

VOICE OVER INTERNET PROTOCOL COMMUNICATION SYSTEM FOR USE IN AIR TRAFFIC CONTROL

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Abstract

This paper describes the design implementation and demonstration of a serverless, peer-to-peer Voice over Internet Protocol (VOIP) application for air traffic control communications. Although simply written in less than 500 lines of Java, the VOIP provided full 'party line' functionality, prevented two 'aircraft' transmitting at once and provided controllers with pre-emption allowing them to 'break-into' any aircraft transmission. The VOIP was integrated with controller displays allowing silent handoff of voice communications. It was developed initially for simulated aircraft but has been demonstrated over SATCOM links to a live aircraft operating outside terrestrial radio coverage in the Gulf of Mexico.

Background

Currently air traffic controllers are using communication equipment that has not significantly advanced in the last 50 years, and which still has the same restrictions on communications capabilities. As aircraft cockpits are becoming revolutionized with the latest technology, communications between pilot and controllers remain the same. While flying in line of sight of land, pilots communicate with controllers using Very High Frequency (VHF) radios. The number of VHF frequencies available is barely sufficient for the number of sectors. This has led Europe to reduce the separation between frequencies in use, at considerable expense to Air Traffic Service providers and aircraft operators. Transoceanic flights rely upon High Frequency (HF) radio communications. In-flight pilots contact Oceanic Air Traffic Control Centers (OATCC) via HF radio frequencies. These pilots are not always communicating directly with the controllers. Frequently, the requests and transmissions are relayed

through Aeronautical Radio, Inc. or international flight service station, finally arriving to the OATCC. Utilizing a relay station causes delays in transmissions.

Air traffic controllers in some sectors experience high workloads due to the increase in air traffic movements. Nearly half of their workloads can be attributed to the handover/takeover process and the associated radio frequency changes and check-in.

While controllers are relying upon out-dated equipment to provide guidance over aircraft in the skies, increasingly businesses and individuals are having 'telephone' conversations and conferences utilizing voice over Internet Protocol (VoIP). A solution to the limited number of radio frequencies, crowded frequencies, utilizing relay stations and many other limitations, would be to transition air traffic communications to VoIP technology. This technology would enable pilots and controllers to communicate via voice over data-link that could be carried on VHF Data-Link (VDL) or over satellite links. VoIP could be a solution to the lack of VHF radio frequencies while decreasing controller workload.

Embry-Riddle Air Traffic Management (ATM) Research Laboratory (EARL) has an in-house designed and built object-oriented Real-Time Distributed ATM Simulator (RTDS). This simulator is used to prove new concepts or simulate specific scenarios in ATM. The design concept behind the RTDS is to use a User Datagram Protocol (UDP) Multicast messaging which mirrors the real world object behavior. This broadcast approach allows the addition of new components without adding to the communication load or bandwidth; thus, new controller or pseudo-pilot positions can be added. They receive the UDP-multicast messages and display what they are interested in and discard the rest. The amount of traffic generated by human inputs

into the display is very small; therefore, there is no real limit to the number of displays that can be added.

Having a simulator of this size requires voice communication between controllers and pseudo-pilots. Originally, a system similar to Public Switched Telephone Network (PSTN) had been developed and installed that provided basic voice communication. However, it was not expandable, nor was it simulating real radio transmissions. Therefore, after investigating different concepts of voice communications, a voice communication system (VCS) utilizing VoIP technology was developed to compliment the RTDS. The basic functionality provides high quality voice communications between controllers and pseudo-pilots and simulates real world radio transmissions. The system also has the capability for step-on prevention, controller precedence, and automated handover of voice communications on silent handoff of aircraft between controllers.

VCS Architecture

Traditionally, most VoIP applications were based on the client-server architecture model (Figure 1) where the system is composed of server and client applications. Clients rely on servers routing sound packets between clients. This model has the disadvantage of a single point of failure: if the server fails, the whole system ceases to be operational.

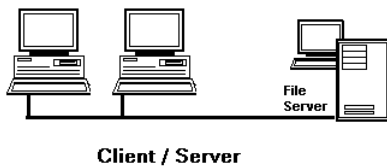


Figure 1. Client-Server layout

The architecture model chosen for VCS matches the object model of the RTDS and is a multicast peer-to-peer (Figure 2), which allows two or more clients to exchange data with each other without a server. Unlike a client-server architecture, where data is routed through servers and replicated for each interested client, a multi-cast peer-to-peer network is uniquely decentralized and allows computers to communicate directly with each other and share data without replication.

