Towards An In-flight Infrared Peer-to-Peer Media Streaming Network

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Abstract

In-flight entertainment systems are prone to many restrictions such as non-interference with aircraft control and navigation systems, bandwidth bottleneck, space and weight limitation. Based on light transmission, infrared technologies are excellent options of cabin wireless communication as they are lightweight, safe and interference-free. With the development of infrared and peer-to-peer networking technologies, there is a feasibility of setting up an in-flight wireless peer-to-peer network for streaming of media content with high level of quality and reliability. This paper provides an extensive review of state-of-the-art technologies that are relevant in setting up a new generation of aircraft media streaming networks using infrared communication and decentralized decision making.

Key Words: peer-to-peer, in-flight, optimization, network, communication

1. Introduction

In-flight entertainment (IFE) is a fast growing business that provides multimedia and other services to aircraft passengers during a flight. Although the first in-flight movie was in 1921 when passengers on Aeromarine Airways were showed a movie called Howdy Chicago, it was not until 1960s that in-flight entertainment became mainstream and popular. Today, in-flight entertainment is offered as an option on almost any wide-body aircraft and provides many services such as music, video-on-demand and computer games. Although, in general, the user-friendliness improved and the content offer increased, there were no major technological breakthroughs in the past five years. Instead, a continuous evolution of classical server-client architectures based on fixed wired network topologies is still a dominant trend.

There are inherent obstacles that prevent significant technological breakthroughs in this field. Especially, IFE systems are prone to many restrictions such as non-interference with aircraft control and navigation systems, bandwidth bottleneck, space and weight limitation. Although, it is well-known that infrared (IR) technologies are excellent options of cabin wireless communication as they are lightweight, safe and interference free, IR technologies has not played a major role in establishing a suitable link-layer for IFE systems. This is because with the traditional client-server architecture, limited bandwidth provided by IR technologies cannot offer high quality of services in IFE systems.

In this paper, we argue that with recent advancements in peer-to-peer (P2P) technologies and resource optimization techniques, we are able to harness the lightweight, safety, and noninterference of IR technologies and at the same time resolve the bandwidth issue. We envision that there is a feasibility of setting up an in-flight wireless P2P network for streaming of media content with high level of quality and reliability.

The organization of this paper is as follows. Sections 2 and 3 briefly introduce IFE systems and their limitations. Section 4 reviews current IR technologies, and Section 5 presents recent developments of P2P technologies. In Section 6, we discuss several optimization techniques to efficiently distribute content across P2P networks. We present the idea of next generations of in-flight infrared peer-to-peer media streaming network in Section 7 and conclude the paper in Section 8.

2. In-flight entertainment systems

In-flight entertainment can be dated back to the early days of the air transport industry in 1930s where live singers or even fashion shows were performed onboard the aircraft to entertain passengers on long haul flight [1]. Today, passengers on most airlines can enjoy high quality services such as music, video on-demand and computer games thanks to the breakthrough in technology such as mini LCD screens and micro-processors. The affordable cost of IFE systems also allows many airlines to offer IFE not only to first and business classes but also to all other classes of passengers. Table 1 summarizes some of the most common services offered by current IFE systems.

Table 1.Some common services of current IFE systems

Screen-based	Audio	Communication
• Video-on-demand/ TV • Aircraft display map • Computer games • Shopping	• Radio • Music on-demand • Cabin-crew announcements	• Satellite phone • Fax • Satellite internet

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With the increasing levels of competition in the air transport industry, most airlines are trying to differentiate their product with other competitors in a bid to get more shares in this multi-billion dollars industry. In-flight entertainment is an area that catches much attention as it caters to the increasing demand of customers who have to spend hours on long flights. To provide state-of-the-art quality of in-flight entertainment services to their customers, leading airlines are spending billions of dollars to upgrade their IFE systems [6]. This has created the motivation for extensive research and development of new IFE systems recently. Figure 1 shows the spending of world airlines on IFE based on data from the Word Airline Entertainment Association (WAEEA).

