Transmitting GBAS messages via LDACS

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***Abstract*—The Ground Based Augmentation System (GBAS) is a landing system for aircraft based on Global Navigation Satellite Systems (GNSS). It consists of a reference station at an airport that generates corrections and integrity parameters that are transmitted to arriving aircraft. The broadcast is currently accomplished via a VHF data broadcast (VDB). In recent years it turned out that proper siting and frequency planning for the VDB is a challenging task in an operational environment. Coverage, as well as signal power issues, especially at large and complex airports have led to a number of considerations that have to be taken into account when installing VDB transmission antennas. Furthermore, current GBAS only broadcast corrections for the L1 frequency of GPS satellites. Availability issues, mainly due to ionospheric effects in equatorial regions, however, drive the development of expanding GBAS from a single frequency single constellation system towards a dual frequency multi constellation architecture. Transmitting additional corrections and integrity parameters at the same update rate is challenging due to the limited capacity of the VDB data link. Finally, transmission should offer the potential to provide secure transmissions with an authenticated signal in order to be robust also from a security perspective. For all these reasons it can be envisioned to provide the GBAS messages via LDACS which is currently in the process of standardization. This could resolve the issues mentioned and thus support GBAS implementation in the future. This paper provides an overview of the expected benefits mentioned above and provides a first performance estimation of GBAS over LDACS.**

Keywords—GBAS; LDACS; VDB; Landing system;

I. Introduction

In order to cope with the ever-increasing amount of air traffic, several new technologies are developed that allow for more efficient and reliable communication, navigation and surveillance. These new technologies are enablers for a more efficient use of airspace and airport capacity. In this paper, the concept of using a new communication system (L-band Digital Aeronautical Communication System, LDACS) to support a new precision approach guidance system (GBAS) is explored, starting from a discussion of the current status and describing ongoing developments, future needs and the potential when bringing those technologies together.

A. GBAS

The Ground Based Augmentation System (GBAS) is currently providing CAT-I approach service (GBAS Approach Service Type (GAST) C in GBAS terminology) at a number of airports throughout the world (e.g. in Bremen and Frankfurt in Germany, Newark and Houston in the US, Zurich in Switzerland, Málaga in Spain, Sydney and Melbourne in Australia). Standards for GAST D (the service type also supporting CAT-II/III operations) were finalized by the end of 2017 [1]. Operations using this service are expected in the 2020 timeframe. A GBAS ground station consists of typically four reference receivers at carefully surveyed locations at the airport. These sites are selected to be far from any obstacles that might cause navigation errors caused by signal reflections. By precise knowledge of the reference positions corrections for the navigation signals coming from the satellites can be generated and transmitted to arriving aircraft. All the stations mentioned above are only providing corrections and integrity information for the L1 frequency of the GPS satellites. The most challenging task for a GBAS is to protect users against steep gradients in the ionospheric delay, the major error source in single frequency positioning with Global Navigation Satellite Systems (GNSS) [2][3][4]. In GAST C it's the ground station's sole responsibility to ensure protection of the airborne users against this kind of threat. The architecture therefore makes very conservative assumptions and inflations of integrity parameters in order to ensure protection of users [5]. In GAST D the strategy was somewhat changed: In order to ensure reliable and timely detection of potentially hazardous ionospheric errors, a sophisticated architecture of monitors in the GBAS ground station and the airborne receiver using GBAS was developed. One of the consequences is, however, that the GBAS reference antennas cannot be placed freely. They rather have to be spaced very specifically and have to be orientated considering the orientation of the runways to which approach service is provided [6]. Together with the protection against multipath and the required distanced to reflecting objects such as buildings or shelters, siting a GBAS at an airport has turned out to be a highly challenging task. Furthermore, the GBAS concept as it is today only provides operationally acceptable availability in mid-latitudes where severe ionospheric activity is rare. In equatorial and polar regions the current integrity concept would result in very limited availability [7].

B. LDACS

The L-band Digital Aeronautical Communication System (LDACS) is a broadband air-ground datalink proposed to supplement the VHF communication infrastructure in the L-band [8]. It is designed to provide air-ground data communication with optional support for digital voice. It is a cellular broadband system based on Orthogonal Frequency-

Division Multiplexing (OFDM) technology [9] and supports quality-of-service while taking the requirements of aeronautical services into account. Moreover, it shares many technical features with 3G and 4G wireless communications systems.

