Key Factors in Designing In-Flight Entertainment Systems

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Key Factors in Designing In-Flight Entertainment Systems

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1. Introduction

Most of researches concerning *In-Flight Entertainment (IFE)* systems are done on case bases without a global view that encompasses all IFE components. Thus, we try to highlight the key factors of designing IFE system, and showing how its various components can integrate together to provide the required services for all parties involved with the system.

1.1 Background and historical issues

Flight entertainment started before the First World War by the Graf Zeppelin (see Figure 1). This aircraft had a long, thin body with a teardrop shape; it was about 776 feet long and 100 feet in diameter, filled with hydrogen, and the cabin was located under the hull; five engines were fixed to the hull to power the aircraft.

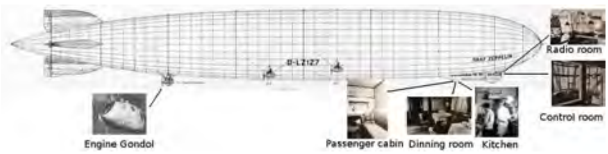


Fig. 1. The Graf Zeppelin aircraft

From the passengers comfort perspective, this model was equipped with a kitchen having electric ovens and a refrigeration unit, a small dinning room, washrooms for men and women, and passenger cabins with a capacity of two passengers each. Unfortunately, the craft was not heated, so passengers were dressing heavy coats and covered with blankets during winter flights. As developments went on, the "*Hindenburg*" aircraft came with heated passenger area, larger dinning room, passengers lounge with a piano as the first audio entertainment, a decorated writing room, a more enhanced passenger cabins, and promenades with seating and windows that can be opened during the flight (Airships.net, Last visit 2011).

In 1949, the "*De Havilland DH 106 Comet*" was the first commercial jet airliner to go into service. It had four jet engines located into the wings. It provided passengers with low-noise pressurized cabin (when compared to propeller-driven airliners), and large windows; hot and cold drinks, and food are serviced through the galley; separate women and men washrooms were available (Davies & Birtles, 1999).

Starting from 1960, *In-Flight Entertainment (IFE)* systems started to attract attention; they were basically a pre-selected audio track that may be accompanied with a film projector. They had shown improvements in both vertical and horizontal dimensions. They expanded horizontally by improving the existing services; audio entertainment moved from using simple audio devices to surround sound and live radio; video display progressed from using a film projector, to CRT displays hanged in the ceiling, to LCD displays dedicated to each passenger. The vertical improvement was noticed through introducing new technologies; cabin telephones allowed passengers to make phone calls during the flight; the system become interactive and allowed passengers to select their own services, while in the past they were forced to follow fixed services; web-based internet services allowed passengers to use some services such as emails and SMS messaging.

The basic idea behind IFE systems was to provide passengers with comfortableness during their long range flights; especially with long transatlantic flights where passengers see nothing but a large blue surface, so that services were initially based on delivering food and drinks to passengers. As passengers demand for more services grows, accompanied with an increase in airlines competition and technology advancement, more services were introduced and modern electronic devices played a remarkable role. This caused a change in the basic concept behind IFE systems; it becomes more than just giving physical comfortableness and providing food. It is extended to provide interactive services that allow passengers to participate as a part of the entertainment process as well as providing business oriented services through connectivity tools. Moreover, it can provide means of health monitoring and physiological comfort.

In recent years, market surveys have revealed a surprising and growing trend in the importance of *IFE* systems with regard to choice of airline. With modern long range aircraft the need for "stop-over" has been reduced, so the duration of flights has also been increased. Air flights, especially long distance, may expose passengers to discomfort and even stress. (Liu, 2007) mentioned that the enclosed environment of the aircraft can cause discomfort or even problems to passengers. This may include psychological and physical discomfort due to cabin pressure, humidity, and continuous engine noise. IFE systems can provide stress reduction entertainment services to the passenger which provides mental distraction to decrease the psychological stress. This can be done by using e-books, video/audio broadcasting, games, internet, and On Demand services. On the other hand, physical problems can range from stiffness and fatigue to the threat of *Deep Vein Thrombosis (DVT)* (Westelaken et al., 2010). IFE systems can provide different solutions such as video guided exercises to decrease fatigue, and seat sensors to monitor the passenger's health status

In fact, passengers from highly heterogeneous pools (i.e., age, gender, ethnicity, etc...) cause an impact on the adaptive interface systems. In non-interactive IFE systems, services (i.e., video and audio contents) are usually implemented based on previous concepts of what passengers may like or require. Using an interactive system based on context-aware services can make passengers more comfortable since they are able to get their own personalized entertainment services. However, such system must be user friendly in terms of easiness to use, and varieties of choice; otherwise, the passenger may get bored and is not able to get the expected satisfaction level.

From the airlines companies' perspective, productivity and profitability are one of the main targets. Achieving these targets is always hindered by the strong competition between companies. Thus, airlines are trying to maximize their attractiveness to get more clients because every empty seat means a revenue loss. IFE systems can play a remarkable role in customer satisfaction and attraction, and it can be used as an efficient portal for in-flight shopping. Moreover, one of the main tasks of aircraft attendants is to keep the passengers calm, unstressed, and to quickly respond to their requests. IFE systems can be a factor of stress elimination, decreasing passenger's movements during the flight, and providing request information quickly to the attendants.

Achieving such level of services requires various technologies and design concepts to be integrated together for implementing such systems. A single networking technology is not capable of providing all types of services. Thus, a good heterogeneous communication network is required to connect different devices and provide multiple services on both system and passenger's levels. For example, a GSM network can provide telephony services; WiFi, Bluetooth, and Infrared to keep passenger's devices connected to the system; LAN and/or *Power Line Communication (PLC)* to form the communication network backbone.

1.2 Chapter structure

Section 2 presents the different types of services provided by IFE systems, and shows the various components which are directly used by passengers as well as the components working at the background, which passengers are not aware of their existence. Section 3 introduces our proposed SysML model that integrates parts of the IFE system to help designers to have a global view of the whole system. Section 4 presents our conclusion. Finally, section 5 discusses future issues of IFE systems.

2. IFE services and components

IFE systems can provide various services for different parties such as airline companies, crew members, and basically passengers. These services are provided through software and hardware components; some components are used directly by passengers, while the others are used indirectly.

2.1 IFE services

IFE services can give solutions for different domains. They can provide health care and monitoring for passengers of health problems, business solutions to advertise products and support business decision making through surveys, and the expected service of entertainment.

2.1.1 Crew services

Although it seems that IFE systems are providing services to passengers only, but it can be extended to provide the cabin attendants with services to facilitate their job. Attendants have to keep a big smile and descent attitude during their work regardless of the current situation, and are burdened with various responsibilities and tasks. We believe that IFE systems can create a dynamic link between passengers and attendants. When an attendant respond to a passenger call, he does not know the reason for the call, so he has to make two moves, one to know the request and the second to fulfill it. An IFE system can allow the passenger to inform the attendant with their request (i.e., drinking water), so that the attendant can finish the service in one move instead of two. Moreover, the IFE system can ask the passenger if he had requested a special meal or not, so the attendant can bring the exact meal to the desired place without moving around with all meals in hand while asking passengers.