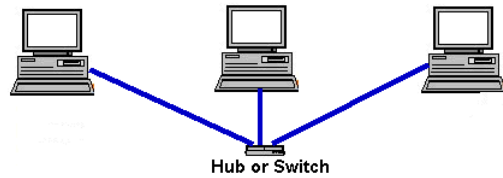


Figure 2. Peer-to-peer layout

That architecture model provides several advantages over client-server one:

- Expandable over any multicast enabled network
- Content and resources can be shared from the center and the edge of the network
- A network of peers is easily and almost limitlessly scaled and more reliable than a single server
- Reduced network traffic as VCS uses UDP multicast for communication

VCS Design

The VCS application was designed and implemented using Object oriented methodology to model the actual Radio Telephony, (R/T) between a Controller/Controller and Controller/Pilot. This design methodology provides several advantages: allow modeling of real world R/T system more accurately, ease of reusing components and handling requirement changes more gracefully.

The application was implemented using the Java Core Sound API, providing cross platform compatibility. The EARL VCS system consists of two main components: Controller Application and Pilot Application, see Figure 3.

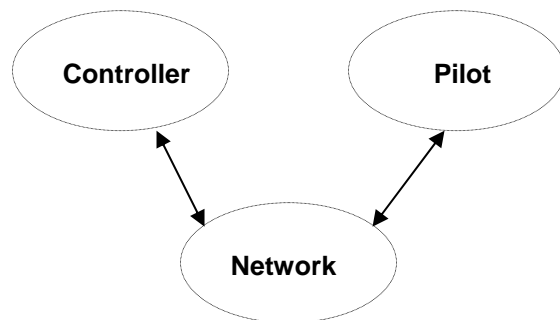


Figure 3. VCS Diagram

The VCS was built from six basic Java modules; see Figure 4.

- Vcs: The main package for starting and initializing VCS
- Vcs_GUI: The user interface contains a list of classes for the user interface and setting up communication
- Vcs_Sound: Provides classes for playing and sending sound packets across the net
- Vcs_Messages: Provides classes for handling messages between clients, such as requesting and accepting communication
- Vcs_PeripheralDevices: Provides classes for interfacing with peripheral devices, such as the parallel port for the transmit switch
- Vcs_RTS: Provides classes for interfacing with the real time simulation and for silent hand-off of clients to a different multicast IP

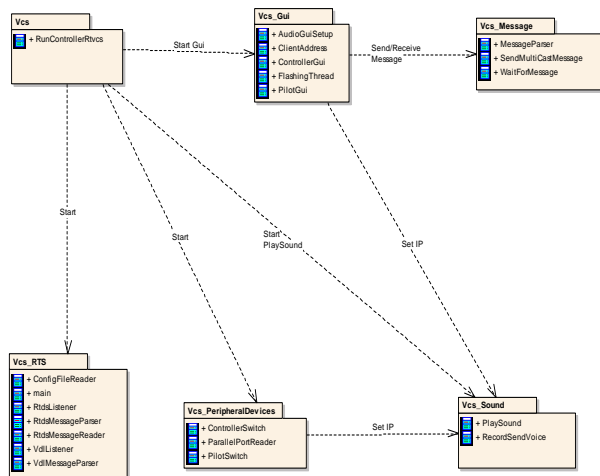


Figure 4. VCS Category Diagram

Controller Application

The Controller Application provides voice communication between the controller and the (pseudo-)pilots in the sector. Each sector has a unique multicast IP address and a port number that replicates the controller R/T radio frequency and allows all controllers and pilots in the sector to communicate with each other as they would with conventional VHF radio utilizing a push to talk switch.

Additionally, to provide controller-controller communications, each controller listens to a unique multicast IP address and port number for communicating person-to-person to any other controller. This utilizes a graphical user interface (GUI) running on a touch sensitive screen, similar to the Voice Switch Control System of the Display System Replacement, allowing the controller to initiate or accept “telephone” communication with other controllers.

