currently one of the major means of surveillance in ATM. Addressed surveillance enables the elicitation of replies from Mode S transponder on board of an aircraft containing different flight information in the so-called BDS registers. The type of BDS register as well as its content is characterised by a number of the BDS registers which is determined according to SSR interrogation by default. The study deals with the development of a heuristic algorithm for identification of a particular BDS register with the assumption that the radar query is unknown. A BDS number is assigned to the appropriate message on the basis of the unique bit sequences and other criteria. The algorithm provides the opportunity to obtain various flight data from the aircraft by only receiving addressed surveillance replies on 1090 MHz frequency.

1 Introduction

SSR Mode S addressed surveillance is being used across Europe and other regions with high traffic density to ensure supplementary information which exceeds ATM data and is suitable for ATS. There is an assumption for the system functionality: both subjects shall be equipped with corresponding Mode S equipment, which consists of the SSR Mode S interrogator and the aircraft SSR Mode S transponder. The carrier frequency of the interrogation is established at 1030 MHz and the carrier frequency of the reply transmission shall be 1090 MHz [1, 2].

In response to Mode S interrogation there are four Mode S reply categories transmitted:
• Mode S all-call replies (DF 11);
• Surveillance and standard-length communication replies (DF 4, 5, 20 and 21);
• Extended length communication replies (DF 24);
• Air-air surveillance replies (DF 0 and 16) [3].

The category with downlink format 20 and 21 is represented by long interrogation and replies which contain the BDS (Comm-B Data Selector) register, providing Comm-B is considered a 112-bit reply containing the 56-bit message field. This field is used by the downlink standard length message, ground-initiated and broadcast protocols [2]. The BDS register represents the 56-bit MB part of the received message, which may contain different information from real operation depending on a BDS register number, for example, velocity, heading, meteorological information, etc. [4].

Required flight data can be provided to the ground station through the GIBS protocol which elicits a Comm-B message from a Mode S transponder on board the aircraft. This transponder may obtain a 56-bit buffer with real-time information from aircraft avionics, such as aircraft state data within 255 transponder registers. These 56-bit sequences are known as BDS registers such as

GIBS[20]. If the contained information has not been updated within the allocated time, the register shall be deleted [2, 5].

The replies may be obtained by any receiver getting data on 1090 MHz frequency. However, the number of the received BDS register is not possible to decode from specific part of the message, because there is no identification which may determine the interrogated register number in the 112 bits of the reply. The required BDS register is recognised by knowing the initial interrogation.

The ATM laboratory at the Department of Air Transport operates ADS-B receivers which constantly collect any messages transmitted by Mode S transponders on frequency 1090 MHz. Only the replies induced by the SSR Mode S interrogation are received. Thus, the query with the initially required BDS register number is unknown. In order to acquire the information from the replies on the SSR Mode S addressed interrogation, a heuristic algorithm is created to distinguish passively received BDS codes. The algorithm is evaluated through a comparison with data from real operation provided by ANS CR.

2 Examined BDS registers

All aircraft operating IFR/GAT in Europe are required to carry and operate Mode S Level transponder(s) with Mode S Elementary Surveillance (ELS) capability. All State aircraft operating IFR/GAT in Europe are required to have aircraft with the Mode S ELS equipment by the 7th December 2017. All aircraft operating IFR/GAT in Europe, MTOW exceeding 5700 kg or with a maximum cruising TAS capability greater than 250 knots are required to be equipped with and operate Mode S transponder with Elementary Surveillance (ELS) and

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Enhanced Surveillance (EHS), (as well as ADS-B 1090 MHz extended squitter). This regulation is applicable for aircraft with a certificate of airworthiness first issued on or after 8th June 2016, and the rest of the aircraft shall be retrofitted by 7th June 2020 [6-8]. Besides BDS registers involved in ELS and EHS, there is a concentration on MRAR (Meteorological routine air report) for obtaining more accurate meteorological data. There are currently no European regulations requiring MRAR equipment. Nevertheless, there is a small number of SSRs using MRAR technology and a small proportion of aircraft (around 2-3%) equipped with Mode S transponder providing MRAR registers [1].