The cabin intercommunication service allows the pilot and cabin crew to make announcements to passengers, such as boarding, door closure, take off, turbulence, and landing announcements. These announcements are very important and need to be delivered to all passengers without any interruption; they are usually introduced via a loudspeaker installed in the cabin. If the passenger is wearing his headset, or is not able to understand the announcement language, then few numbers of passengers will comprehend the message. An IFE system can elevate the service through its audio system. When an announcement is introduced while the passenger is running an entertainment service, the entertainment pauses and he hears the announcement through the IFE audio system. Moreover, if it is a standard message such as "*Fasten your seat belt*", it can be directly translated into the language currently used by the passenger.

Safety demonstrations are used to increase passenger safety awareness. The demonstrations are usually done by crew members. This means that an attendant will stop any current activity and dedicate himself to the demonstration. As an alternative, the IFE system can be used to provide *Aviation safety education for passengers* via multimedia services; insuring accurate instructions, situational awareness, emergency responses, and relevant cabin-safety regulations (Chang & Liao, 2009), so that the attendants can be freed to perform other tasks. Moreover, IFE systems can be used in pre-flight briefing for crew members to improve the quality and availability of information provided to flight crew (Bani-Salameh et al., 2010).

2.1.2 Entertainment services

They are the basic services introduced by IFE systems. They aim at providing multimedia contents for passenger entertainment, audio tracks for different types of music channels, special programs recorded for the airlines, games, and printed media

- ***Video on Demand:*** As mentioned by (Alamdari, 1999), IFE systems usually include screen-based, audio and communication systems. The screen-based products include video systems enabling passengers to watch movies, news and sports. These systems had progressed into *Video on Demand (VoD)*, allowing passengers to have control when they watch movies. The general VoD problem is to provide a library of movies where multiple clients can view movies according to their own needs in terms of when to start and stop a movie. This can be solved by using an *In-flight Management System* to store the pre-recorded contents on a central server, and streams a specific content to passengers privately.

  The service can be enhanced by using subtitles as a textual version of the running dialogue; it is usually displayed at the bottom of the screen with or without added information to help viewers who are deaf or having hearing difficulties, or people who have accent recognition problems to follow the dialogue. In addition, they can be written in a different language to help people who can not understand the spoken dialogue.

- ***Single and multiplayer games:*** Video games are another emerging facet of in-flight entertainment. Gaming systems can be networked to allow interactive playing by multiple passengers. Providing high quality gaming in an aircraft cabin environment presents significant engineering challenges. User expectation of video quality and game performance should be considered because many users had experienced sophisticated computer games with multiplayer capabilities, and high quality three dimensional video rendering. Network traffic characteristics associated with computer games should be studied to help in system design; (Kim et al., 2005) measured the traffic of a *Massively Multi-player On-line Role Playing Game (MMORPG)*, showing the differences in traffic between the server and client side. In a *Massively Multiuser Virtual Environment (MMVE)*, where large number of users can interact in real time, consistency management is required to realize a consistent world view for all users. (Itzel et al., 2010) present an approach that identifies users which actually interact with each other in the virtual world, groups them in consistency sessions and synchronizes them at runtime. On the other hand, there is a trend to use wireless networks in IFE systems; the feasibility of using wireless games is studied in different researches (Khan, 2010; Khan et al., 2010; Qi et al., 2009).
- ***E-documents:*** An in-flight magazine is a free magazine usually placed at the seat back by the airline company. Most airlines are distributing a paper version, and some of them are now distributing their magazines digitally via tablet computer applications. Furthermore, ebooks are widely available electronically with value-added features and search options not available in their print counterparts. Electronic versions are not limited to just text; they may present information in multiple media formats, for example, the text about a type of bird may be accompanied by video depicting the bird in flight and audio featuring its song. Using an electronic version of printed media can change their importance by adding interactive features such as e-commerce services where a passenger can choose his products and buy them instantaneously.

2.1.3 Information services

Air map display provides passengers with up to date information about their travel. They are aware of the plane location and at which part of earth it is passing over. Information telling the outside temperature, speed, altitude, elapsed time, and remaining time gives passengers the sense of movement, because it is difficult at high altitudes, where you can find nothing except blue sky, and sun or moon, to evaluate and sense the aircraft motion. Missing this feeling can be boring for many passengers.

Exterior-view cameras also enable passengers to have the pilot's forward view on take-off and landing on their personal TV screens. The cameras can have different locations. A tail-mounted camera is located in housing atop the vertical stabilizer of the aircraft; it provides a wide-angle view looking forward and typically shows most of the aircraft from above. A belly-mounted camera provides a view looking vertically down, or down at an angle that includes the horizon. A quad-cam belly installation offers a choice of four views covering 360 degrees.

Passengers can pass their time navigating through available entertainment contents to have information about their destination. This can include city maps, sightseeing, languages, and cultural information. Such information will allow passengers to pass a fruitful time and minimize the feeling of being a stranger in a foreign country.

2.1.4 E-business services

Airborne internet communications allows passengers and crew members to use their own WiFi enabled devices, such as laptops, smart phones and PDAs, to surf the Web, send and receive in-flight e-mail with attachments, Instant Message, and access their corporate VPN. Many companies are offering solutions to provide passengers with Internet connectivity. FlyNet (FlyNet, Last visit 2011) is an example for onboard communication service provided by Lufthansa to allow passengers to connect to the Internet during their flight. ROW44 (ROW44, 2011) provides a satellite-based connectivity system that allows airlines to offer uninterrupted broadband service

Mobile phones are one of the most demanded devices by passengers. Many passengers, especially businessmen, are welling to make calls through their personal mobile phone during their flight. However, there are doubts that cell phone signals may endanger aircraft safety by interfering with navigational systems. To overcome this situation, different techniques (i.e., (AeroMobile, Last visit 2011)) were introduced to the market, where an on-board pico cell can connect the mobile phones to the ground stations through the satellite link and managing the signal strength to insure that there is no interference with the navigational systems.

On-board conferencing can turn wasted flight time into productive time for traveling teams of salespersons. Also, it will reduce the effort done by passengers to trade seats after boarding to bring their group together. With the addition of a headset with *Active Noise Cancellation*, the experience can be extended to conversing with someone in the next seat, due to the reduction of ambient noise.

Personal Electronic Devices (PEDs) such as laptop computers (including WiFi and Bluetooth enabled devices), PDAs (without mobile phones), personal music (i.e., iPods), iPads, ebooks and electronic game devices are electronic devices that can be used when the aircraft seat belt sign is extinguished after take-off and turned off during landing. On the other hand, other PEDs using radio transmission such as walkie-talkies, two-way pagers, or global positioning systems are prohibited at all stages of flight, as it may interfere with the aircraft communication and navigation systems.