The LDACS access network contains several ground stations in order to provide complete coverage. Each of the ground stations provides one LDACS radio cell for communication and ranging.

The LDACS air interface is a cellular datalink with a star-topology connecting aircraft to ground stations with a full duplex radio link. Each ground station is the centralized instance controlling all air-ground communications within its radio cell. An aircraft connects to one base station while periodically scanning other base stations for quick handovers as illustrated in Figure 1.

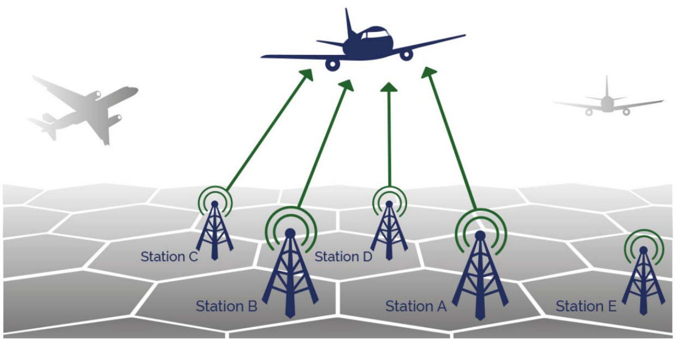

Figure 1: LDACS cellular concept.

The LDACS protocol stack defines two layers, the physical layer and the data link layer.

The physical layer provides the means to transfer data over the radio channel. The LDACS ground station supports bi-directional links to multiple aircraft under its control. The forward link direction (FL; ground-to-air) and the reverse link direction (RL; air-to-ground) are separated by frequency division duplex. Forward link and reverse link use a 500 kHz channel each. The ground station transmits a continuous stream of OFDM symbols on the forward link. In the reverse link different aircraft are separated in time and frequency using a combination of orthogonal frequency-division multiple-access and time-division multiple-access. Aircraft thus transmit discontinuously on the reverse link with radio bursts sent in precisely defined transmission opportunities allocated by the ground station.

The data-link layer provides the necessary protocols to facilitate concurrent and reliable data transfer for multiple users. The LDACS data link layer is organized in two sub-layers: The medium access sub-layer and the logical link control sub-layer. The medium access sub-layer manages the organization of transmission opportunities in slots of time and frequency. The logical link control sub-layer provides reliable and acknowledged point-to-point logical channels between the aircraft and the ground station using an automatic repeat request protocol.

II. New Developments and Challenges in GBAS

With the introduction of the latest generation of GPS satellites (Block IIF) a new signal was introduced in the L5 frequency band, a band usable for aeronautical navigation. This new feature now enables efficient mitigation of the ionospheric threat by using dual frequency methods and either remove the ionospheric delay or enable effective monitoring for ionospheric gradients between the ground station and airborne users. The European Galileo constellation provides signals on the same two frequencies on all the satellites and the remaining satellites to complete the constellation are planned to be launched in the coming years. Additionally, also the Russian Glonass is currently being modernized and the Chinese Beidou is launching satellites at a high rate. This means that within the next few years there will be more than 100 GNSS satellites available for navigation, many of them providing dual frequency capability. It is therefore a natural evolution of GBAS to extend from single frequency single constellation to dual frequency and multi-constellation services. It is expected that this service will make GBAS usable in all regions of the world, including regions with active ionospheric conditions and remove many of the siting constraints that currently persist.

GBAS installations use the VHF Data Broadcast (VDB) in order to provide approaching aircraft with differential corrections, integrity parameters and approach definitions. This data link operates via time division multiple access (TDMA) on frequencies ranging between 108 and 118 MHz. For this, VDB divides each second into two frames, and each frame into 8 slots. Per frame, each slot can be assigned to a ground installation individually. This way, multiple GBAS installations can jointly operate on the same frequency.

An airborne user equipped with a GBAS receiver, has to receive the VDB data as well as GNSS data. The parameters transmitted via VDB and the received GNSS data are then used for calculating a position solution and for providing path guidance, meeting all requirements for precision approaches with the different service levels.