Step-on Prevention

One of the major problems with conventional radios is two aircraft transmitting at once, known as ‘step-on’, when all that is received by the controller is a ‘squeal’. To prevent step-on with the VCS, whenever the controller application receives a transmission from an aircraft application, it issues a mute command to all other aircraft applications. If two or more aircraft try to transmit simultaneously there is always a transmission that arrives first. The first aircraft continues transmitting while the remaining aircraft receives a mute that terminates their transmission without any effect on their reception. This functionality prevents more than one pilot from transmitting at any give time.

Controller Precedence

It is not uncommon for an aircraft to unintentionally monopolize a VHF frequency, often due to failure such as a ‘stuck’ transmit switch. The controller application provided controller priority functionality pre-emption which allowed the controller to break into any transmission by a (pseudo-)pilot at anytime by sending a mute message to all pilots in that specific sector preventing them from sending their sound packets.

Controller Automated handover: To reduce controller workload the VCS application was integrated with the controller display application. The VCS control processes “listened” to the UDP multicast messages on the display control channel. When a controller assumes control of an aircraft, after a silent handoff, by clicking on the position symbol or entering the computer identification (CID), the display issues an “assume control” message to provide aircraft identification, the handing-over sector and receiving sector, among other information. The VCS control process then sends a message to the aircraft VCS application to switch to the multicast IP/port of the assuming sector. No extra controller or pilot action is required; the transfer of

communications is automatic. Pilots can override automated transfer by reselecting a particular sector¹.

Pilot Application

The pilot application provides a GUI that lists all sectors available for the pilot to select from. Once the pilot selects a specific sector for communication, the pilot will hear the controller as well as the other pilots in that sector, analogous to selecting a sector VHF frequency. The application has two modes of operation one that allows a pseudo-pilot to be logged-on using a designated flight number or as not logged-on which allows a pseudo-pilot to communicate for multiple aircraft at any given time without having the hand-off functionality. If a pilot is logged-on as an aircraft with a specific flight number and handed over between sectors, the pilot may override the frequency change by selecting a different sector from the GUI.

Functionality

The VCS is a user-friendly system requiring minimal input as possible from the controllers and (pseudo-)pilots. The display requires all pseudo-pilots and sectors to be logged onto the system. Logging onto the system enables the user to view all sectors logged on.

Controller Application

The controller application allows a controller to communicate with aircraft as they would with radio transmissions and to communicate with other controllers as they would via telephones. Each controller station is set-up with a headset, foot pedal, and a touch-screen display. Air traffic controllers use a foot pedal switch to communicate with aircraft on their frequency. Controllers utilizing VoIP use the same technique to communicate with aircraft by pressing the foot pedal switch and speaking into a microphone, which is usually attached to their headset. All the pilots on the frequency hear the controller transmission, as over radio transmissions.

Currently, controllers communicate with each other utilizing telephone lines. Rather than communicating via telephones, controllers using VCS communicate

on the same communication system as they do with the pilots. Figure 5 shows Riddle West logged onto the system, which indicates Riddle East is active and the other sectors are not active. Controllers can communicate with any other sectors that are logged onto the system, by touching the desired sector. Once the desired sector is selected, the system sends an alert to the selected sector. On the receiving sectors end, the sending sector's box blinks repeatedly until accepted or declined. Upon receipt of this alert, the sector's controller has to touch the sending sector's blinking box to accept. Once the receiving sector has accepted the line of communication, the controller microphones become 'open' microphones. Both controllers can now communicate via the microphones without depressing the foot transmit pedal. Controllers can only have one line of communication with another sector, or controller, open at a time. While a call is in progress, both controllers can still communicate with the pilots in their sector. They simply depress the foot pedal and start transmitting their messages. The line of communication with the other controller is still open. Controllers can hear both, the other controllers and the (pseudo-)pilots in their sector on the same headset.



