Towards Selective Addressing of Aircraft with Voice Radio Watermarks

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The current voice communication system in use worldwide for Air Traffic Control (ATC) was standardised more than sixty years ago. Digital watermark technology for intellectual property right protection is part of many digital medias like music, pictures and videos. The EUROCONTROL Experimental Centre (EEC) proposed employing this mass-market technique to embed a digital signature as watermark in ATC voice communication. The project is called Aircraft Identification Tag (AIT). Watermarked speech allows the automatic identification of the originator of the received voice message in real-time. This AIT concept helps to increase the safety in ATC and secures the legacy voice communication system against malicious attacks. Embedding the destination address of the called aircraft into the controller's speech would extend AIT's safety benefit towards the aircraft by an automatically generated attention getter in the cockpit when the aircraft is called. For this, active controller cooperation is required. This paper proposes the replacement of the currently used 'Push To Talk' (PTT) switch by the concept of a selective PTT switch, with which the controller indicates the addressed aircraft. An early demonstrator of the selective PTT switch concept was presented to former controllers for a preliminary scenario-based evaluation of the usability. The results are positive.

Introduction

A. Safety and security issues in ATC voice communication

Tactical Air Traffic Control (ATC) guidance over continental areas relies worldwide on voice radio communication between pilots and controllers. The concept and the technology of this communication was standardised more than sixty years ago. The standards have not been modified in any significant way since. This technology is expected to remain in use for the provision of Air Traffic Management (ATM) for many years to come, even if the use of data link communications will progressively increase in the medium and long terms [1].

The air-ground party line voice communication takes place on a shared VHF radio channel. In one airspace sector all aircraft speak with the one controller in charge on the same physical channel. Therefore all voice messages, both air to ground (downlink) and ground to air (uplink), have to start with the call sign of the aircraft in order to identify the originator or the addressee, respectively.

The identification of the actors on the party-line channel is inherently threatened by, among others, poor quality of the audio signal and human error. A call sign can be misunderstood or the wrong call sign can be given by accident. The risk of misidentification rises where aircraft with similar call signs are present within the same ATC sector. Mishearing, misunderstanding and call sign confusion are an important issue in ATC safety. A recent EUROCONTROL study [5] showed: "Incidents involving air-ground communication problems between controller and pilots are rare and encompass about 1% of all reported incidents and 23% of ATC related incidents". Reducing the risk of wrong identification and thereby increasing the level of safety in ATC is the motivation for research in this area.

Another risk is the security of the party-line communication. The appearance of jokers as well as phantom pilots or controllers on the radio channel is known. Only national laws and procedures offer some kind of protection against this security issue of the air-ground communication. The communication equipment currently in use does not provide counter-measures against many security threats.

B. Aircraft Identification Tag (AIT) concept

The Aircraft Identification Tag (AIT) concept [2] has been developed in order to reduce the call sign based identification problems of the ATC controller. AIT relies on digital speech watermarking technology. It embeds an aircraft identifier into the pilot's voice message before its transmission to the ground via the standard transceiver equipment. The embedded tag represents a digital signature of the aircraft. Figure 1 presents how the AIT watermark embedder is placed in the analogue voice path of the VHF transmitter. The embedded AIT is hidden in the voice message and unnoticeable for the human listener of the party-line communication.