For reliable GBAS services, sufficient VDB coverage is operationally crucial and has to be considering when planning for a new GBAS installation. The VDB field strength requirements (minimum and maximum thresholds) are tested during initial and periodic flight inspection of a GBAS installation for the whole coverage area. Due to additional strict siting constraints, it can be very challenging to find a suitable location for the installation of a single VDB transmit antenna for complex airports. This is why the newest ICAO GBAS documents allow for multiple VDB transmitters to be used. In such a setup, the VDB transmitters operate in distinct slots, so that the required capacity is reduced, however signal coverage is ensured so that the intended operations can be supported.

For future GBAS services, however, the restriction to this data link poses a significant bottleneck as will be described more in detail shortly.

Another issue of GBAS is its susceptibility to spoofed VDB signals. In order to mitigate this security-related threat, the GBAS authentication feature has been added to the GBAS standards lately, being optional for current GAST-C services and mandatory only for GAST-D. However, some threat scenarios are not completely mitigated by this approach.

LDACS, being a digital broadband datalink designed for air traffic management, may provide a viable approach to overcome these issues.

A. Support of multiple constellations and frequencies

Within the European research program SESAR (work package 15.3.7), a concept for transmitting corrections and additional integrity parameters for two frequencies and two constellations was developed [10]. In order to remain backwards compatible with GAST C and D, any additional messages providing corrections and integrity parameters for additional constellations and signals from a second frequency have to fit into the remaining space within the specified VDB message format. The maximum capacity of the current VDB is limited to 3552 Bytes per second. While it is possible to transmit corrections and integrity parameters for two constellations at the currently specified update rate of 2 Hz, it may already be impossible to transmit corrections and integrity parameters for all satellites in view if it is intended to provide corrections for three constellations. Other scenarios under consideration (such as e.g. two transmitters on a shared frequency due to frequency availability) may further restrict capacity and require a slower update rate of the corrections. This then impacts all integrity considerations and requires significant additional effort in the development phase.

Transmitting the corrections and integrity parameters via LDACS could resolve the capacity issue. For safe GBAS operations, GBAS messages need to be received by an approaching aircraft continuously for the defined coverage volume. In general, GBAS over LDACS has to at least maintain the same level of safety compared with the current VDB. This leads to two constraints for GBAS over LDACS:

On the one hand, the percentage of missed GBAS messages must be limited. This implies that LDACS messages must be receivable by any approaching aircraft throughout the complete GBAS service volume. This is in line with the VDB coverage volume requirements.

On the other hand, the message integrity needs to be ensured. For VDB, cyclic redundancy checks (CRC) and forward error corrections (FEC) are used to ensure that transmission errors cannot affect the GBAS processing. LDACS employs similar techniques to ensure data integrity and coverage and is thus in principle a suitable alternative to the VDB.

With the increased capacity of LDACS, GBAS could be able to support additional services in the future. For multi-constellation and multi-frequency GBAS, LDACS could enable transmitting corrections and integrity parameters for the four global core constellations and two frequencies simultaneously as will be shown in the Results section in more detail. It would thus eliminate some of the drawbacks of the currently developed GBAS service types that exist only due to the VDB limitations previously described.

LDACS is a broadband communication system designed to support a wide range of aeronautical applications in the airport, TMA, and en-route airspaces. The current LDACS specification [11] foresees 300 kbps up to 1.3 Mbit, depending on the configuration, in the ground-to-air direction, thus offering sufficient spare communication capacity for GBAS correction data of multiple constellations. It should also be noted, that if LDACS has already been deployed for ATM communication, no additional deployment is necessary for GBAS correction data. We assume in this paper that the coverage and integrity of an LDACS deployment certified for safety and regularity of flight communication would also be sufficient for GBAS service.

B. Potential to improve coverage at complex airports

Operational experience showed that siting a GBAS VDB transmitter is a highly complex task. Especially at large and complex airports it is extremely challenging to provide sufficient coverage at all runways with a single VDB transmitter.

LDACS could potentially overcome the coverage issue since the system is cell-based and designed to be robust against multipath interference common in the airport domain. LDACS' robust signal considerably improves the availability of correction data in the airport domain, however, if sufficient coverage still cannot be achieved, additional LDACS cells can be deployed. Since LDACS is a cell-based system by design, it supports automatic and seamless handovers between cells using different frequencies. That is, additional LDACS cells, e.g. for improved coverage, do not reduce the communication capacity of other cells as it was proposed in [10] for the case of shared VDB frequencies

C. Possibility to add a security layer

Finally, there is an increasing wish to protect critical infrastructure from interference and make it robust against any potential external influence. One component of a GBAS security program is to provide a secure and authenticated GBAS message in order to ensure that the received message at the aircraft was generated by the GBAS ground station at the airport and is unaltered.

