Efficient Deployment of Cloud Computing in an Aircraft Data Network

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Abstract—the introduction of data networks within an aircraft has created several service opportunities for the air carriers. Using the available Internet connectivity, the carriers could offer services like Video-on-Demand (VoD), Voice-over-IP (VoIP), and gaming-on-demand within the aircraft. One of the major road blocks in implementing any of these services is the additional hardware and software requirements. Each service requires dedicated hardware resources to run appropriate software components. It is not possible to accommodate every hardware component within the aircraft due to space, power, and ventilation restrictions. Also, it is economically not viable to install and maintain hardware components for every aircraft. One solution is to use cloud computing. C loud computing is a recent innovation that is helping the computing industry in distributed computing. Cloud computing allows the organizations to consolidate several hardware resources into one physical device. The Cloud computing concept helps organizations in reducing the overall power consumption and maintenance costs. The cloud computing concept could be extended to the Aircraft Data Network environment with every aircraft subscribing to the cloud resources to run their non-miss ion- critical applications. In this paper, the authors explore the possibility of using cloud services for Aircraft Data Networks. The authors evaluate the performance issues involved with the aircraft mobility and dynamic resource transfer between servers when the aircraft's point-of-attachment changes. The authors predict that using cloud computing concepts would encourage many carriers to offer new services within the aircraft.

Key words: Aircraft, Cloud computing, VOIP, VOD, VM, VPC.

I. INTRODUCTION

Over the past decade, the aviation industry has seen a considerable increase in both passenger air travel and cargo traffic. As the competition increases, aircraft carriers are looking at various options to make air travel more convenient to passengers. Internet service within the aircraft is one of the services the airline industry is pushing forward, especially in long-distance flights. Apart from Internet service, aircraft carriers are trying to introduce various other services to be more customer-oriented. Wireless devices like PDA's, laptops , and smart phones are now ubiquitous and allowing passengers to use them in an aircraft will be a competitive advantage. Existing Internet service can also be used to provide other user centric services like Voice over IP (VoIP) [1], Video on Demand (VoD) [2], enterprise email and gaming services.

Advances in wireless infrastructure and satellite communication have made Aircraft Data Networks (ADNs) simpler and more efficient. A typical aircraft network has a transceiver which is used to communicate with the ground station through a satellite link as shown in Figure 1. This satellite link can be leveraged to provide passenger services like VoIP and VoD. One way to provide these services is to host the servers directly on an aircraft using the wireless link for minima l communication. However, implementation of these services on an aircraft would require expensive infrastructure be installed on each aircraft. In addition to this installation expense, carriers would have to deal with significant additional costs associated with operating and maintaining the infrastructure.

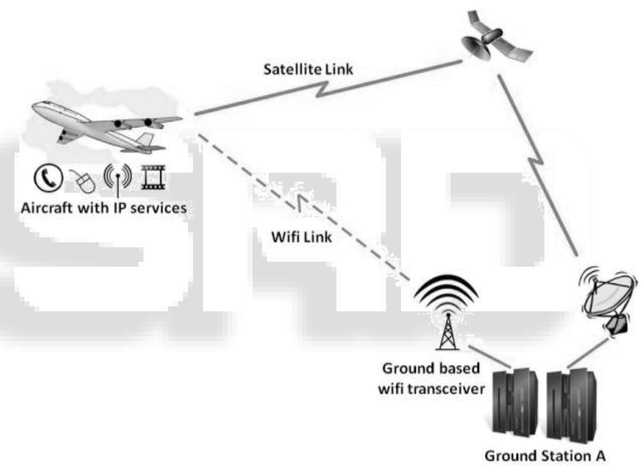

Fig. 1: Typical Aircraft Data Network

A feasible way to provide the above mentioned services without significant costs is to host them on a ground server and provide those services as needed. Once in place, the infrastructure will be available to provide services to all the aircraft in range through a services-hub, reducing the overall infrastructure costs. This set-up would only require minima l infrastructure upgrades to aircraft and 'in-air' operating and maintenance costs would be minimized while providing improved flexibility. This paper proposes using cloud computing to accomplish the task of providing data-intensive services like VoIP, VoD etc. over an aircraft.

Frame work for cloud computing in ADN is shown in Figure 2. All the ground stations are connected securely over high speed links and the authors assume there is enough redundancy with respect to Internet connectivity between the ground stations. Details regarding cloud computing, virtual machines and migration of virtual machines are discussed in the following sections.