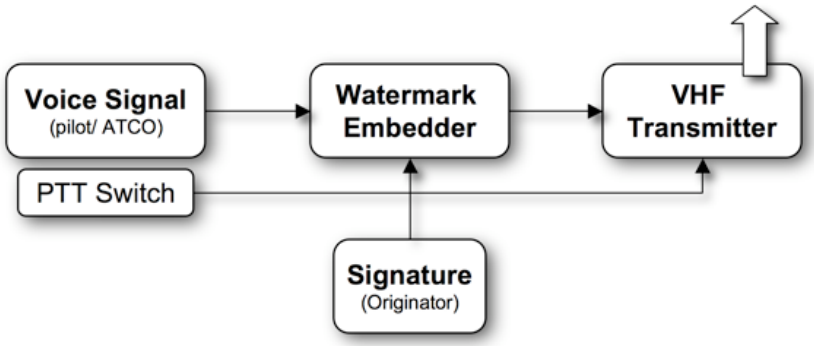


Figure 1: Embedding of an AIT watermark in the analogue voice path

On ground the AIT data is extracted, correlated with flight plan data and then for example transformed into a visual stimulus on the radar screen. The goal of AIT is to visually animate the aircraft in the moment the pilot is communicating with the controller. As a result the likelihood of successful identification of the originator is increased through simultaneous hearing and seeing. Figure 2 shows how the transmitting aircraft could be identified on the radar screen.

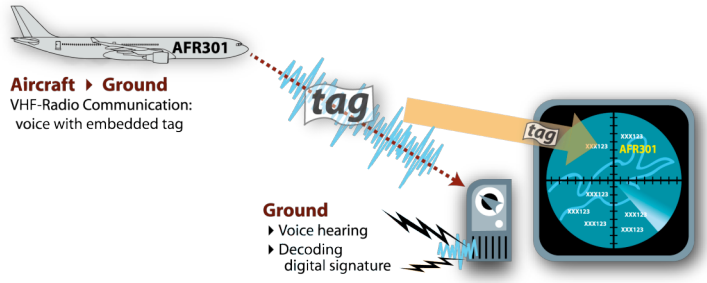


Figure 2: Identification of the transmitting aircraft with AIT

AIT embeds one or more hidden watermarks in the voice communication during the time the "Push To Talk" (PTT) switch is pressed. The length of an AIT data set has to be adapted to the shortest possible voice messages, which is the transmission of only the call sign. The average duration of a call sign transmission was found to be 1.8 seconds [3]. Consequently an AIT data set (one complete watermark) should be transmitted in less than one second to allow the human to take advantage of the resulting visual stimulus while hearing the message.

C. Extensions of the AIT concept

A EUROCONTROL initial feasibility study [4] identified further aspects to secure the legacy air ground voice communication. As a first line of defence in communication security, AIT could uplink an ATC domain identifier. This would allow pilots to identify "jokers" that use simple equipment and pretend to be controllers. However this would not help against malicious attackers using more sophisticated methods and equipment. A higher level of security could be reached with cryptographic signatures. This requires the development of appropriate procedures for cryptographic key distribution and management [8]. Currently a project of the European Commission called SAFEE [9] develops an application for the exchange of encrypted signatures embedded as watermarks to secures the air-ground voice communication.

With the concept as presented above, the main benefits of AIT are on the controllers' side. However, with another extension of the concept, also the cockpit crew could benefit of an AIT implementation: aircraft identifiers added to the ground-air messages can point the cockpit crew to those radio messages that are addressed to *their* aircraft. We first outline the principal idea and then focus on the human-machine interface on the controllers' side, which would have to allow the specification of the addressed aircraft in a simple manner.

Attention getter for aircrew

A. Monitoring of the radio communication

Air ground voice communication plays an essential role for the safety of flights in controlled airspace. In today's two-man cockpits it is usually the 'pilot non-flying' who communicates with the ATC station. This pilot has to monitor all communications on the voice channel attentively in order to filter out controller messages addressed to his flight. In core Europe with small and highly charged sectors, four, five or even more voice messages per minute occur on the voice communication channel. VOCALIS [10] studied 60 hours of voice communication in twelve distinct French en-route sectors featuring heavy traffic periods. On average VOCALIS recorded 324 air-ground speech acts per hour, which are more than 5 controller/pilot utterances per minute. A large number of other tasks, as well as cockpit noise, low channel quality and the large number of messages make it difficult for the pilot to identify the messages addressed to his aircraft. An automatic selective attention getter that signalises in real-time when a message is addressed to the own aircraft could support the aircrew's communication task. The workload resulting of the air-ground voice communication for pilots and controllers is less studied and should be subject of further research.