LDACS is currently being updated in the context of the Single European Sky ATM Research (SESAR) to fully support cyber security. The updated specification will support authentication, integrity, encryption, and non-repudiation. Although encryption may not be of interest for GBAS correction data, the application of authentication and integrity would guarantee that correction data comes from a legitimate source and has not been altered.

III. GBAS OVER LDACS

A. Approach

The initial approach of this study is to transmit GBAS correction information over LDACS in exactly the same VDB message types and formats as currently proposed for dual frequency dual constellation GBAS within the SESAR project. Thus, for a single GBAS installation we assume the messages and message sizes according to [10] and as illustrated in Figure 2 as baseline for our simulations. Note, that the VDB slot structure displayed in the figure is, however, not relevant for transmitting GBAS over LDACS and is therefore not considered. The message types contain the corrections for the GNSS pseudorange measurements, integrity parameters to enable error bounding at the aircraft, and approach reference coordinates describing the approach trajectory and runway geometry. It should be noted here that this concept is not necessarily to be seen as the final transmission scheme that will be used as the development is still ongoing. Furthermore, when operating with a data link such as LDACS, some of the capacity restrictions would be obsolete, the alternating transmission concept for two VDB transmitters at complex airports would not be required and other optimizations would be possible regarding the message structure. Such an optimization is, however, beyond the scope of this paper and subject to future work after this higher-level feasibility study and a discussion of potential benefits.

We assume that these messages would be provided to the LDACS ground radio at 2 Hz for transmission similar to VDB. Contrary to VDB we assume no slot structure. The messages would be transmitted via LDACS as binary data packets statistically multiplexed into the packets of other air management communication services.

In our approach GBAS packet transmitted via LDACS as broadcast packets and not as addressed packets. This implies that GBAS packets will suffer from uncorrected transmission errors according to the bit error rate of LDACS after forward error correction. Note that uncorrected bit errors are detected by the check sums transparently added by LDACS and can therefore be safely discarded.

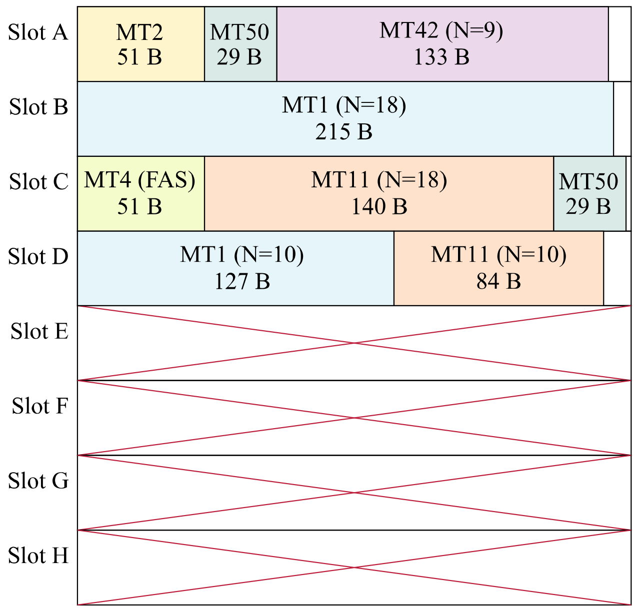

Figure 2: GBAS message types (MT), for number of satellites (N) and maximum size of message (in B) transmitted via VDB according to [10]. Note that the Slot structure is an artefact of the technical implementation of VDB and does not apply to LDACS.

B. *LDACS Security Concept*

The LDACS Security Concept follows five objectives namely that (1) the operation of the LDACS system security functions shall not diminish the ability of the LDACS system to operate safely and effectively, (2) the LDACS system shall support reliability and robustness to mitigate denial of service attacks, (3) the LDACS system shall support message authentication and integrity to prevent message alteration attacks, (4) the LDACS system should support encryption to mitigate eavesdropping and (5) the LDACS system shall support entity authentication to mitigate impersonation attacks [12]. For transmitting GBAS messages securely over LDACS especially (3) and (5) are important, as the end nodes of communication as well as message integrity, authenticity and timeliness must be protected.