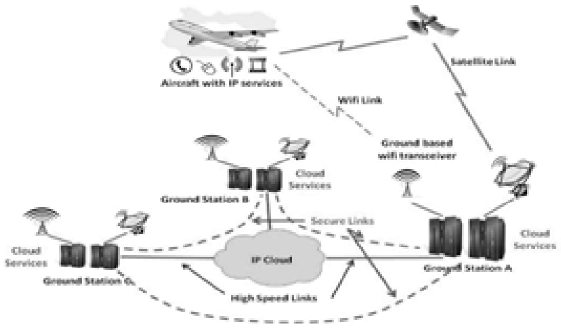

Fig. 2: Typical Frame work for Cloud Computing in ADN

A. Cloud Computing

Cloud computing is a demand based service provided to the user through the Internet. The services can include Infrastructure, Platform, and Software. The primary goal of cloud computing is to provide scalable access to computing resources and IT services [3-8].

1) Software as a Service (SaaS): In a SaaS platform, the applications are offered to the users on demand. Software is managed centrally at the server and no maintenance is required from the user perspective. This ensures that end users have access to the latest software always.
2) Platform as a Service (PaaS): PaaS is a highly scalable solution where hardware is provided as a virtualized entity to the end users. End users can always gain access to additional resources or relieve resources based on necessity.
3) Infrastructure as a Service (IaaS): In IaaS based service, a set of hardware like servers, routers, and storage is provided to users to run custom applications. End users are not liable for the infrastructure as such but have administrative control over the devices and software running over them.

The proposed cloud architecture for ADNs is the combination of all three types of services. Apart from being differentiated based on the services they offer, clouds are also defined based on their implementation. Types include private cloud, public cloud & hybrid clouds. The main difference between these implementations is that public clouds are more generic and open whereas private clouds are more tweaked and personalized based on client requirements. Hybrid cloud is a combination of both public and private clouds where partial resources are managed internally and others externally.

The proposed cloud to be used by ADN's is a Virtual Private Cloud (VPC). VPC uses public cloud resources to create a cloud of its own. Typically in a VPC network, the customer network is connected to the cloud services via an IPSEC tunnel [9-14].

Advantages of using VPC in ADN's:

1) Effective use of Bandwidth.
2) Scalable, interchangeable, remotely managed, and easily upgradeable.
3) Industry standard products can be used similar to office.
4) Easily modified or extended as requirements change with the addition of new applications
5) Standard interfaces provide a wide variety of network configurations while minimizing installation costs
6) Minima l impact on aircraft installation and certification.
7) Noncomplex architecture and overcomes space constraints in aircrafts.

Though VPC provides a secure way to access the cloud, it reduces throughput due to security overhead. Not every application running on the cloud, especially in passenger network needs a high level of security. In such cases, Virtual Hybrid Cloud (VHC) could be used in the Aircraft network, which is a combination of the public and private cloud. Whenever there is a spike or workload burst and the private cloud resources are exhausted, public cloud resources can be used and then relinquished back to the public cloud when it is no longer needed.

II. MIGRATION OF VIRTUAL MACHINES

A virtual machine (VM) contains all the components of a physical machine. However, a physical machine can support multiple VMs, providing flexibility in the size and applications available on VMs. In the proposed schema, one or more VMs can support the applications for a single aircraft.

A virtual machine is a replication of an actual machine, which is actually a program running on a host. Each VM can run its own operating system and is capable of running applications over the installed OS. This gives the flexibility of running a separate VM for each specific service offered over an ADN.

Since it is not tied to physical hardware, a virtual machine can be moved from one physical machine or server to another without any interruption to the services running on it. There are two ways of moving the virtual machine:

1) The first method involves two virtual machines sharing the same storage space and the control of the VM is shifted. Both machines refer to the same path for their data.
2) The second method involves moving the virtual machine completely along with its storage files from one server to another.

Several vendors support both of these methods. For this research, the authors have chosen Xen Hypervisor [15, 16] and VMWare [17, 18]. A main criterion for migrating VMs is to save the running state of the VM on one node and transfer it to another transparent to the user [19-21]. XEN provides these migration options through 'XM restore' and 'XM migrate' commands respectively. VMware provides these two types of migrations using motion and Storage vMotion. In vMotion, the execution state and the active memory of the virtual machine are transmitted over a high speed network from one physical server to another and the access to the disk storage is instantly switched to the new physical host. In storage vMotion, all the virtual machine disk files are moved across storage locations. Both these methods do not have any interruption to the applications running on the VMs. The user is not involved in the migration of the VMs.

Security is one of the major concerns in VM migration. In a cloud, security has to be implemented both at hardware and software level. For this paper, authors assume that all possible security implementations are in place and VM migration is happening in a secure environment.