Almost the entire European region is covered by the SSR system, which enables Mode S ELS to interrogate. Mode S EHS is based on the same principle as ELS, and the number of SSR EHS interrogation has enormous potential to be upgraded from ELS in the future. The MRAR BDS register $4,4_{16}$ is currently interrogated by every second radar rotation over the Czech Republic [1]. Unfortunately, there is no interrogation of BDS code $4,5_{16}$.

2.1. ELS

Mode S Elementary Surveillance shall provide transponder parameters such as ICAO 24-bit aircraft address, SSR Mode 3/A, altitude reporting in 25ft increments and flight status (airborne/on the ground). In addition, BDS registers shown in Table 1 are required to be transmitted within ELS.

Table 1. ELS BDS registers [1, 9].

No.	BDS register	BDS register Name
1	$1,0_{16}$	Data link capability report
2	$1,7_{16}$	Common usage GIBC capability report
3	$2,0_{16}$	Aircraft identification
4	$3,0_{16}$	ACAS active resolution advisory

2.2. EHS

The main objective of implementing EHS BDS register is to improve ATC systems of current and real-time information in order to predict the future trajectory of the flight. Every Mode S Enhanced Surveillance transponder shall provide all services of ELS automatically. EHS is extended by parameters known as DAPs (Downlink Airborne Parameters), it ensures additional data for the air traffic controller (CAPs – Controller Access Parameters), and for the upgrade of ATM systems functionality (SAPs – System Access Parameters) [2]. GIBS protocol shall enable transmission of BDS registers, which are specified in Table 2.

Table 2. EHS BDS registers [1, 9].

No.	BDS register	BDS register Name
1	$4,0_{16}$	Selected vertical intention
2	$5,0_{16}$	Track and turn report
3	$6,0_{16}$	Heading and speed report

2.3. MRAR

Meteorological Routine Air Report registers are neither part of ELS, nor of EHS. They may however provide meteorological data obtained directly from sensors, which an aircraft may be equipped with. There is no need for further data processing in a ground station. Two BDS registers may be transmitted in Mode S replies shown in Table 3. Based on the contained parameters in BDS registers $5,0_{16}$ and $6,0_{16}$, some meteorological information may be obtained by indirect calculation. The resulting data does not ensure high level of accuracy [10].

Table 3. MRAR BDS registers [1, 9].

No.	BDS register	BDS register Name
1	$4,4_{16}$	Meteorological routine air report
2	$4,5_{16}$	Meteorological hazard report

3 Heuristic algorithm

The heuristic algorithm was created to determine the relevant BDS register number and is specified by a MATLAB script and its supplementary function. Before a received BDS register is tested by the algorithm, the initial processing is necessary to obtain data samples in a required form. A suitable input for the algorithm is considered a 56-bit array of a binary sequence from a received message with DF 20 or DF 21, which specifies the reply on the Mode S addressed interrogation. The result of the algorithm assigns a BDS register number to the examined 56-bit register when all appropriate conditions are met.

3.1. Assigning a BDS number according to unique parts

Initially, the bit analysis was made to find unique bits and combinations of bits which determine a specific BDS register to enable distinguishing particular BDS registers. According to the data structure in every register, different conditions were found and implemented into the algorithm. They may be represented, for example, by the group of the first eight bits of the message, so-called BDS1 code (1.-4. bit of the 56-bit sequence) and BDS2 code (5.-8. bit). These codes characterise the number of BDS register. Therefore, the first four bits of BDS register $1,0_{16}$ must be decoded as hexadecimal value "1" and the BDS2 code as "0". Unfortunately, this condition is not applicable for all registers. Other unique parts create bits stated as reserved which have to be set at zeros, or some groups of bits which can take only a limited value. In addition, availability of flight information in part of the register is specified by status bit and its following data field containing flight information [11]. This implies a status bit condition, where the status bit is set at "0", the following bits representing appropriate data field must be padded with zeros as well, otherwise the status condition is not met. Afterwards, some of the data fields are decoded and compared with a limitation of their values which were determined according to decoded BDS registers from real operation provided by ANS CR. The status bit test and

structure formed by status bits and data field is typical for EHS and MRAR register.