Figure 5. Riddle West controller logged onto the controller VCS

Pilot Application

The pilot application is similar to that of the controller application. Pilots see all available voice channels on their display. The pilot display and controller display are also similar in the way they display all available sectors. Each active sector is indicated by a name in black lettering with a gray background. Dark gray lettering and the same gray background indicate inactive sectors (Figure 6). Pilots open lines of communication by first logging onto the system that opens their line of communication. Upon successfully logging on, the pilot selects the desired sector by touching that sector's box. Once the sector is selected, the pilot can transmit to the controller by depressing the foot pedal. Once the pedal has been

¹ The Controller Pilot Data Link Communication (CPDLC) application is similarly integrated with the controller display. When the transferring controller initiates the silent handoff, a CPDLC 'Next Data Authority' message is sent to the aircraft and when the assuming controller assumes control, the CPDLC application issues a 'Current Data Authority' message to the aircraft.

pressed, the microphone becomes active and transmissions will be relayed to the controller and the other pilots who have the sector selected.

In use, both applications, controller and pilot, proved to be very similar to the current R/T systems used today by air traffic controllers and pilots.



Figure 6. Aircraft, CBB1, logged onto the pilot VCS system

Testing Environment

This VCS was deployed and tested within the Global Communication, Navigation, and Surveillance Systems (GCNSS) project sponsored by the FAA and Boeing. The intent of the GCNSS project is to

“...explore and develop next generation Communication, Navigation, and Surveillance/Air Traffic Management concepts and provide for demonstrations of application of space-based Communication, Navigation, and Surveillance technologies to enhance the capacity, efficiency, and security of air travel in the National Air Space...”[1].

The demonstration of the VCS involved the Connexion by Boeing’s B737-400 experimental aircraft flying in and out of land-based radar and VHF coverage over the Gulf of Mexico, while maintaining full communication and remaining under air-traffic control. In support of the demonstrations, the EARL real time simulation, including the VCS, was widely distributed from Daytona Beach, Florida with two simulator positions in each of Boeing ATM Laboratory McLean, Virginia; FAA Houston Center, Texas; Boeing Enterprise Operations Center, Irvine California and also in the Connexion by Boeing Boeing 737-400. The VCS demonstrated the feasibility of a global satellite-based communication, navigation and surveillance system, using a highly integrated Common Information Network architecture. The communications were a mix of dedicated T1 based wide area network (WAN) and satellite communication (SATCOM) over both Ku geostationary and L band (Iridium) links.

Throughout the demonstration, VCS provided a full party-line capability with step-on prevention with controller precedence, and controllers at Houston were able to transfer voice communications as part of a standard ‘silent handover’. The VCS system proved pilots and controllers can communicate efficiently via SATCOM without noticeable transmit delay problems and unrestricted by terrestrial VHF coverage. It showed that the VCS integrated approach could greatly reduce controller workload and that the controller task was eased considerably by step-on prevention and controller precedence.

Benefits

Controllers have become used to the implications and limitations of the current VHF radio systems. These limitations include problems with step-on and ‘stuck’ transmit switches.

Nearly half of a controller’s workload can be due to transfers of control and frequency changes. By incorporating automated handover of communications, controller workload would be reduced, potentially leading to an increase in sector capacity.

Currently, the VHF, is limiting the number of sectors. This has led to the mandated introduction of radios with 8.33-Khz frequency spacing for aircraft operators. However, a VOIP based VCS can share a single VHF data-link connection with other multicast messages by multiplexing the voice over data-link. Therefore, The VOIP VCS has the potential to reduce or remove the current contention for VHF frequencies.

The VCS does not have the geographical limitations of terrestrial VHF. Consequently, pilots and controllers can be on the same multicast channel, no matter where they are located, worldwide. For example, a pilot crossing the Atlantic Ocean would be able to communicate with another aircraft or controller who is located in the Pacific. This function would eliminate the use of relay stations and the limitations associated with them.

Conclusion

The use of VoIP technology in the air traffic control communications system would enable controllers to control aircraft without geographical limitations. Added functionalities, such as controller step-on prevention, controller precedence, and automated handovers have considerable potential to reduce controller workloads and increase safety. These

concepts were proven successful during the GCNSS project.

Reference

[1] Boeing Air Traffic Management, 2004, *GCNSS Demonstration Segment B Report*, Document number: D794-10141-1, pg. 3.

Biography

Jennifer King is a research assistant at Embry-Riddle Aeronautical University's Air Traffic Management Research Laboratory. Jennifer received her Bachelor of Science in Aeronautical Science degree from Embry-Riddle Aeronautical University in Daytona Beach, Florida in 2003 and is currently pursuing her Masters of Science in Aeronautics at Embry-Riddle.

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