Power outlets are hardly reached by passenger during traveling to their destination. Spending too much time without a power source can cause PEDs to run out of power, and causing passengers to be frustrated. As a solution for such situation, airlines (AmericanAirlines, 2011; Qantas, 2011) add power outlets to passenger seats. These outlets are usually present in first and business class seats. For safety reasons, some outlets are designed to provide 110 Volt (60 Hz) with 75 watts, however, this may be unsuitable for PCs that consumes more power. Other companies provide 15 volt cigarette lighter outlet, which needs an adapter to connect devices.

2.1.5 E-commerce services

In-flight shopping is dragging more attention from airlines as it is considered as a source of revenue, and a way for passengers to utilize their flight time. (Liou, 2011) presented passenger attitude towards in-flight shopping. He mentioned that customer's convenience increases when the shopping process takes less time, less effort in planning ahead, and less physical effort to obtain the product or service. Moreover, many factors can affect the decision making process (i.e., to buy a product); this includes pre-purchase information searching, and evaluation of alternatives.

An IFE system can be a remarkable factor for in-flight shopping. It can increase passenger convenience and facilitate decision making. An electronic catalogue viewed through the IFE display unit can provide search options that allow passengers to find other alternatives and make his own comparisons, and it can provide him with exhaustive information about the product. In turn, this will allow passenger to plan ahead without making two much physical effort, and in a relatively shorter time than making the same process in a paper document or through discussion with a crew member. Furthermore, the IFE system can play an extra ordinary role to e-commerce, not only for in-flight shopping, but also for shopping outside the flight. The IFE system can be connected to ground commercial services, so that the passenger can buy products or services (i.e., transport tickets, and duty free products), and receive them directly when he reaches his destination. In addition, multimedia advertising can attract companies to use it as a way to reach passengers.

Surveying is an important part of market evaluation. (Balcombe et al., 2009) held a survey to determine passenger's *Willingness To Pay (WTP)* for in-flight service and comfort level. The survey focused on seat comfort, meal provision, bar service, ticket price, entertainment (i.e., overhead screens for pre-set programs). He reported that older passengers are WTP more for seat comfort, while younger passengers are WTP more for bar and screen services.

However, performing such surveys is very tedious and difficult. (Aksoy et al., 2003) held a survey to evaluate Airline service marketing by domestic and foreign firms from customers viewpoint. The usable responses were 1014 out of 1350 responses, producing a 75.1% response rate. An IFE system can be an effective tool to increase the response rate, where an electronic version of the survey can guarantee that more passengers will participate, erroneous answers can be reduced, and analyzing the results becomes faster and accurate.

2.1.6 Health services

An elevated type of services, which IFE can provide, is health services. Flight conditions may cause the cabin environment to be tough; especially for persons who can face ill conditions. Flight duration, dehydration, pressure, engine noise, and other factors can be reasons of physical and/or psychological problems. A sensory system integrated in IFE system can provide a way to sense bad health conditions of passengers having health problem, and either inform the crew members or perform an action to reduce the effect.

(Schumm et al., 2010) and (Westelaken et al., 2010) suggest solutions based on sensory systems embedded in passenger's seat to sense his current status. (Schumm et al., 2010) introduce the design of smart seat containing sensors to measure *Electrocardiogram (ECG)*, *Electrodermal Activity (EDA)*, respiration, and skin temperature. These measured values can give a good indication about physical and psychological state. ECG is measured in two ways; without skin contact through sensors embedded in the backrest, and with a sensor fixed on the index finger. The second type is more obtrusive, but is more reliable. The same fixation system to the finger includes the EDA, and temperature sensors. The passenger movements can affect the reading quality, so a 3-axis accelerometer is added to compensate the errors. Respiration level is detected through sensors fixed in the seatbelt. The combined reading of these sensors can give a good indication about the passenger's health status.

Physical exercises can reduce physical stress and fatigue. However, the challenge is how to stimulate passengers to do them. (Westelaken et al., 2010) introduces a solution to reduce physical and psychological stress by detecting body movements and gestures to be used as an input for interactive applications in the IFE system. The basic idea for implementing these applications is to allow the passenger to participate in a gaming activity. His movements are captured as inputs for the chosen game. Three techniques were introduced to capture movements; sensors integrated in the floor, sensors integrated in the seat, and video-based gesture recognition. However, each of these techniques has its own pros and cons which need more investigation.

For passengers of special health needs, IFE system can be an effective tool to relief their pain. Passengers of *Spinal Cord Injury (SCI)* are not able to sense pressure acting on certain parts of their body that are cut off nervous system. This may increase the risk of decubitus ulcer, especially for long flights, where passengers may sit for several hours. (Tan, Chen, Verbunt, Bartneck & Rauterberg, 2009) proposed an *Adaptive Posture Advisory System (APAS)* for people of SCI. The passenger's seat plays a great role by having various sensors and actuators. Sensors are used as input source for a central processor connected to a database which is used to record passenger's sitting behavior and conditions. The suitable decision is taken and sent to the actuator to change the seat shape, and softness. This system helps SCI passengers to reposition their sitting posture to shift the points under pressure so that decubitus ulcer risk is minimized.

2.2 IFE components

The IFE components can be categorized into passenger and system components. In (Akl et al., 2011), we identified passenger components as the devices that the passenger uses directly to achieve a service, and system components as the components which are provided by the system and used indirectly by the passenger.

2.2.1 Passenger components

Passenger components are usually designed to be very simple and familiar in appearance and functionality in order to allow passengers of different background to use them; such as display units, remote controls, seat control buttons, headphones, etc...

2.2.1.1 Passenger seat

From the first sight, the passenger's seat may seem to be out of the scope of IFE systems, which are basically designed for entertainment. However, a deep look shows the contrary since passenger's seat is one of the main comfortableness components; especially when we consider that it is the place where the passenger spends most of his travel time. From one side, a poorly designed seat can causes discomfort, which can be extended to a musculoskeletal disorders regardless of the presence of any entertainment or stress reduction techniques; imagine the stay on such a seat for three or two hours, you will think in nothing except the time when the flight ends. Furthermore, when the passenger sits upright and inactive for a long period of time, he may be exposed to several health hazards. The central blood vessels in his legs can be compressed, making it harder for the blood to get back to his heart. Muscles can become tense, resulting in backaches and a feeling of excessive fatigue during, and even after the flight. The normal body mechanism for returning fluid to the heart can be inhibited and gravity can cause the fluid to collect in the feet, resulting in swollen feet after a long flight.

From another side, modern technologies can be used to elevate seat entertainment and comfortable role. Thus, we propose two terms, *Passive Seat (PS)*, and *Active Seat (AS)*. The *PS* is providing the service through its own structural design without any interaction with the passenger. The *AS* is providing the service in response to an intentional or unintentional input captured from the passenger.