B. Embedding of the aircraft address in uplink messages

The attention getter would be generated in the cockpit when the own aircraft address is identical with the address that is embedded as an AIT watermark in the controller message. Such an attention getter would support the aircrew's monitoring of the ground-air voice communication task, especially as the attention getter would be available in real-time during the ongoing speech hearing.

With the previous AIT concept the uplink of a destination address was not possible, as the current ATC systems have no knowledge of which aircraft is called by the controller. To overcome this restriction and to allow the uplink of the addressed aircraft identifier with AIT, this paper proposes a solution called 'selective Push To Talk (PTT) switch.

Selective PTT Switch

The selective PTT switch concept requires the controller's cooperation. The controller has to indicate to a new system the identification of the aircraft that will be called. It is evident that this has to be as simple as possible for the controller. Also modifications to the established communication procedures should be avoided.

The concept assumes that beside the conventional PTT switch a pointing device for the radar screen (e.g. computer mouse) is available, and that both are accessible to the embedding software. The concept also assumes that all aircraft are equipped with AIT.

A. Conventional PTT switch usage

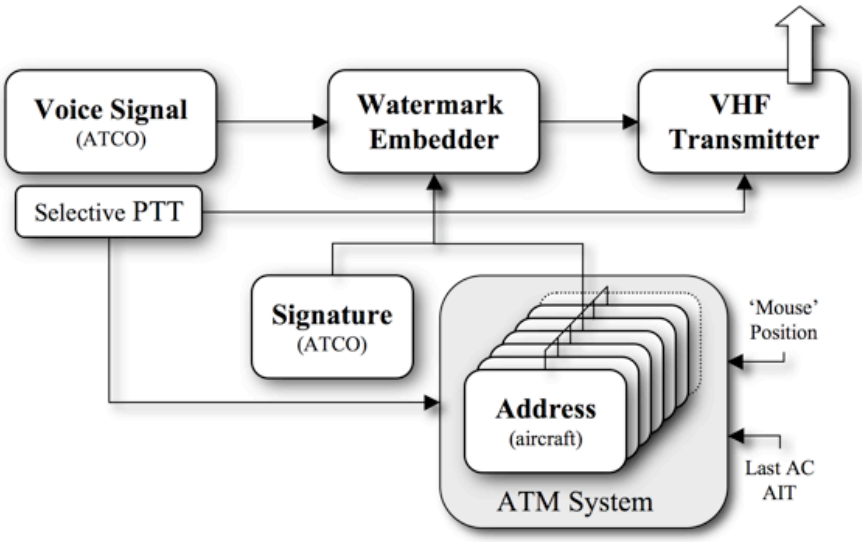
In order to transmit the voice signal on the radio, the controller has to press and hold the PTT switch. Pressing the PTT switch to activate the transmission is the well-established working procedure for both the downlink and the uplink of a voice message (Figure 3). Physically the PTT switch is realized as a pushbutton, which is integrated in the headset cable or is at special positions of the working environment. The radio transmitter transmits the voice signal of the microphone as long as the PTT button is pressed. Otherwise the transmitter is in a stand-by mode.

Figure 3: Current PTT switch

B. Logic of the selective PTT switch

The current ATM system for controlled airspace is based on flight plans that are filed in advance with the ATC service providers. The local control system correlates the filed flight plan data with the real-time radar data. The selective PTT switch requires the availability of this data.

With the selective PTT switch the controller informs the ATM system of the destination address (aircraft identification) of the starting voice communication. The destination address is forwarded to the AIT system in order to be embedded in the controller speech.



Pressing the selective PTT switch selects the destination aircraft address and allows the embedding of both the aircraft address and the ATC signature into the ground-to-air voice message. Furthermore it will activate the ground transmitter for conventional transmission. Figure 4 shows the interaction of the selective PTT switch with the ATM system.