A 56-bit binary sequence is tested by every possible condition to assign or exclude an assignment of the all examined nine BDS registers in one for-loop. Gradually, a message is examined whether it meets all conditions for one BDS register number after another. While all tested bits are set at required values, the number of tested BDS register is saved into a variable corresponding with a row of the bit sequence. It follows that there can be more BDS numbers assigned to one message. The basic structure of the created algorithm is shown in the Fig 1.

3.2. Final BDS number assignment

In order to assign only one final BDS number to every message, part of the script is created for resolution of conflicts where more than one BDS number is estimated to the tested binary sequence.

The direct BDS number assignment is processed by messages where no BDS number was estimated and the final BDS number is regarded as "Unknown", on the assumption that this BDS register is not included in any group of tested BDS codes or the message is incorrectly received. If there is more than one estimated BDS number by BDS code $1,0_{16}$, as well as by BDS $2,0_{16}$, it is always considered the final number. The last direct assignment is applied when there is only one guessed BDS number, with the exception of BDS register $4,5_{16}$. While this register is not transmitted, the messages with its assigned number are also marked as "Unknown". When a conflict of two or more estimated BDS numbers occurred, there was another data analysis processed to find out, whether there are any other conditions to be explored to make a final decision. Based on conflict analysis of provided data from real operation, an additional condition was not needed in most of the cases and the double assignments had been solved as the final allocation of one of the registers.

Variable "BDS final" represents the output of the algorithm where one appropriate BDS number is assigned to the corresponding row of the tested message. All original messages of distinguished BDS registers may be saved into a MAT-file which enables easy accessibility of the data for possible decoding or further processing.

4 Evaluation of the algorithm results

A sample of data from real operation provided by ATN CR was chosen for evaluation of the heuristic algorithm results. Every assigned BDS number by the algorithm is compared to the known number of an appropriate message from the ATN data sample. It makes it possible to evaluate the algorithm for six of nine examined registers.
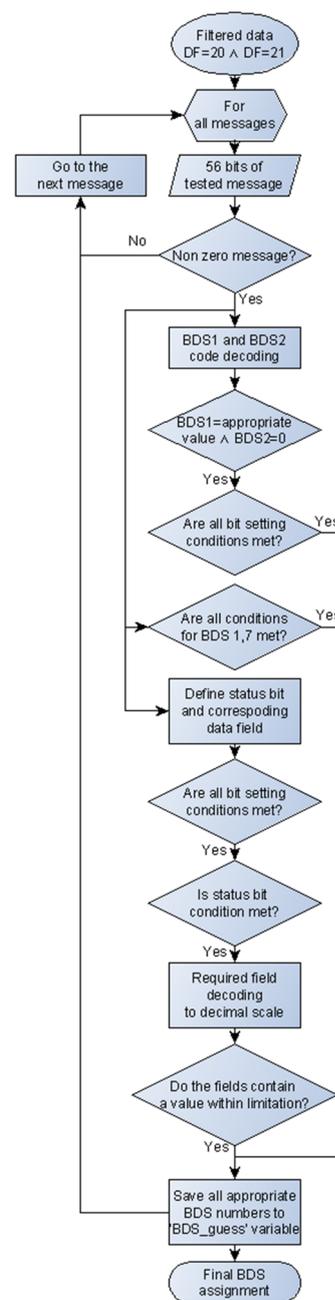
On the condition that the BDS number identified by the heuristic algorithm corresponds to the known BDS number from the ASTERIX data, this BDS number is regarded as a correctly assigned one. Conversely, a wrong assignment is considered to be a different BDS number assigned to the known BDS register by the program. In other words, the BDS register is incorrectly identified or marked as unknown.