Thus first, we need to make sure that only legitimate participants in our communication system are transmitting. Therefore we need ways for entities to authenticate to each other so that trust between parties can be established. We propose to fulfill this goal via introducing a Public Key Infrastructure (PKI) and handing out certificates to all necessary entities in a chain-of-trust form. Following ideas of the AeroMACS PKI [13], the root of trust lies with an offline root certificate authority (CA) issuing compliant sub-CAs. The online Sub-CAs can be used for governmental applications and form a chain of Sub-CAs with the End-Entity Certificates for the terminal being the end of that chain. Those certificates can be uploaded onto aircraft or ground stations e.g. on dedicated maintenance events by authorized staff [13]. When all participants have received their End-Entity Certificate, allowing for global interoperability, and are integrated into the LDACS PKI, they can mutually authenticate to each other. Consequently, we have made sure that every party providing information to LDACS or are transceiving via LDACS, are identified and recognized as a certain entity by all other parts of the system. One way to achieve this exchange and to also establish key material among communicating parties is the Station to Station (STS) protocol, thus at the end of the exchange, parties can trust each other and derivate keys for certain tasks from the acquired key material.

This is the groundwork to achieve message integrity, authenticity and timeliness. Implementation wise, LDACS provides a variation of the TESLA authentication broadcast protocol [14]. Given that transmitting nodes in the LDACS system are mutually authenticated, have negotiated key material to derive an arbitrary number of keys and are at least loosely time synchronized, using the TESLA broadcast authentication protocol allows us to securely transmit GBAS over LDACS.

Thus, we conclude that the cyber security architecture provided by LDACS guarantees that correction data comes from a legitimate source and has not been altered.

C. Evaluation

We evaluate GBAS over LDACS on the basis of communication evaluation scenarios developed by EUROCONTROL and FAA for the Future Communication Infrastructure (FCI) [15]. The FCI scenarios provide detailed evaluation scenarios for the airport (APT Zone), terminal maneuvering area (TMA), en-route (ENR), and oceanic/remote/polar (ORP) airspaces. GBAS messages need to be received within the GBAS service volume around the airport, on all approach paths and on all runways in order to support roll-out guidance. We therefore focus on the TMA and APT zone.

The FCI defines several rectangular TMA evaluation scenarios ("service volumes") according to their size from 25 x 25 nautical miles up to 75 x 75 nautical miles. For each of these scenarios the expected aircraft population and air traffic management communication load is defined. Since the radius of a GBAS service volume is 23 nautical miles we evaluate only FCI scenarios that are similar in size or larger as the GBAS service volume as illustrated in Figure 3: TMA 45x45 nm, TMA 60x60 nm, and TMA 75x75 nm. The air traffic communication load is defined through a set of air traffic control and airline operational communication applications[1]. In our evaluation we assume that GBAS data would come on top of the air traffic management traffic.

Note that the FCI evaluation scenarios define only service volumes, i.e. the number of aircraft to be serviced and the amount of data traffic to be handled, but do not make any assumptions on the underlying communication infrastructure.

In this paper we assume that an LDACS cell providing GBAS correction data would cover the vicinity of one airport, thus covering one APT Zone and the TMA service volumes We have therefore added the service load of the APT service volume to the respective TMA service volume in our evaluation. This is illustrated in Figure 4. We assume that en-route communication services would be provided by additional long-range LDACS cells that are not considered in our simulation. Further we assume in out simulations the anticipated "nominal" bit error rate of 10^{-6} after forward error correction. In addition to forward error correction, LDACS uses 32-bit cyclic redundancy checks for error detection. Since GBAS packets are broadcast in our simulation we apply no retransmission mechanism i.e. GBAS packets are sent using the unacknowledged data link service of LDACS. Packets detected to be corrupted by the CRC are silently discarded. The duration of our simulations is 3.600 seconds with additional 50 seconds of ramp-up and ramp-down time, each, that are not taken into account.

