

PREDICTIVE MANAGEMENT OF AIR-GROUND COMMUNICATION INFRASTRUCTURE

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Abstract

The FAA's Next Generation Air Transportation System (NextGen) provides a more convenient and dependable air transportation system. As part of NextGen the FAA is planning to use VDL Mode 2 radios to support data communications under the aegis of the DataComm program to provide ATC services. The DataComm program will require fundamental changes in NAS operations. As a VDL-2 equipped aircraft traverses its flight path across airport, terminal and en route domains, it will connect to appropriate VHF Ground Stations (VGSs) based on factors such as availability and signal coverage. In areas of high traffic density, supporting capacity and latency requirements for the DataComm service will require use of multiple radios on different frequencies at the VGS locations in the NAS.

In this paper, we will explore the operational requirements imposed by use of DataComm at the communication layer, and the relationship between air traffic events such as Weather & Traffic Reroutes including the National Playbook and Severe Weather Avoidance Plan (SWAP) and the management of the underlying communications infrastructure. In particular, we will demonstrate the need for predictive management of the Air-Ground communications infrastructure in reaction to air traffic events and weather reroutes.

Background & Motivation

The FAA's Next Generation Air Transportation System (NextGen) provides a more convenient and dependable air transportation system. As part of NextGen the FAA is planning to use VDL Mode 2 radios to support data communications under the aegis of the DataComm program to provide ATC services.

A VDL Mode 2 network can be considered a cellular-type network in that each VHF Ground Station (VGS) provides a "cell" of limited geographic

coverage, while a collection of cells can provide signal coverage over a wide area. Figure 1 depicts an example of VDL-2 coverage as seen from an aircraft flying at 16,000 feet with VGSs placed at all major airports and some regional airports in order to achieve CONUS coverage.

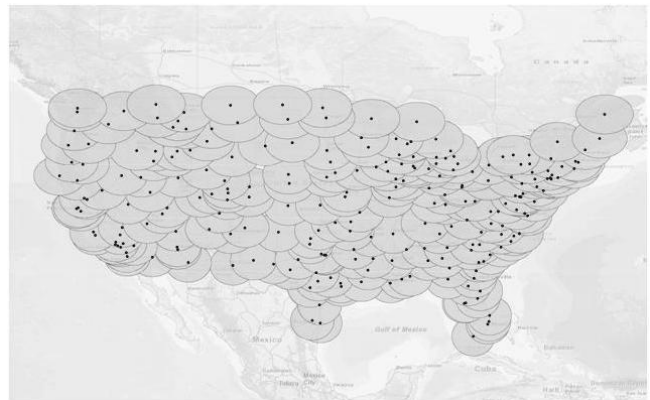


Figure 1: Example VDL-2 coverage.

To allow for continuous radio service, there must be some overlap between VGS coverage areas, thus providing some signal redundancy on the cell boundaries where signal strength is lowest. Since aircraft need to maintain connectivity all the way to the terminal, VGSs are necessitated at all airports where VDL-2 service is required. Signal connectivity is maintained as an aircraft traverses these cell boundaries through procedures that allow the aircraft to direct its communications at the VGS with the highest quality RF signal at any time.

In addition to signal quality triggers for handoffs, too many packet retransmissions, or timeout of network timers can cause initiation of handoffs as well. This process is called "Frequency Recovery". Relying on these mechanisms to maintain connectivity between the aircraft and VGSs can lead to unacceptable levels of latency and overall degradation of VDL subnet performance. For instance, the Frequency Recovery process is typically initiated once the signal quality deteriorates,

potentially leaving the aircraft with a degraded data-link for an extended period of time. Further, the selection of a VGS by an aircraft only takes into account signal quality. Such selection does not take into account the load on a particular VDL subnet that may be served by a VGS, and could lead to “hot spots”, i.e. overloading of certain VDL subnets along certain flight paths.

Hot-spot overloading is not unique to VDL-2 networks. Cellular network operators have been dealing with hot-spots for many years. Several solutions have been proposed for hot spot relief, including time-of-day and day-of-week cell size modifications to accommodate varying load conditions [1].

Performing load management in cellular networks is somewhat difficult due to the unpredictable nature of the traffic loading, unknown locations of the users, and complex propagation conditions that exist within built-up areas. In comparison to cellular networks, VDL-2 networks have more predictable traffic loads due to **known flight paths of the aircraft** and the knowledge of their current locations, and have a mostly line-of-sight propagation channel. We propose that this predictability be exploited for two purposes (1) to provide **predictive load** management, minimizing the probability of hot spots and (2) **predictive** handoff management to minimize the latency involved in frequency recovery based handoff.

The authors in [9] outline several network management considerations that may be used in the assignment of ground radios to aircraft to avoid some of these previously described problems.

VDL Mode 2 Handoff Mechanisms

When an aircraft VDL-2 radio first powers-on, initial radio contact is established through the Common Signaling Channel (CSC), which is on a single common frequency. The CSC also serves as the fallback communication channel for aircraft to locate new ground stations or in cases when handoff fails.

The ARINC 631-6 Specification [2] states that it is the responsibility of the Link Management Entity (LME) on the aircraft to manage all handoffs within the same ground system. There are two types of handoffs defined in this specification [2]. First, there

is Aircraft-Initiated handoff, in which the aircraft sends the `XID_CMD_HO` message to the ground station requesting a handoff (the ground node responds with `XID_RSP_HO`). Second, there is Ground-Requested Aircraft-Initiated handoff. In this case, the VGS sends an `XID_CMD_HO` message to the aircraft, and the aircraft starts an Aircraft-Initiated handoff as described above.