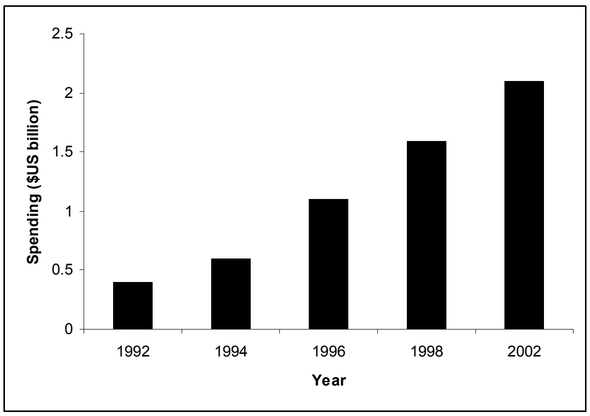

Figure 1. Airlines spending on IFE

3. Limitations in current IFE systems

While IFE manufacturers and suppliers are continuously working on developing new systems and enhance the services offered, efforts to bring the quality of in-flight services to the level of ground entertainment systems face many difficulties due to the many constraints onboard an aircraft such as space and weight limitation and security issues. The soar of oil prices in the 2000s has forced many airlines to lighten up and be more selective in choosing the IFE systems by paying much attention on the weight and space factors. Most of the current centralized wire-based IFE systems are heavy and consume a significant portion of space in the aircraft cabins. Another important factor in an IFE system is reliability. Most current IFE manufacturers and suppliers offer 98% reliability of their product [1] which translates to an average of 2% unsatisfied passengers for airlines using such systems. On larger aircraft such as the Airbus A380 with more than 500 passengers, the level of dissatisfaction will be large over time.

4. Infrared communication and IFE systems

Infrared technology allows bi-directional (time-division duplex) short-range wireless communication and can be classified into directed or diffused, which relates to the directionality between the transmitters and receivers. Directed links require the transmitter and receiver to have direct line-of-sight (LOS) and are limited to narrow angles, point-to-point transmissions. Additionally, transmitters and receivers are required to remain motionless with respect to each other. However, directed link design maximizes efficiency and minimizes contention caused by noise in the form of environment light. Diffused links use wide-angle transmitters and receivers that are not necessarily aimed directly at each other. These links usually have non-LOS capability and rely on infrared light reflected from surrounding surfaces. Table 2 shows the specifications of selected IR technologies.

Table 2. Specifications of selected IR technologies

Acronym	Name	Range (m)	Data Rate (kbps)	Alignment angle (degree)
SIR	Slow Infrared	1	9.6-115.2	30
MIR	Medium Infrared	1	576-1,152	30
FIR	Fast Infrared	1	4,000	30
VFIR	Very Fast Infrared	1	16,000	30
AIR	Advanced Infrared	10+	16,000	30

The basic protocol for IR communication is specified by the Infrared Data Association (IrDA). Although application-level programs can use the IrDA protocol via infrared sockets that share the same API as windows sockets, the IrDA protocol is a point-to-point means of communication. That is, this protocol does not transfer TCP/IP messages over infrared links. To address this drawback, Microsoft proposed the IrNET protocol in 2001 to enhance IR device connectivity. The IrNET protocol provides infrared-enabled device connectivity to the Internet or to any other network that uses the Point-to-Point Protocol (PPP) family of network access protocols.

Although infrared link-layer is not frequently used in normal applications due to the popularity of Bluetooth, Wifi and the LOS requirement, it has the potential to be a suitable link layer for in-flight wireless communication when the bandwidth restriction can be resolved by peer-to-peer technologies and efficient routing strategies.

5. Peer-to-Peer network

Many current Internet/intranet applications are using the client-server framework. In this architecture, a single entity called "server" performs many functions such as gathering requests, processing data, sending answers to requestors or providing them with services. As the amount of workload in a network increases tremendously with respect to the number of clients, the client-server framework suffers from several problems. The most fundamental problem is the bandwidth bottleneck on the server side since the centralized architecture does not distribute the workload evenly across the network. P2P architectures solve this problem by reducing the centralized components to a minimum if not completely. As a result, all the mentioned functions in the centralized network are shared evenly across the P2P network. Consequently, the bandwidth bottlenecks are reduced or even eliminated.