- ***Passive Seat*:** (Nadadur & Parkinson, 2009) discussed different seat design problems. Airlines are aiming at increasing the seats density inside the cabin to increase their revenue. However, such approach diminishes the comfortableness factors in seat design. Increasing the seats density negatively affects the seat pitch, causing a decrease in the passenger's leg room (see Figure 2), which is considered as an important factor especially for tall passengers. He also mentioned that passengers should minimize the pressure between their lower thighs and the surface of the seat to prevent the occurrence of *Deep Vein Thrombosis (DVT)*. This can be achieved by keeping the knees height greater than the seat's height. A design contradiction here arises because lower seat height requires more leg room causing seat pitch to increase, and consequently seats density will decrease. On the other hand, increasing the seat height increases discomfort and the probability to have DVT problems. To find a compromise between these contradictions he proposed a mathematical solution to embed the passenger comfort as a design parameter and link it with the passenger's willingness to pay higher prices. (Vink, 2011) introduced other factors to be considered during seat design such as wider seats, adjustable headrests, space under the armrest, backrest angle, and ideal distribution of pressure over body parts. A better pressure distribution can be achieved by using support under the front part of the legs to spread the load, and ergonomic design of seat back and seat pan. Also, a well designed headrest and neck rest can increase the comfort feeling.

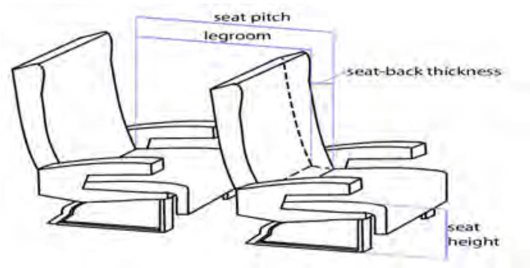


Fig. 2. Some aircraft seat design parameters from (Nadadur & Parkinson, 2009)

Sleeping and sitting posture is an important factor for passenger's comfort especially in long haul flights and it can affect the pressure distribution over the body. (Tan, Iaeng, Chen, Kimman & Rauterberg, 2009) held an analysis of passengers' postures in the economy class to help in seat design. In their study, they identified seven different sleeping positions for passengers. When considering the anthropometry differences between humans of different origins, we can say that it is difficult for a passive seat to achieve all comfort positions of different postures for all passengers, so an active seat with adjustable moving parts is usually required.

- ***Active Seat*:** A *Passive Seat* provides services of static features. On the contrary, an *Active Seat* is able to get an input from the passenger to change the service it provides. The input can be an activity to change the angle or position of adjustable parts of the seat; for example, the passenger can freely set the backrest angle or adjust the height of headrest to match his posture. In business class, the seat can accommodate a variety of postures for different activities such as watching TV, reading, sleeping, etc... Figure 3 shows a simple mechanical button (in economic class) for changing backrest angle Vs an electronic buttons (in business class) that can easily change the orientation of different parts of the seat using embedded motors.

Fig. 3. Electronic Vs Mechanical seat adjustment

In economy class, the degrees of freedom of an *Active Seat* are very limited where minimal parts are allowed to change their orientation due to limited space. For example, the armrest can be moved from the horizontal position to the vertical position to give more space, and the backrest angle can be changed to increase the body inclination and reduce the pressure exerted on the back. However, the inclination angle is usually very small in order not to reduce leg space of the behind seat. On the contrary, the business class seat is featured by large spaces; thus, different parts can be reoriented easily. A premium seat may be in a pod and capable of opening out into a flat sleeping configuration or folding up into a seat for take-off and landing. Moreover, it includes more amenities such as power, task lighting, and has also a design trend towards a higher level of privacy.

2.2.1.2 Visual display units

A *Visual Display Unit (VDU)* is the principal component in the entertainment process. It is the main interface between passengers and the IFE system, as well as their ability to provide interactive services. There are different types of VDUs. At the very beginning, *Cathode Ray Tube (CRT)* displays were used. Although they were able to provide the required service at that time, but were suffering of many drawbacks. They were relatively large in size and heavy in weight, so they were used as a shared display between a set of seats. Furthermore, the ambient lighting may affect the clearness of images. As technology advances, *Liquid Crystal Display (LCD)* units were introduced. They are small in size and light in weight. These characteristics helped greatly in introducing *Video on Demand (VoD)* service, where each passenger has his own display unit to watch his selected items. At the same time LCDs can still be used as shared displays. Nowadays, displays are equipped with an extra feature that allowed them to be used as input devices. Touch screens allow users to choose their own selections by touching the screen in the appropriate location.

Although a normal VDU is usually sufficient to display the required contents, certain services may have special needs. Table 1 shows the characteristics required to display different media services. With respect to the display quality, Video games do not need high resolution for their images since small moving objects are the main constitute of Video games. On the contrary, movies and virtual reality applications need high resolution to present their high quality images. The interactive feature of Video games and Virtual Reality applications require special input devices, since touch screens are usually suitable for simple selections and not for quick repetitive pressing.

Service	Realistic	Interactive	Immersive	Detailed Character
Video Games	No	Yes	No	Yes
Movies	Yes	No	No	Yes
Virtual reality	Yes	Yes	Yes	Yes

Table 1. Various Display requirements

The VDU location depends on the philosophy of the installed IFE system. If the system is going to present the pre-selected media without any intervention from the user, then a global VDU is installed in the cabin ceiling (see Figure 4(d)). If VoD service are presented with user interaction to select his own media contents, then each passenger seat is provided with a private VDU fixed in the back of the front seat (see Figure 4(a)). Furthermore, seats of special locations such as seats of first row or in the business class may have special VDU placement (see Figure 4(b) & 4(c)).

The VDU viewing angle is an important satisfaction factor. The viewing angle of VDUs fixed at the back of the front seat may change when the front passenger changes the position of his seat back, so that VDUs are usually fixed on a pivot to allow the user to change their inclination; otherwise, the user has to move his head to a fixed position to be able to view the VDU. Another solution is to fix the VDU on a movable axis to give the VDU different degrees of freedom (see Figure 4(b))

(a) Private VDU (b) Movable VDU (c) First seat VDU (d) Ceiling VDU

Fig. 4. Different VDU placements

2.2.1.3 Remote control

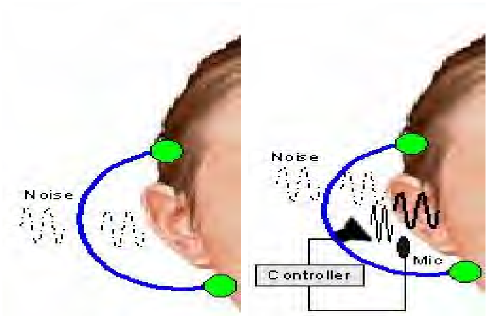
As IFE systems are becoming more and more interactive, a *Remote Control Device (RCD)* is needed to control the surrounding devices. It should be compact and easily held. Moreover, the pocket holding the RCD has to be placed in a way that makes it easily reached and not to affect passenger comfort. At the beginning, RCD used to be fixed aside to the VDU at the back of the front seat. This orientation introduced a problem when the passenger setting beside the window wants to move to the corridor; where all his neighbors have to replace their RCDs to allow him to pass. To overcome this problem, RCDs are now connected to their VDUs through wires passing via their seat. Using wireless technology can minimize such physical complexity (Akl et al., 2011).