Figure 4: ATC transmits watermarks with embedded aircraft address

The selective PTT switch has two built-in logics to determine the addressed aircraft:

1. The controller positions the mouse cursor above the aircraft label that will be called. The system determines the aircraft address at the moment the selective PTT is pressed down. Afterwards, also while the selective PTT switch is still pressed, other tasks with the mouse can be performed as usual.
2. Alternatively, assuming that the controller is often replying to aircraft calls, the destination address can be preset to the aircraft that called just beforehand within the last ten to twenty seconds. In this case the controller would not have to hover over the aircraft label but can directly press the selective PTT switch. Moving the cursor over another aircraft label while pressing down the PTT switch precedes the previous default preset.

C. Signalizations of the selective PTT switch

AIT permits to extract the embedded digital signature of an aircraft from pilots voice message. The digital signature is available with a delay of about one second after aircraft's transmission started. After this delay the calling aircraft will be highlighted on the radar screen until the end of the voice message. The mean duration of an ATC voice message is about five seconds [3]. On the radar screen a blinking frame around the label highlights the speaking aircraft. Figure 5 shows an example[1].

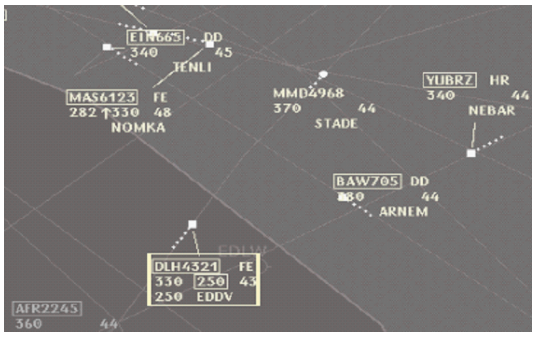


Figure 5: Highlighting of the calling aircraft 'DLH4321'

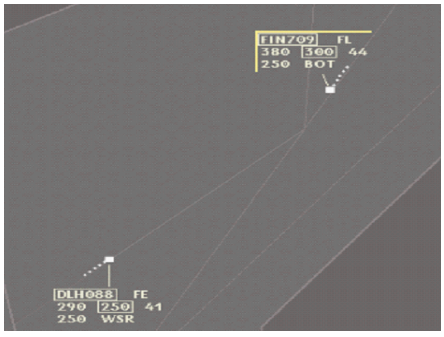


Figure 6: Controller transmitting to aircraft 'FIN709'

[1] The indication with a blinking frame is an arbitrary example. The best method has to be found in a separate study.

When the controller presses the selective PTT switch, the destination aircraft is indicated on the radar screen with another type of frame as shown in Figure 6, until the selective PTT switch is released.

As every message has to be read back, the air-ground voice communication is always a dialog between pilots and the controller. In all cases when the controller directly answers to a pilot message, the controller can use the selective PTT switch without the need to point to the aircraft label.

If the controller decides to call another aircraft than the last one calling in, the mouse cursor must point to the according aircraft label when the selective PTT switch is pressed down. In this case the system displays not only a frame around the selected aircraft, but during two seconds also another type of frame around the aircraft that last called in. The aim is to remind the controller that this aircraft may await an answer to its message. This logic is active for a limited amount of time, only.

D. Scenario-based evaluation of the selective PTT switch

A demonstrator of the described selective PTT switch concept was built in order to perform an early usability test. The demonstrator is built around a screenshot of a EUROCONTROL Experimental Centre (EEC) real-time simulation. This static screenshot is animated with the described signalling of calling and addressed aircraft, and previously recorded pilot voice messages are replayed. The demonstrator is implemented using the scripting language AutoHotKey [7]. The demonstrator facilitates simple scenario-based user experience tests on the usage of AIT and selective PTT switch features.

The demonstrator was used for a scenario-based evaluation of the usability. The aim was to collect controllers' basic opinion on the selective PTT switch concept. It was presented in a short experiment of five minutes to twelve EEC controllers in order to get preliminary ideas on the operational usability of the selective PTT switch concept. All test subjects have worked in the past as operational controllers but were at the time of the evaluation not working as controller anymore. The demonstrator is based on a static scenario as shown in Figure 7. It includes a 'public PTT' switch, which allows the controller to call all aircraft at once.