III. PROPOSED SCHEMA

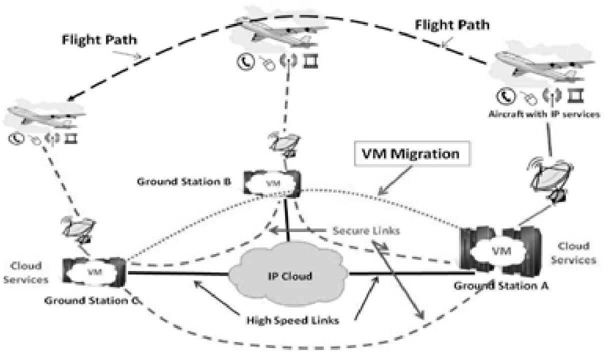

Fig. 3: VM Migration in an ADN Cloud

Considering a flight path from location A to location B, the authors propose to implement a cloud at each geographical location. Each cloud will be connected to a Storage Area Network (SAN) and there could be more than one node in that cloud which are located around that geographical network. When an aircraft moves from one geographical location to other, the aircraft's VM will be moved from one node on a cloud to a node on the different cloud in the new geographic location of the aircraft. If the aircraft is moving to a place in the same geographic location, its VM can be moved around from one node to other node in the same cloud. VMs can be moved in between nodes within the same cloud to facilitate proper resource management and avoid overloading on any physical node. All the nodes on a cloud will be connected to a SAN through a high speed link over which the VMs will be running. Figure 3 explains the proposed architecture of VM migration for ADNs.

A. *Real time Replication*

When an aircraft moves far away from a node it is connected to, performance degradation occurs in the VM and this issue increases as the aircraft moves farther from the node. Moving the VM and its disk storage from one cloud to another at that moment is not a feasible option since the copy would take too long and be too disruptive to the services. To reduce this performance degradation, the authors propose to use live replication across the SANs as shown in Figure 4. Replication will help maintain similar copies of data at two or more locations. This can be done synchronously, so that every write will be executed simultaneously. The data stored for the application is expected to be relatively constant while in flight making replication a feasible solution.

When an aircraft starts at a location, a VM will be created in the node located near it. As the aircraft's path is already set, an instance of original VM will be created on each SAN along the aircrafts path and the disk storage for each of these VMs (VM States) will be synced using real time replication. When an aircraft moves from one location to the other, the VM will not be moved completely. As the data is already in sync and the memory already allocated, only the control of the VM is transferred from one node to another through an Internet connection. The bandwidth consumed at any point will be minimized because all the changes done in the VM will be updated dynamically. The downtime of the VMs will be insignificant even if latency is taken into account. When the aircraft's virtual machine is contacting a particular node, all the VMs on other nodes will be locked out.

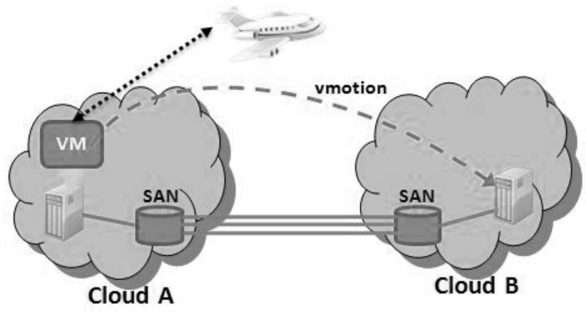

Fig. 4: Migration be twee n Clouds with Re al Time SAN Replication

IV. MULTI SERVICES OVER IP

A. *Voice-over-IP*

VoIP in flight is achieved by routing the voice traffic over the Internet or any IP based network. It is the service provided to passengers on board an aircraft that lets them call other passengers or any other person in the world at a low cost.

As voice is an analog signal, it needs to be converted to a digital signal; this digital signal is transmitted over a packet switched network which enhances the speech quality while the signal's efficiency is improved through the use of codecs. There are three types of codecs: Waveform codec, source codec, and hybrid codec. VoIP also employs two types of protocols for signal control: Call controlling and signaling protocols, and Carry voice payload protocols. Examples of call controlling and signaling protocols are H.323, session initiation protocol, media gateway control protocol, and skinny client control protocol.

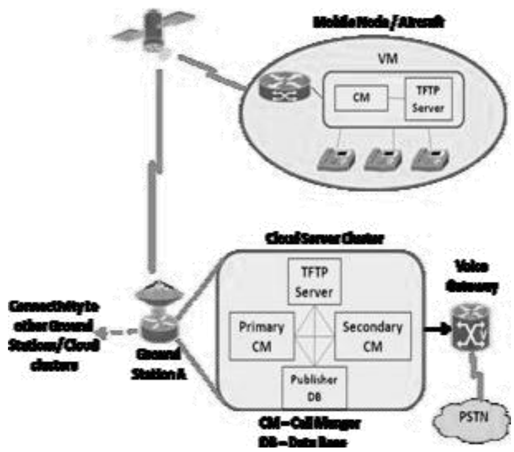

Fig. 5: Proposed Network Architecture for Voice Communication in an AND

A VoIP implementation in aircrafts requires the installation of a call manager and a separate network to transfer voice data. The infrastructure used to support VoIP in aircraft is an overhead which can be overcome by using cloud computing. In our proposed schema, the VM running on the ground would route the call, and the aircraft itself would just have the call manager (CM), thus decreasing the infrastructure overhead. The infrastructure framework for VoIP in ADNs is shown in Figure 5.