Furthermore, passengers of no knowledge about using modern technology must be able to use RDCs easily. Usual control buttons (i.e., Volume, Rewind, Forward, etc...) are known for almost everyone; especial purpose controls such as *Settings*, and *Mode* can be carefully manipulated and, if used, to be provided by explanatory information when possible.

2.2.1.4 Noise canceling headphones

Headphones are used to privatize audio contents, so that each passenger can listen to his own selection without annoying his neighbors or being affected by the surrounding noise. Ordinary headphones are usually enough to do the job. However, modern technology can elevate the service level, by introducing active headphones capable of reducing the effect of surrounding noise (see Figure 5).

Generally, headphone ear cups have passive absorption capability which allows them to block some high frequency noise. However, they are not efficient for attenuating low frequency noise. A *Noise Canceling Headphones (NCH)* can reduce the noise through active noise cancellation techniques (Chang & Li, 2011)



(a) Passiveheadphones (b) Activeheadphones

Fig. 5. Headphones

2.2.1.5 Personal Electronic Device (PED)

Nowadays, people are getting more sticky to their *Personal Electronic Devices (PEDs)* such as laptop, mobile phone, and PDA, so most passengers are traveling with their PEDs. Connecting PEDs do not require special interfaces since modern IFE systems are moving towards wireless communication such as WiFi, Bluetooth, and IrDA, which are already used in most PEDs.

Using PEDs can have several advantages for both Airlines and passengers. Passengers will be able to use their devices to interact with the IFE system. They do not need to use or investigate unknown devices. Also, they can utilize their own data if the system permits them. Furthermore, if the IFE contents can be copied, the passenger can continue it at his hotel.

From the airlines perspective, PEDs can be used to save some dedicated devices of IFE systems. It is cheaper for airlines to remove expensive seatback monitors and let passengers to use their own devices; this is a good option for airlines offering cheap flights. Many companies (Lufthansa, 2011; Thales, 2011) are now offering broadband communication for PEDs.

2.2.2 System components

System components are usually complex to be able to handle the services while keeping simplicity of passenger components. Furthermore, the cabin environment is strict in terms of safety and imposed constrains. These characteristics encouraged the solution of using multiple technologies to form a heterogeneous system where each technology provides a solution for a part of the problem.

A context-aware IFE system can increase passenger satisfaction level. If there are many choices and the interaction design is poor, the passenger tends to get disoriented and is not able to achieve the most appealing contents. This is because most IFE systems are user adaptive systems where the user initiates system adaptation to get his personalized contents. (Liu & Rauterberg, 2007) showed the main architectural components to make a context-aware IFE system which can provide the passenger with entertainment contents based on his personal demographic information, activity, physical and psychological states if the passenger was in stress. Furthermore, the passenger is able to decline the proposed contents, and create his personalized contents.

For IFE networking, wireless technology can introduce different solutions to solve many existing problems as well as providing new services. Nowadays, wired networks are the principal technology of implementing IFE systems. Ethernet is currently the standard for wired communication in different fields. (Thompson, 2004) showed that it is characterized by interesting features such as good communication performance, scalability, high availability, and resistivity to external noise. Using off shelf technologies such as routers can reduce the costs of networking inside the cabin. In spite of all these advantages, IFE system designers are welling to exchange it -or part of it- by wireless technology to achieve more targets. Ethernet cabling is considered a burden for aircraft design because lighter aircrafts consume less fuel, and it imposes difficulties on easiness of reconfiguration and maintenance of the cabin (Akl et al., 2011). Accordingly, using different technologies within the same communication network can introduce a solution to the limitations of using each of them individually.

2.2.2.1 WiFi and Bluetooth

WiFi is a well known technology used in different commercial, industrial, and home devices. It can easily coexist with other technologies to form a heterogeneous network (Niebla, 2003). Moreover, (Lansford et al., 2001) stated that WiFi and Bluetooth technologies are two complementary not a competing technologies. They can cooperate together to provide users with different connecting services.

However, using large number of wireless devices in a very narrow metallic tunnel like the cabin has a dramatic effect on network performance. Furthermore, a major concern for using wireless devices in aircraft cabin is their interference with the aircraft communication and navigation system, especially unintended interference from passenger's *Personal Electronic Devices(PED)*. (Holzbock et al., 2004) said that the installed navigation and communication systems on the aircraft are designed to be sensitive to electromagnetic signals, so they can be protected against passenger's emitters by means of frequency separation. In addition, (Jahn & Holzbock, 2003) mentioned that there are two types of PEDs interference, intentional and spurious. The former is the emissions used to transmit data over the PED allocated frequency band. The latter is the emissions due to the RF noise level. However, indoor channel models mainly investigate office or home environments, thus these models may not be appropriate for modeling an aircraft cabin channel. Attenuation of walls and multi path effects in a normal indoor environment are effects, which are not expected to be comparable to the effect of the higher obstacle density in a metallic tunnel. The elongated structure of a cabin causes smaller losses, than that expected in other type of room shapes. However, the power addition of local signal paths can lead to fading of the signal in particular points. In addition, small movements of the receiver can have a substantial effect on reception. The same opinion was emphasized by (Diaz & Esquitino, 2004).

Different efforts were held to overcome this problem, (Youssef et al., 2004) used the commercial software package *Wireless Insite* to model the electromagnetic propagation of different wireless access points inside different types of aircrafts. (Moraitis et al., 2009) held a measurement campaign inside a Boeing 737-400 aircraft to obtain a propagation development model for three different frequencies, 1.8, 2.1, and 2.45GHz which represent the GSM, UMTS, and WLAN and Bluetooth technologies, respectively. Nowadays, many airline companies allows WiFi devices on their aircrafts such as Lufthanza (FlyNet, Last visit 2011), and Delta Airlines (DeltaAirline, Last visit 2011).