The aircraft monitors signal quality (SQP) for the currently connected VGS and on frequencies listed in the GSIF “Frequency Support List” parameter. When the signal quality from the current VGS is poor and the signal quality from another VGS is better, the aircraft can initiate a handoff by sending the `XID_CMD_HO` message. The ground station responds with the `XID_RSP_HO` message containing the frequency with which the aircraft is expected to tune to using the Autotune function. The Autotune function allows the VGS to command the aircraft to change frequencies without manual intervention of a radio operator [3].

VGS Boundary Predictions

It is possible to predict cell boundaries at various altitudes using a propagation modeling tool that is capable of simulating air-to-ground propagation conditions. For instance, Telcordia’s WINPLAN network planning tool contains the Gierhart-Johnson (IF-77) air-to-ground propagation model and can be used to predict performance of VDL-2 cell boundaries. This type of simulated result can be used to generate handoff candidate lists for populating the GSIF Frequency Support List parameter in the VGSs.

WINPLAN has also been used to compute the number of VGSs above certain minimum received power thresholds; our results indicate that in most CONUS airspace, multiple ground stations are visible from any particular point in space above FL16. This implies that there are several handoff candidates in these areas that have acceptable signal levels across which load can be shifted.

In terrestrial cellular systems, when a Base Transceiver Station (BTS) (equivalent of a VGS) senses that a Mobile Station (MS) (equivalent to the aircraft) is experiencing poor signal quality, as evidenced in the Bit Error Rate (BER), it commands the MS to send a report of measured signal strength to the surrounding BTSs (see [4]). Since there is no

Replacement Ground Station List can then mitigate problems with existing techniques:

1. Selection of replacement ground stations based not only on the signal strength but also based on the ground station or VDL subnet loading. Thus, lightly loaded ground stations would be preferred over heavily loaded ground stations, if they have substantially similar coverage areas.
2. Selection of ground stations based on overlap with the aircraft flight path as well as destination airport coverage, if applicable.

An example scenario depicting this process is shown in Figure 3 and outlined below.

Example scenario walkthrough:

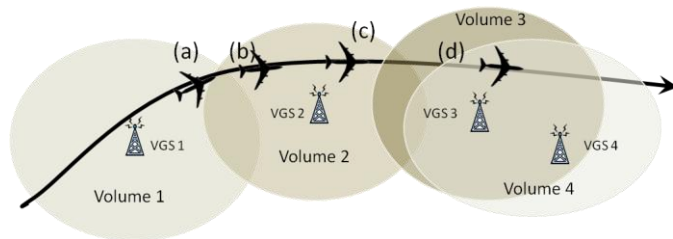


Figure 3: Predictive handoff management and load balancing leveraging aircraft flight paths

- (a) Aircraft approaches boundary of Volume 1; VGS1 retrieves aircraft position from external data sources, predicts upcoming handoff to Volume 2 from flight data object.
- (b) VGS1 sends ground-requested handoff message to aircraft to establish link to VGS2 on frequency F2. Aircraft initiates and completes link establishment to VGS2 in Volume 2 without frequency recovery procedure.
- (c) Aircraft approaches boundary of Volume 2; VGS2 retrieves aircraft position from broadcast information, predicts upcoming handoff to Volume 3 or 4; Volume 4 is selected owing to high current load in Volume 3.
- (d) VGS2 sends ground-requested handoff message to aircraft to establish link to VGS4 on frequency F4. Aircraft initiates and completes link establishment to VGS4 in

Volume 4 without frequency recovery procedure.

This type of predictive handoff can be used as a method to manage load as aircraft approach VGS boundaries and is a reactive method to manage network load.

A second proposed method for performing network load balancing would be a **proactive predictive method** that triggers ground-requested aircraft-initiated handoffs based only on network load (as opposed to when an aircraft approaches a cell boundary). That is, when a VGS (or multiple VGSs) approaches a critical load condition, we search through the list of currently active aircraft attached to that heavily loaded VGS to look for candidates that can be handed-off. Using the predicted coverage maps, we can find areas where multiple VGSs are expected to be visible and hand-off aircraft that fall in those regions to other, more lightly loaded VGSs that are visible.

Impact on Network Performance

In cases of high network load, as aircraft attempt packet transmissions, they may experience network timeouts due to too many competing packet requests on the serving ground station (the strongest one at this location in space). Current operating procedure would cause the aircraft to go into the frequency recovery mode where it tunes to other candidate frequencies. The aircraft will dwell on a frequency while attempting to establish a link for several minutes. If other channels in the candidate list are also heavily loaded, it could take several attempts to establish a new link on a lightly loaded VGS, which could result in 10s of minutes of delay and lost connection. Using the proposed load balancing mechanisms, the VGS with the lightest load will be indicated for a ground-requested handoff, thus avoiding delays associated with frequency recovery for particular aircraft.

In addition to the benefits associated with handoff of a particular aircraft, in a network that implements the proposed load balancing technique, overall load will be more equally distributed resulting in fewer hotspots and less reliance on frequency recovery processes. This can result in overall lower network wide latency.

Conclusions

As VDL-2 networks are widely deployed and used for transporting FAA Air Traffic Control (ATC) messages in addition to current applications involving Airline Operational Communications (AOC) traffic there will be increasing emphasis on the performance and reliability of VDL mode 2 networks. In this paper, we have outlined schemes for predictive load balancing and network management for VDL networks that have the potential to substantially alleviate significant deployment issues including the formation of traffic “hot-spots” within the VDL network as well as reduce the latency & performance deterioration associated with frequency recovery.

In future efforts, we plan to study the performance of these proposed techniques via simulation and analytics, and quantify the potential benefits in contrast to the current mode of operations.

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