[1] In this paper we considered the addressed FCI communication services for phase II: Air traffic services: ACL, ACM, AMC, ARMAND, COTRAC, D-ALERT, D-ATIS, DCL, D-FLUP, DLL, D-ORIS, D-OTIS, DRV-R, DSC, D-SIG, D-SIGMET, D-TAXI, DYNAV, FLIPCY, FLIPINT, PPD, SAP, URCO; Airline operational communication: AOCDLL, CABINLOG, ENGINE, FLTLOG, FLTPLAN, FLTSTAT, FREETXT, FUEL, GATES, LOADSHT, MAINTPR, MAINTRT, NOTAM, OOOI, POSRPT, SWLOAD, TECHLOG, UPLIB, WXGRAPH, WXRT, WXTEXT; Network services: NETCONN, NETKEEP. The broadcast services are not included: A-EXEC, AIRSEP SURV, C&P SURV, ITP SURV, M&S SURV, PAIRAPP SURV, C&P ACL, ITP ACL, PAIRAPP ACL, M&S ACL, SURV ATC, WAKE.

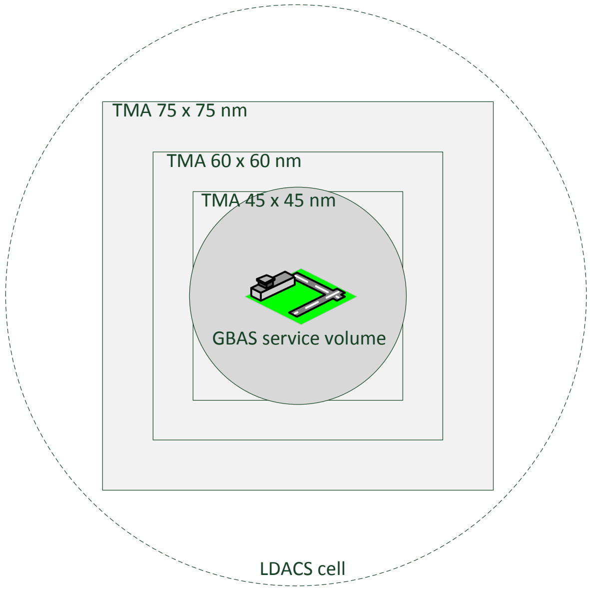

Figure 3: FCI terminal maneuvering area (TMA) service volumes covering a GBAS service volume (innermost) inside an LDACS cell (outermost). Note that the figure is not drawn to scale and that the radius of the LDACS cell may be up to 200 nautical miles.

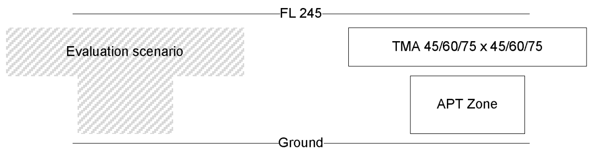

Figure 4: The evaluation scenarios in this paper (left) are the union of TMA and APT Zone service volumes (right) as defined in [15].

We perform our evaluation of GBAS over LDACS in a computer simulation called Framework for Aeronautical Communications and Traffic Simulations 2 (FACTS2). Reference [16] provides a detailed description of FACTS2 and the implementation of the air traffic and data traffic simulation.

For the evaluation of GBAS over LDACS we used the following two requirements derived from the Time to Alert (TA) requirement of GBAS (1.5 seconds):

Requirement 1: Each GBAS message must be received successfully at least once within 1.5 seconds. In this way it is ensured that the required time to alarm allocated to the GBAS ground system is not exceeded (according to the GAST D SARPS section 7.5.12.3 *GBAS signal-in-space time-to-alert*, Table D5-B *[1]*).

Requirement 2: A GBAS message is only considered received successfully (in addition to being successfully and correctly received by LDACS) if it is not older than 1.5 seconds. This requirement addresses the fact that corrections may not be "too old" when processed at the aircraft. This message time-out at aircraft requirement is also given in the same table as the ground system TTA above.

Both requirements must be fulfilled simultaneously. The LDACS security concept for GBAS is not evaluated by simulation in this paper.

IV. RESULTS

This section presents the results obtained by our simulations with the assumptions and against the requirements described in the previous section.