2.2.2.2 Wireless Universal Serial Bus (WUSB)

Universal Serial Bus (USB) technology allows different peripherals to be connected to the same PC more easily and efficiently than other technologies such as serial and parallel ports. However, cables are still needed to connect the devices. This raised the issue of *Wireless USB (WUSB)* where devices can have the same connectivity through a wireless technology. (Leavitt, 2007) stated that although it is difficult to achieve a wireless performance similar to wired USB, but the rapid improvements in radio communication can make WUSB a competent rival. It is based on the *Ultra Wide Band (UWB)* technology. In Europe, it supports a frequency range from 3.1 to 4.8 GHz. Moreover, (Udar et al., 2007) mentioned that UWB communication is suitable for short range communications, which can be extended by the use of mesh networks. Although WUSB was designed to satisfy client needs, but it can also be used in a data centre environment. They discussed how WUSB characteristics can match such environment. This application can be of a great help in IFE systems, which strive to massive data communication to support multimedia services and minimizing connection cables. Moreover, (Sohn et al., 2008) discussed the design issues related to WUSB. He stated that WUSB can support up to 480 Mbps, but in real world it does not give the promised values; and they showed the effect of design parameters on device performance.

2.2.2.3 PowerLine Communication (PLC)

A PLC network can be used to convey data signals over cables dedicated to carry electrical power; where PLC modems are used to convert data from the digital signal level to the high power level; and vice versa. Using an existing wiring infrastructure can dramatically reduce costs and effort for setting up a communication network. Moreover, it can decrease the time needed for reconfiguring cabin layout since less cables are going to be relocated. However, such technology suffers from different problems. A power line cable works as an antenna that can produce *Electromagnetic Emissions (EME)*. Thus, a PLC device must be *Electromagnetic Compatible (EMC)* to the surrounding environment. This means that it must not produce intolerable EME, and not to be susceptible to them. To overcome this problem, the transmission power should not be high in order not to disturb other communicating devices (Hrasnica et al., 2004). However, working on a limited power signal makes the system sensitive for external noise. In spite of this, the PLC devices can work without concerns of external interference due to two reasons. Firstly, the PLC network is divided into segments; this minimizes signal attenuation. Secondly, all cabin devices are designed according to strict rules that prevent EME high enough to interfere with the surrounding devices. (Akl et al., 2010) presented a PLC network dedicated for IFE systems to replace part of the wired communication network, where two PLC devices were used; *Power Line Head Box (PLHB) and Power Line Box (PLB)*. PLHB connects the two terminals of the power line to connect data servers with seats. Each PLHB service a group of seats, which are equipped with PLB per seat (see Figure 6).

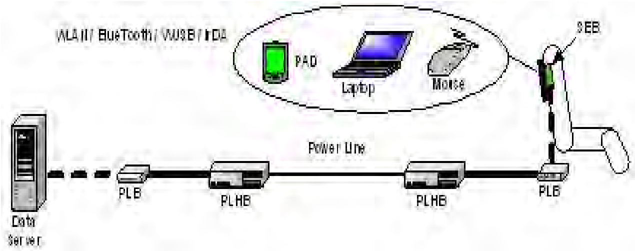


Fig. 6. Heterogeneous network architecture

2.2.2.4 GSM

For several years the aircraft industry has been looking for a technology to provide, at a reasonable cost, an onboard phone service (see Figure 7). Nevertheless, some technical hitches make successful calls via the terrestrial *Global System for Mobile Communications (GSM)* network impossible. The mobiles are unable to make reliable contact with ground-based base stations, so they would transmit with maximum RF power and these RF fields could potentially cause interference with the aircraft communications systems. On the other hand, the high speed of the aircraft causes frequent handover from cell to cell, and in extreme cases could even cause degradation of terrestrial services due to the large amount of control signaling required in managing these handovers. In order to avoid these problems and allow airline passengers to use their own mobile terminals during certain stages of flight, a novel approach called *GSM On-Board (GSMOB)* is used. The GSMOB system consists of a low power base station carried on board the aircraft itself, and an associated unit emitting radio noise in the GSM band, raising the noise floor above the signal level originated by ground base stations. Thus mobiles activated at cruising altitude do not see any terrestrial network signal, but only the aircraft-originated cell. This way, the power level needed is low, which reduces the interference with aircraft systems.

The AeroMobile (AeroMobile, Last visit 2011) is a GSM service provider for the aviation industry that allows passengers to use their mobile phones and devices safely during the flight. Passengers can connect to an AeroMobile pico cell located inside the craft which relays text messages and calls to a satellite link which sends them to the ground network. The AeroMobile system manages all the cellular devices onboard. This system is adopted by Panasonic to be part of its in-flight cellular phone component.

2.2.2.5 Satellite communication

In-cabin communication can be extended by being connected to terrestrial networks through satellite links (see Figure 7). Using satellite channels allow passengers to use their mobile phones, send emails, access internet, and achieve online entertainment services. However, the satellite link is considered as the connection bottleneck, so traffic flow in and out of the cabin must be analyzed (Niebla, 2003). (Radzik et al., 2008) performed a satellite system performance assessment for IFE system and *Air Traffic Control (ATC)*, where the satellite link can be shared between IFE and ATC streams. (Holzbock et al., 2004) presented, in details, two systems that allow in-cabin communication to be connected to assessment networks; the ABATE system (1996-1998), and the WirelessCabin system (2002-2004). Another recent project is the E-CAB project (ECAB, Last visit 2011) which was held by Airbus.

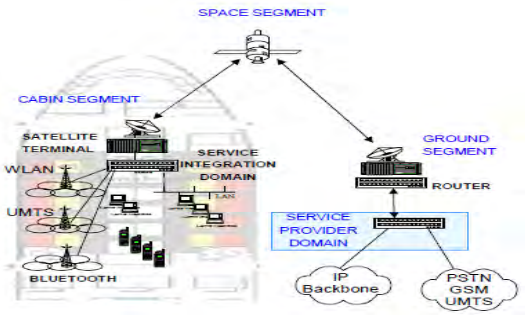


Fig. 7. Satellite link from (Niebla, 2003)

3. Design and evaluation of modern IFE systems

To design an IFE system, different types of requirements need to be defined and constrains must be considered. It is not just adding some entertainment devices, but it is a system which will be located in a very strict environment. This system will have an impact on passengers, airlines, and aircraft design. Therefore, a formal modeling of IFE systems is a paramount need which can be achieved through *System Modeling Language (SysML)*. SysML is a modeling language for representing systems and product architectures, as well as their behavior and functionalities. It is an important tool to have an understanding of a system to prevent complex failure modes leading to costly product recalls. Furthermore, it uses generic language, which is not specific to any engineering discipline, able to present the incremental details of system modeling. Modeling starts by gathering the required functionality until reaching the complex system model. This is achieved by presenting its sub-system structures, and showing their behavior of interacting together as well as with external system. However, we have to stress on the fact that there is no optimum model for any system, but we can have a good model. A good model is the one that fulfills all of system functional and non-functional requirements.

3.1 Proposed IFE model

In this section, we propose a SysML model that takes us through a step by step design process as a systematic design approach to help designers to handle such complex system. The model will show system components, the involved actors, and their interactions with the system. We believe that the model can give the designer an idea on how to adapt his own IFE system to achieve the expected services.