Recently, extensive research has been carried out in the field of P2P technologies. However, there is a lack in standardization and most of the current P2P applications are just focusing on file-sharing issues. As a simple classification, Caviglione and Cervella [2] grouped the P2P applications into three main categories: unstructured, structured and hybrid systems. In all of these systems, the most important challenge is the localization of resources among peers in the absence of servers. In unstructured systems such as Gnutella [2], peers organize themselves without any external control. In such systems, the centralized entities are completely removed; therefore, locating of resources is a hard problem. Searching and routing of data have to rely on pseudo-flooding or random walks [5] techniques. These techniques, however, incur large overheads [5], which are difficult to reduce or eliminate. Conversely, in structured P2P systems, peers are forced to group themselves in organized structures based on Distributed Hash Table (DHT) principles [10]. As a result, the localization of resources is much simpler. However, there is an overhead in organizing the peers and maintaining the consistent status of the system by updating the DHT. The problem is exacerbated if peers constantly enter or leave the network. Hybrid architectures combine the benefits of both centralized and P2P architectures. This is especially useful in media streaming because the most challenging task here is the actual transfer of large chunks of data to every peer while searching and paging operations require light workload and do not consume much bandwidth. Based on this observation, hybrid systems distribute the media transfer among the nodes in the network while keeping the decision making process centralized or partially centralized.

6. Efficient resource management

In P2P systems that have hard real-time requirements (limited bandwidth, random interruptions etc.), there are many problems that need to be addressed such as resources allocation, data transfer methods and optimal content replication strategy. Hence, in the next section, relevant research results and technologies that have been developed recently are reviewed.

6.1. Data allocation

As mentioned earlier, in all P2P applications, localization of resources is a key factor. Chord [8], a P2P resource allocation application developed by MIT, solves this problem by providing the crucial function: given a key, it maps this key onto a node. In previous works on consistent hashing [8], every node is assumed to know about every other node. The efficiency of Chord lies in the fact that each node only needs "routing" information about a few other nodes and, thus, is practical to scale to a large number of nodes. From a development point of view, Chord provides a communication channel at the application layer. Figure 2 shows a simple example of a distributed system using Chord as a resource locater.

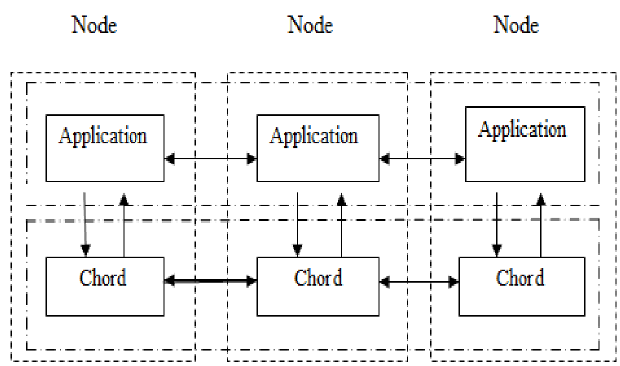

Figure 2. Example of a distributed system using Chord

Another advantage of Chord is that it is resilient to randomly entering and exiting of nodes in the system. In the steady state, in an N-node system, Chord resolves all lookups via O(logN) messages to other nodes. In a stochastic framework where nodes constantly enter and leave the system, Chord resolves all looks up with high probability of incurring no more than O(log2N) messages.

6.1. Data transfer

There are three main methods for distributing data across the network: Unicast, broadcast and multicast. Unicast transmission is the sending of information packages to a single destination. Broadcasting is the transmission of data to all users at the same time. Multicasting [4] is similar to broadcasting but is implemented in a more efficient manner where information is delivered to a group of destinations simultaneously. Multicast uses the most efficient strategy to deliver the messages over each link of the network only once, creating copies only when the links to the multiple destinations split. In bandwidth-limited environments, multicast is the solution to ensure the scalability of the number of nodes and amount of data to be transferred.