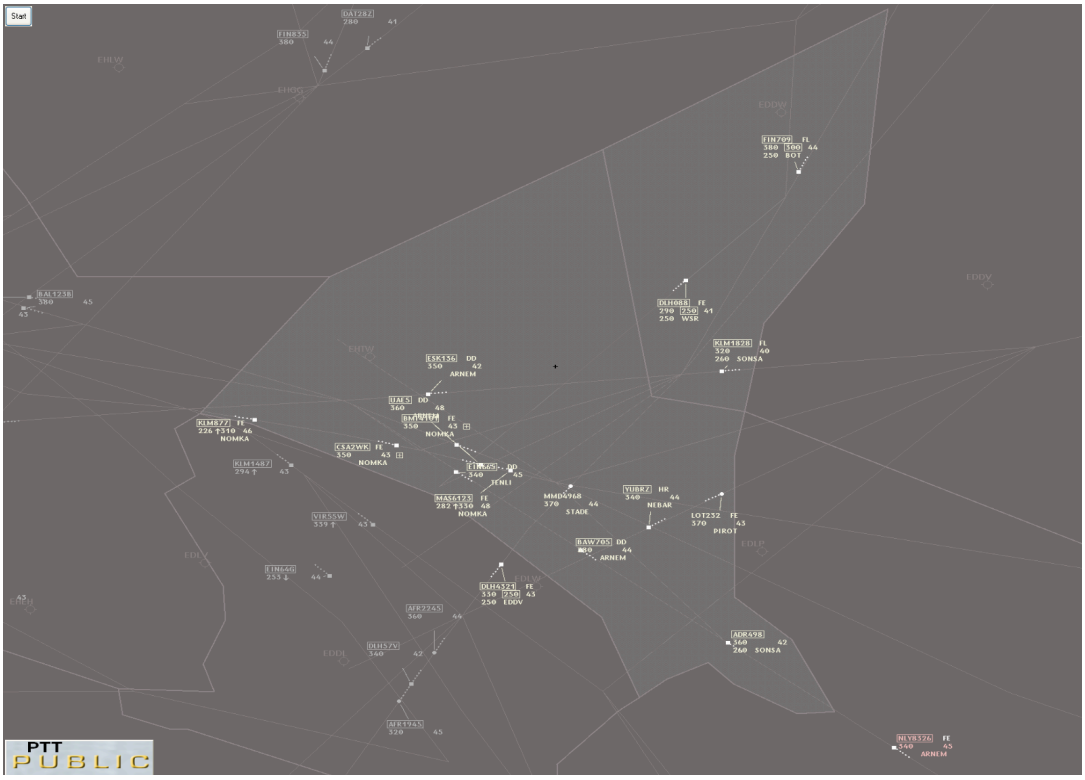


Figure 7: Static scenario of the demonstrator

After the test the usability was evaluated using a questionnaire, which was based on the 'Computer System Usability Questionnaire' [6]. Compared to the original questionnaire the word 'system' was replaced of by the word 'concept', which better suits the abstract idea of the selective PTT switch. The statement 'The system gives error messages that clearly tell me how to fix problems' was skipped, as the presented demonstrator did not include any error handling. The original authors evaluated the questionnaire and found the reliability coefficients alpha of the system use, information quality, interface quality and overall scale to be larger than 0.9, where zero stands for no reliability and one for perfect reliability of the outcome of the survey.

The questionnaire consisted of the statements listed below. The statements could be rated between ‘strongly agree’ (numeric value 1) and ‘strongly disagree’ (numeric value 7). Each statement could also be answered with ‘not applicable’.