A real IFE system is a large system, where its model can not be fully presented in a book chapter, so we will consider a small case study, and stress on the basic steps and techniques that should be considered during the design process.

Our case study is based on the work done by (Loureiro & Anzaloni, 2011), and our previous work in (Akl et al., 2010) to model the part related to the VoD service and the PLC network. (Loureiro & Anzaloni, 2011) introduced a peer-to-peer networking approach for using VoD for IFE systems and propose two solutions for the problem of content searching in such network. We chose their work because it is a recent research that presents two different techniques to distribute video content over a peer-to-peer network rather than using traditional client-server architecture. The peer-to-peer approach allows passenger IFE units to monitor, store, and serve media contents to each other. This can be achieved by having a *Distribution Table (DT)* containing the video file information (i.e., file ID and IP of storing peer). The work is based on how to build and update the DT. In (Akl et al., 2010), we proposed using a PLC network to replace traditional LAN (see Figure 6). The PLC system consists of a *Power Line Head Box (PLHB)* and a *Power Line Box (PLB)*, where the PLHB connects the two terminals of the power line. Each PLHB service a group of seats which are equipped with PLB per seat. The PLB is responsible for distributing the signal received by the PLHB to the seat attached devices. Each PLHB can support up to 20 PLBs at a rate of 3480 bit/sec each. We will use the model to verify if the technique proposed by (Loureiro & Anzaloni, 2011) can be supported by the PLC network or not.

3.1.1 Use Case diagram

A *Use Case* describes system functionality in terms of how its users (i.e., passengers, crew) use the system to achieve the needed targets. It represents a high level of abstraction to model IFE requirements and interaction with users. Consequently, it typically covers scenarios through which stake holders (i.e., actors) can use the IFE system. Hull et al. (2011) stated that *"A stake holder is an individual, group of people, organization or other entity that has a direct or indirect interest (or stake) in a system"*.

In a Use Case, the system boundaries are identified by a square box to decide what belongs to the system and what does not. For example, a GPS device that provides the IFE system with data used in a map display is considered as a part of an external system (i.e., navigational system).

Figure 8 presents a *Use Case diagram* for our proposed IFE model. There are seven actors; passengers, crew members, a navigational system, a cabin environment, maintenance personnel, airline company, and avionic regulations. The IFE system is enclosed inside the box representing the system boundary. The oval shapes show the interactions of each actor with the system. These interactions are related together through different relations (i.e.,

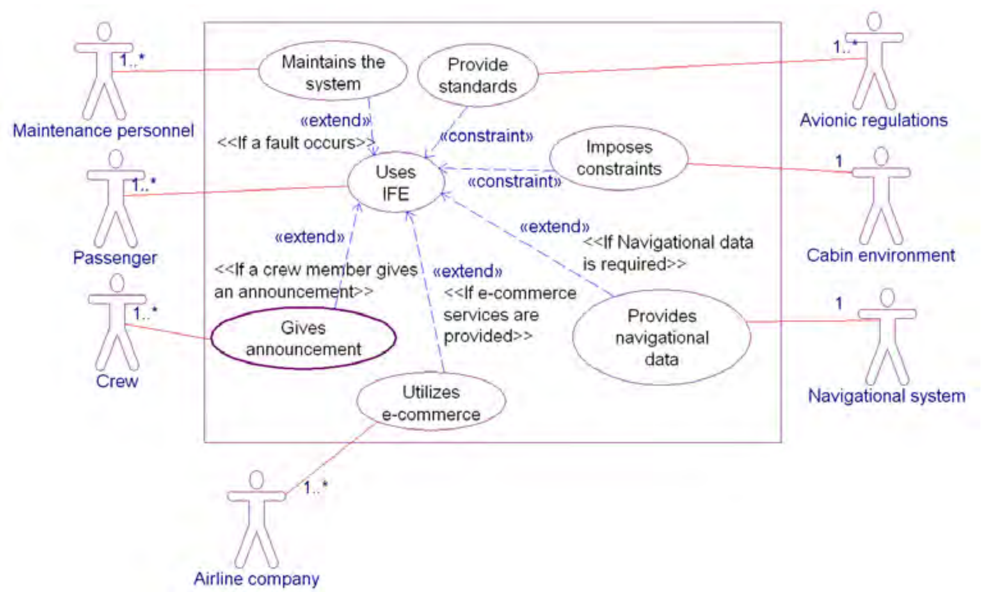


Fig. 8. IFE system Use Case diagram

extended, constrain). *Extend* relationship identify an *extending use case* which is a fragment of functionality that is not considered part of the normal base use case functionality. *Constraint* relationship shows constraints imposed on the system.

The base Use Case is *"Uses IFE system"* which is directly utilized by passengers. It represents the utilization of IFE components (see section 2.2). Its functionality can be extended when a crew member gives an announcement (see section 2.1.1), or the navigational system provides data, or a maintenance personnel performs a maintenance action. Constraints comprise the difficulties imposed by cabin environment, and the standards provided by avionic regulations (i.e., ARINC standard 808, RTCA DO-160E). The next step is to model the requirements needed by stakeholders.

3.1.2 Requirements model

We present a part of the basic requirements related to the entertainment service that can exist in any IFE systems. These requirements are categorized as functional and non-functional requirements. This step helps designers to highlight the basic features of their system.

Defining system requirements seems easy, but in fact, it is not. The defining requirements process is divided into several steps. Firstly, to define stake holders. Second, to start a requirement gathering process, where requirements are collected from stakeholders. Finally, requirements are organized according to well defined rules that guarantee certain requirement characteristics which are essential for requirement analysis. For more information about requirement engineering, we refer readers to (Hull et al., 2011; Young, 2004).

We will assume that the first and second steps are already done, so that our IFE system requirements are already gathered from stakeholders, and we will classify them as functional and non-functional requirements.