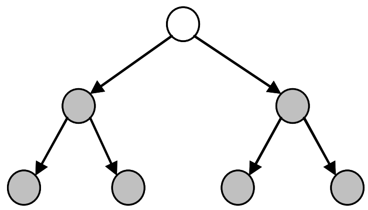

Figure 3. Simple multicast tree

In multicast systems based on a single tree such as in Figure 3, a particular peer is either an interior or a leaf node. It is easy to see that the interior nodes carry the burden of forwarding multicast messages while the leaf nodes simply receive the messages. The larger the number of leaf nodes in the tree, the more unbalanced the workload is divided in the system. For example, in a binary tree, more than half of the peers are leaf nodes and hence less than half of the peer is actually participating in distributing of data. In [3], Castro et al. proposed the SplitStream approach that splits the content into k stripes and multicasts each stripe using a separate tree. Peers join as many trees as there are stripes they wish to receive and they specify an upper bound on the number of stripes that they are willing to forward. This ensures the load of forwarding is distributed across peers as shown in Figure 4.

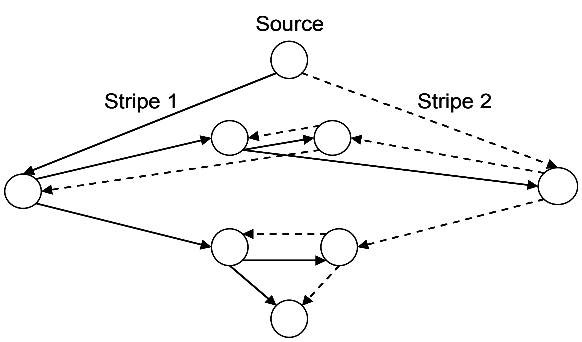

Figure 4. SplitStream approach to balance the workload among interior and leaf nodes

6.3. Optimized content replication in P2P systems

In hybrid P2P systems, the decision maker components (i.e. trackers) face the problem of providing optimal content-sharing schemes. Given the large number of peers in the systems and the large amount of data to be shared, it is of crucial importance to adapt an efficient exploitation of the resources that reduces the costs and time of sharing the data among the nodes. In the previous work by [2], the evolution of the media content distribution process is modelled as a discrete-time system optimization problem. Solution of this optimization problem provides the decisions of the trackers at the beginning of a time stage.

In [9], the authors propose a stochastic optimization for content sharing in P2P systems using stochastic inventory management techniques, where up-load and down-load bandwidth is based on agreed sharing rate. In particular, the authors derive optimal upload policies of individual peers based on estimated future need and previous contribution. Moreover, their algorithm also maximizes the availability of shared content for a coalition of peers.

7. Next generations of IFE systems

With recent advanced peer-to-peer network technology and matured optimization algorithms, it is time to rethink and redesign new generations of IFE systems that harness the power of these technologies. Indeed, we envision a P2P system over infrared links that provides high quality streaming video for onboard passengers in a near future.

The proposed network consists of point-to-point communication paths with an overall high degree of redundancy. Thus, appropriate routing can handle LOS blockage as well as temporarily increase data rates through combining several redundant communication paths. The degree of redundancy is optimized based on bandwidth needed of several groups of peers. Furthermore, the idea of a central media server for IFE is replaced by distributing the data redundantly over the individual nodes. Although each node alone is incapable of providing sufficient resources, the concept of balanced collaboration enables the system to fulfill the overall task, i.e. the provision of multimedia content without observed latency.

Unlike current systems, this concept is highly scalable. In fact, it is expected that the performance will improve for larger systems due to the increase in data redundancy. Eventually, the system has the potential to replace nowadays centralized wired in-flight entertainment systems and pave the road towards the concept of an integrated aircraft.

The main advantage of the described system is the reduction of weight and volume in comparison to current systems. In addition, the usage of interference-free wireless communication enables a new degree of flexibility for cabin design and maintenance. Furthermore, the interference-free architecture provides the possibility of operating as sensor network as well.

8. Conclusions

In this paper, we have reviewed several state-of-the-art technologies that are potential to play a major role in next generations of IFE systems. Especially, IR and P2P technologies and matured optimization methods are the main thrust to generate significant breakthroughs in terms of network topology, architecture and efficient content management. We expect the new IFE systems will be highly scalable, weight and cost efficient, and provide high quality of services.

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