1. Overall, I am satisfied with how easy it is to use this concept
2. It was simple to use this concept
3. I can effectively complete my work using this concept
4. I am able to complete my work quickly using this concept
5. I am able to efficiently complete my work using this concept
6. I feel comfortable using this concept
7. It was easy to learn to use this concept
8. I believe I became productive quickly using this concept
9. Whenever I make a mistake using the concept, I recover easily and quickly
10. The information on-screen provided with this concept is clear
11. It is easy to find the information I needed
12. The information provided for the concept is easy to understand
13. The information is effective in helping me complete the tasks and scenarios
14. The organization of information on the demonstrator screen is clear
15. The interface of this concept is pleasant
16. I like using the interface of this concept
17. This concept has all the functions and capabilities I expect it to have
18. Overall, I am satisfied with this concept

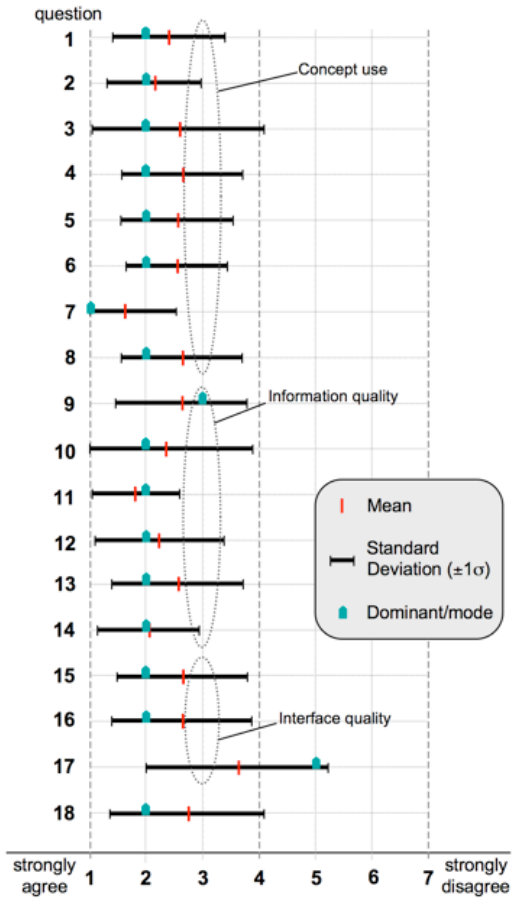


Figure 8: Results of the questionnaire

E. Results from the questionnaires

Figure 8 shows the results of the controllers’ rankings as a graph. The numbers at the vertical axis represent the number of the statement. For each ranking the mean value, the mode and the standard deviation are shown.

Globally, the subjects agree positively on the usability of the selective PTT switch concept, with a mean across all questions of 2.49. The concept usability showed a mean of 2.38, the interaction quality a mean of 2.35, and the interface quality a mean of 3.00. Commonly the subjects agreed that it was easy to learn the concept, but they think that there are still functions and capabilities that are missing. The main aim of this simple usability study was to see if the changes imposed by the selective PTT switch usage are potentially acceptable for controllers, which seems to be the case.

Conclusion

The use of digital watermarks is a mass-market technology for property right protection for music, images and video. The technology is mature to be adapted to the specific ATC application. The implementation of the suggested AIT application requires no major change to the procedures in the current ATC voice communication standard. Depending on the implemented security level, the AIT technique is able to secure air-ground and ground-air voice communication. The most basic AIT application of down linking an aircraft signature prevents the controller from safety issues caused by misidentification through call sign ambiguities or low speech quality. A visual stimulus that accompanies the speech hearing hypothetically also enforces the controller’s situation awareness.

The proposed modification of the controller’s working procedure using the selective PTT switch allows AIT to uplink voice messages with the aircraft destination address being embedded. Through an automatically generated attention getter in the cockpit the aircrew could benefit from the safety and security features of AIT.

Embedding and uplink of the destination address of the aircraft could therefore enhance the safety of the cockpit operation.

The simple usability study with former controllers shows that the required change to the communication procedure is potentially acceptable. The selective PTT switch could also contribute to other new innovative voice communication concepts as it prepares the step towards an end-to-end communication strategy.

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