The number of an erroneously allocated BDS is calculated as the difference between a number of the BDS register assigned by the algorithm and a number of a known BDS number within the ATN data enlarged by the difference between a number of the known BDS number from ATN data and a number of the correct assigned BDS number. For this reason, the number of wrong assignments may exceed the original number of the BDS number allocations. Thus, the sum of both rates may exceed 100%, as well as the error rate itself.

The success rate is simply calculated according to (1). Similarly, an error rate can be evaluated as in (2).

$$Success\ Rate = \left(\frac{Correctly\ Assigned\ BDS\ Number}{ASTERIX\ BDS\ Number}\right) \cdot 100\% \quad (1)$$

$$Error\ Rate = \left(\frac{Wrongly\ Assigned\ BDS\ Number}{ASTERIX\ BDS\ Number}\right) \cdot 100\% \quad (2)$$

Fig 1. The Algorithm basic structure.
Note: No solutions are not processed.

Table 4. Algorithm evaluation.

BDS code number	Algorithm Assigned	ASTERIX BDS	Correctly Assigned	Wrongly Assigned	Success rate	Error rate
BDS code $1,0_{16}$	122	50	48	74	96,00%	148,00%
BDS code $2,0_{16}$	0	0	0	0	-	-
BDS code $3,0_{16}$	0	0	0	0	-	-
BDS code $4,0_{16}$	14033	14046	14033	13	99,91%	0,09%
BDS code $5,0_{16}$	7806	7843	7805	75	99,52%	0,96%
BDS code $6,0_{16}$	15163	15124	15124	39	100,00%	0,26%
BDS code $4,4_{16}$	239	239	239	0	100,00%	0,00%
BDS code $4,5_{16}$	0	0	0	0	-	-
BDS code $1,7_{16}$	404	308	308	96	100,00%	31,17%
Unknown codes	564	721	551	327	76,42%	45,35%
Total	38331	38331	38108	624	99,42%	1,63%

Both rates were evaluated for the six BDS numbers which were possible to compare, as well as for unknown BDS registers. With the exception of the unknown BDS numbers, the success rate exceeds 95% on a case by case basis. The total success rate of the BDS number assignment by the heuristic algorithm is equal to 99,42%. In less than two percent of the cases, the BDS number may be assigned incorrectly. The overview of the algorithm results is given in Table 4.

5 Discussion

According to the expectations, most of the identified registers were identified as BDS registers of the Enhanced Surveillance, followed by the messages of the Elementary Surveillance and the least occurring registers were the meteorological BDS codes. The probability of the correct BDS number assignment may be increased with further analysis of the remaining registers which is of no interest for the present research, although they are certainly transmitted within the SSR Mode Addressed surveillance.

The algorithm output makes it possible to obtain additional flight information from the aircraft by further data decoding. Distinguishing BDS registers are used for the next research activities for the ATM laboratory at the CTU in Prague. The decoded data is considered crucial for further analysis, statistics or databases.

6 Conclusion

The algorithm provides the opportunity to determine a response to Mode S addressed interrogation without knowledge of an uplink query, based only on the data analysis of ELS, EHS and MRAR BDS registers. It is not necessary to have any other information about the aircraft with the identical ICAO 24-bit address. The algorithm is able to assign the BDS number to an appropriate message for eight BDS registers transmitted by default, as well as BDS number $4,5_{16}$ for messages containing meteorological hazardous data. One of the biggest advantages of the algorithm is the evaluation of correct assignment of BDS number with high quality of achieved results.

The success rate of the BDS number correct assignment was calculated at more than 99%. Conversely, the wrong BDS number may be assigned in less than 2% of the cases. The algorithm is suitable for analysis of large amount of received messages and it can provide essential sources for other research of detailed flight characteristics.

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