Requirement 1: The result is calculated from the bit error rate (10^{-6}) and the packet size. The performance criterion evaluated is *P(3 lost packets in a row at 2 Hz packet rate)* which is the probability to violate requirement 1. The following table presents the results per message type:

Service	*P(Requirement 1 violated)*
GBAS MT11 (N=10)	3.00E-07
GBAS MT11 (N=18)	1.38E-06
GBAS MT1 (N=10)	1.03E-06
GBAS MT1 (N=18)	4.96E-06
GBAS MT2	6.75E-08
GBAS MT4	6.75E-08
GBAS MT42 (N=9)	1.19E-06
GBAS MT50	1.24E-08

Requirement 2: The results shown in the next table are computed assuming GBAS data transmission over LDACS together with air traffic management communication services. Note that these results are for the FL (=ground to air) only, since the RL is on a separate radio channel and does not carry GBAS data. Management data for the RL, e.g. acknowledgements for RL retransmissions, are however taken into account. The results were calculated and are shown for the three different sizes of the TMA in addition to the APT zone.

	Service	*Load (kbit/s)*	*95% percentile latency (ms)*	*99% percentile latency (ms)*
APT Zone + TMA 45x45	ATM (broadcast)	7.66	-	-
	ATM (addressed)	36.47	-	-
	GBAS MT11 (N=10)	1.31	113.00	148.00
	GBAS MT11 (N=18)	2.18	113.00	131.00
	GBAS MT1 (N=10)	1.98	113.00	148.00
	GBAS MT1 (N=18)	3.35	113.00	129.00
	GBAS MT2	0.79	113.00	113.00
	GBAS MT4	0.79	113.00	131.00
	GBAS MT42 (N=9)	2.07	113.00	129.00
	GBAS MT50	0.9	113.00	129.00
APT Zone + TMA 60x60	ATM (broadcast)	8.06	-	-
	ATM (addressed)	37.19	-	-
	GBAS MT11 (N=10)	1.31	113.00	149.00
	GBAS MT11 (N=18)	2.18	113.00	133.00
	GBAS MT1 (N=10)	1.98	113.00	149.00
	GBAS MT1 (N=18)	3.35	113.00	133.00
	GBAS MT2	0.79	113.00	129.00
	GBAS MT4	0.79	113.00	133.00
	GBAS MT42 (N=9)	2.07	113.00	133.00
	GBAS MT50	0.9	113.00	131.00
APT Zone + TMA 75x75	ATM (broadcast)	8.54	-	-
	ATM (addressed)	38.18	-	-
	GBAS MT11 (N=10)	1.31	113.00	168.00
	GBAS MT11 (N=18)	2.18	113.00	149.00
	GBAS MT1 (N=10)	1.98	113.00	168.00
	GBAS MT1 (N=18)	3.35	113.00	148.00
	GBAS MT2	0.79	113.00	129.00
	GBAS MT4	0.79	113.00	149.00
	GBAS MT42 (N=9)	2.07	113.00	148.00
	GBAS MT50	0.90	113.00	148.00

V. DISCUSSION

The results presented in this paper show that is generally feasible to use LDACS as communication link for transmitting GBAS corrections, integrity parameters and approach reference coordinates.

The scenario chosen as baseline for the simulations assumes a transmission scheme that was designed to specifically serve the constraints of the VDB data link currently used by GBAS. Further optimizations (e.g. use of larger messages, different allocations, optimized use of slots, etc.) were beyond the scope of this paper. They will change the obtained results, however, as a study of feasibility the concept was evaluated with the current transmission scheme.

In order to ensure integrity, a GBAS message (transmitted at a rate of 2Hz) must be received at least once every 1.5 seconds and the received corrections may not be older than 1.5 seconds. The results showed that the probability to not receive the GBAS message at least once every 1.5s depends on the message type and is in the range of 1E-06 to 1E-08. The latency of the LDACS messages is in the range of just up to 168ms for the 99th percentile for the TMA 75x75 zone, with the exact value again depending on the message type. These results would support the intended operation.

VI. CONCLUSION

This paper presented the idea of providing the GBAS messages via the new LDACS data link instead of the currently used VDB.

The main advantages are that

(1) There is no significant restriction of the capacity w.r.t. the amount of data to be transmitted. This is especially helpful in the development of future multi constellation and dual frequency service types that would require a higher data rate than today's operations GBAS in order to provide improved availability.

(2) Furthermore, it may be easier to ensure sufficient coverage at large and complex airports by the cell-based technology as opposed to a single VDB transmit antenna or a dual VDB architecture. This

would remove several current operational constraints on the GBAS operation.

(3) And finally, LDACS by design supports authentication protocols that may be desirable for future systems in order to provide authenticated GBAS messages to the users.

These benefits strongly support further investigating transmitting GBAS data via LDACS.

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