B. Video-on-Demand

Passengers choose movies from a large database using Video-on-Demand (VoD). Storing movies on the flight digital media server (i.e. on local cabin servers) has a limitation in that the server's storage capacity is usually limited. While current aircraft broadband antennae are enough to provide Video on Demand and live TV, the authors recommend using Ku band (11-14 GHz) for broadband services which offers more bandwidth compared to L band [2].

To implement video on demand, the authors propose to first download user-requested movies from online movie rental companies to the cloud servers. Then get the movies from ground station web-servers and store them on local HDD servers on the aircraft. If any other passenger requests the same movie, he can directly watch the movie from the copy saved on the local server. After every flight, the local movie copies on the aircraft's HDD will be deleted. Infrastructure framework for VoD in ADNs is shown in Figure 6.

The down-link and up-link frequency sharing is done using a technique similar to Time Division Duplex (TDD). The up-link bandwidth needs to be greater to allow for movie downloads while down-link bandwidth could be less since only requests and acknowledgements need to be accommodated. Bandwidth allocation can be dynamically changed using TDD.

Having to just stream the video will reduce the number of servers in turn allowing carriers to provide passengers with a wider variety of entertainment. We can implement live TV channels too by streaming the channels through satellite IP using the same antenna used for VoD.

V. EXPERIMENTAL SETUP AND RESULTS

Two base stations were setup to implement and test the proposed architectures. Both nodes were setup with the Ubuntu operating system and appropriate hypervisors. The Ubuntu image used to start the virtual machine was 4.1 GB in size with a RAM size of 1.068 GB. We moved the virtual machine from one system to another, where the control was shifted. The virtual machine disk files were stored on a storage area shared by both the machines and this migration took 39 seconds.

In the same environment we have tried a block migration of the VM where all files are transferred to destination node. With the same ram size and with the total disk size of 4GB, the migration took 6 minutes 50 seconds. It clearly indicates that the time taken for moving the control took less time than moving the virtual machine completely. Similar behavior is seen as RAM sizes and disk sizes are changed.

Authors were able to implement proposed architecture for VoIP in ADNs by implementing a call manager on one of the VMs running on the aircraft. This call manager was able to communicate successfully with call managers at the ground station. There were two setups; one with IPSEC running (VPC) and one without (hybrid cloud). In the hybrid cloud setup, calls were successfully placed. No major issues were seen in call performance while the VM was migrated from one node to another. With IPSEC running, initial calls were placed without any issues, but new calls were unable to get established while the VM migration was in progress. Existing calls were not affected. Table 1 displays the summary of VoIP setup results. It was observed call performance stats were similar to the results published in [1].

Parameter	Value
Average delay for voice packets (for 10 calls)	604 ms (G.723) 610 ms (G.711) 656ms (G.723 with IPSEC 698ms (G.711 with IPSEC)
PSQM Scores	4-5 (Acceptable)
Call setup time	7-15 sec

Table. 1: Summary of VoIP Setup Results

Implementing VoD was challenging since proper IFE equipment was not present. The authors simulated the setup by streaming video from ground station to the users aboard the aircraft. A multicast streaming server was setup on a VM running on the aircraft. One interesting observation was that when a new movie was requested by user while VM migration was in progress, buffering didn't start until the VM migration was complete.

VI. CONCLUSION AND FUTURE WORK

Cloud computing in aircraft data networks could revolutionize commercial aircraft passenger service by helping carriers add more services at minimal incremental costs. We were able to prove with the help of live migration that switching control of VM results in far better performance than moving the whole VM.

The failure to establish calls during VM migration might be due to IPSEC ACLs and asymmetric routing. Troubleshooting this issue is left as future work. Also, impact of QoS can also be studied as future work. How changing signaling and control protocols can also be studied.

While we couldn't test a complete VoD scenario, results from the experimental setup indicate that the cloud along with the replication VMs could have a great impact on how IFE will be delivered in future.

Future work can be aimed at minimizing the downtime due to delays in transferring the VMs and finding a better ways to migrate VMs. Also, this work is highly dependent on reliably synchronizing data between SANs over extended distances, an area which could be studied further.

Security is another major concern and impact of secure protocols over VM migration can be studied as future work.

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