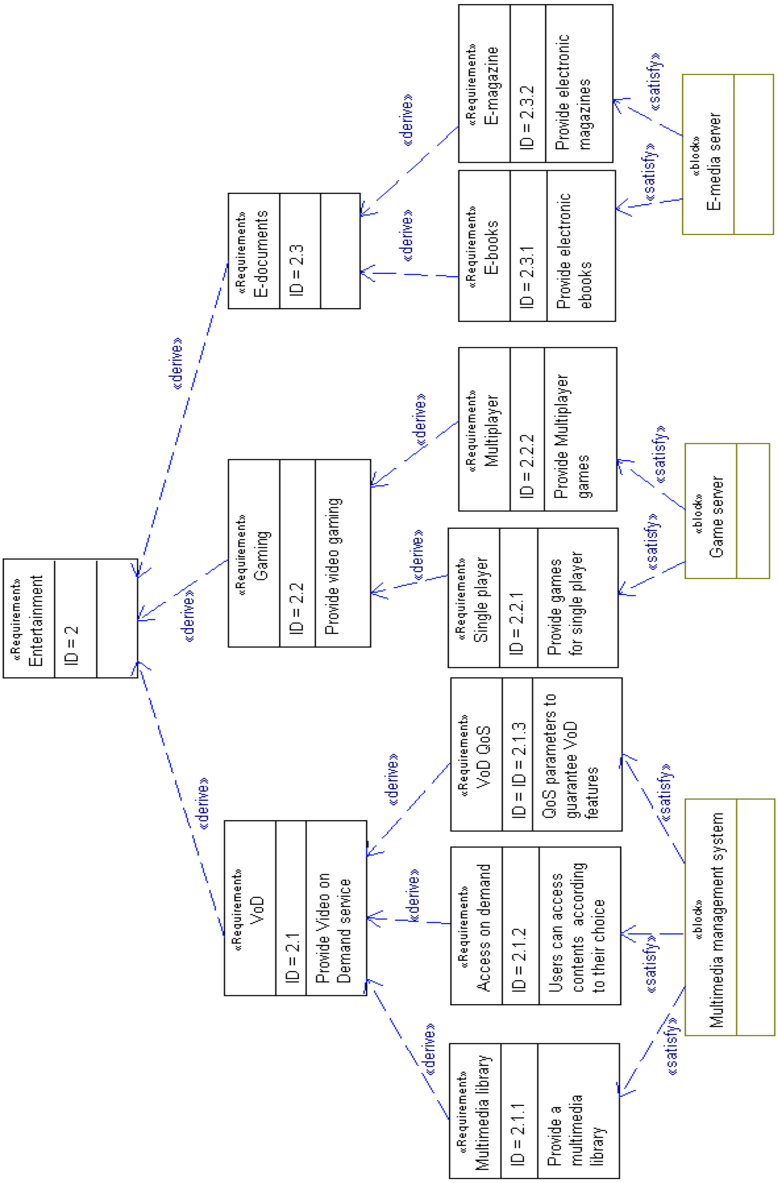


Fig. 9. Requirement diagram of entertainment specifications

3.1.2.1 Functional requirements

Functional requirements describe what the system is supposed to do by defining its behavior (i.e., functions and services). For an IFE system, this includes the different services provided to passengers, and airlines companies (see section 2.1). For each service, there is a dedicated requirement diagram. A group of related requirements are called a specification.

Figure 9 presents the specifications of entertainment service. Each block represents a requirement; showing its name, ID number, and text explaining the purpose of the requirement. The *Derive* relationship shows sub-requirements needed to fulfill the parent requirement. For example, our entertainment service will include VoD, Gaming, and E-documents services. The VoD service will be fulfilled through a *Multimedia Library* to store the VoD contents, and an *Access on Demand* capability. A system component is responsible for satisfying (i.e., represented by the *Satisfy* relationship) these requirements; it is named the *Multimedia Management System*. If necessary, the last level of requirements can decompose into finer levels of derived requirements to show more details of the system. The *Distribution Table* technique (Loureiro & Anzaloni, 2011) will be used to satisfy part of the requirements of VoD service

3.1.2.2 Non-Functional requirements

Non-functional requirements describe constraints and qualities. *Qualities* are properties or characteristics of the system that will affect user's degree of satisfaction. This includes maintainability, reliability, security, and safety issues. Designers usually focus on system functionality and may lately consider the non-functional requirements during the design process. Failing to achieve non-functional requirements may lead to a functional system with undesirable level of satisfaction.

Figure 9 shows QoS parameters as the non-functional requirements needed for the VoD service. (Loureiro & Anzaloni, 2011) identified two main parameters ρ and θ to define the required transmission. ρ and θ represent the amount of information (bytes) that needs to be transmitted across the application layer of the network during system startup, and system normal operation, respectively. They are presented in our model as constraints (explained further in section 3.1.3). ρ and θ are defined as:

$$\rho = nF(c_6 + c_7 L) \tag{1}$$

$$\theta = c_5 n \tag{2}$$

where n is the total number of peers, F is the number of messages sent between two nodes. L is the number of video files stored in the node's local storage, and c_5, c_6, and c_7 are constants. The next step is to model the system components that satisfy these requirements.

3.1.3 Structural model

Block Definition Diagram realizes the structural aspects of the model. It shows which components exist in the system, and the relation between them. It is formalized and reconciled with both behavior model and requirements. Blocks are used to present components; they are connected through relations, and ports to describe the points at which a block interacts with another block.

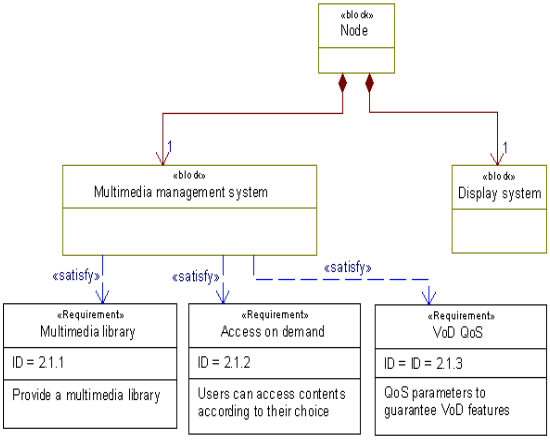


Fig. 10. Block diagram of node structure and satisfied requirements

There are two types of ports: *Flow ports* specify what can flow in and out of blocks (i.e., data or physical items), and *Standard ports* that specify the types of services that a block either require or provide.

Figure 10 shows the main blocks of each node and its relation with the requirements depicted in figure 9. It consists of two main blocks; *Multimedia Management System* and *Display System*. The former manages the multimedia contents, while the later is responsible for displaying multimedia contents and receiving passenger selections. The figure does not show the requirements satisfied by the *Display system* block because we are only interested in the requirements of entertainment service shown in figure 9.

Figure 11 shows the node composition, and its relation with other components (i.e., *Networking System* block). Operations are listed in the *Operations* compartment of the block. However, for readability reasons, we only show the operations of *Multimedia management system* block. *Networking system* is responsible for handling communication between nodes. This is done through the PLHB component that connects different groups of PLBs. The *Multimedia Management System* block consists of three managers; *Content Search Manager*, *Local Storage Manager*, and *Content Selection Manager*. The *Local Storage Manager* handles the local multimedia contents, and defines its location inside the storage device. The *Content Selection Manager* receives the selection request from the *Display System* block, and send back the media content after being received from the *Content Search Manager*. The *Content Search Manager* searches for the requested item in the way mentioned by (Loureiro & Anzaloni, 2011) (the behavior of this technique is modeled in the next section). If the content is not stored locally, a search will be retrieved from neighboring nodes by communicating through the PLB component.

Parametric diagram uses constraint blocks that allow to define and use various system constraints. These constraints represent rules that can constraint system properties, or define rules that the system must conform to. A constraint block consists of constraint name and constraint formula. All variables or constants defined in the formula are linked to the block through an *Attribute* box or through an input from another block.

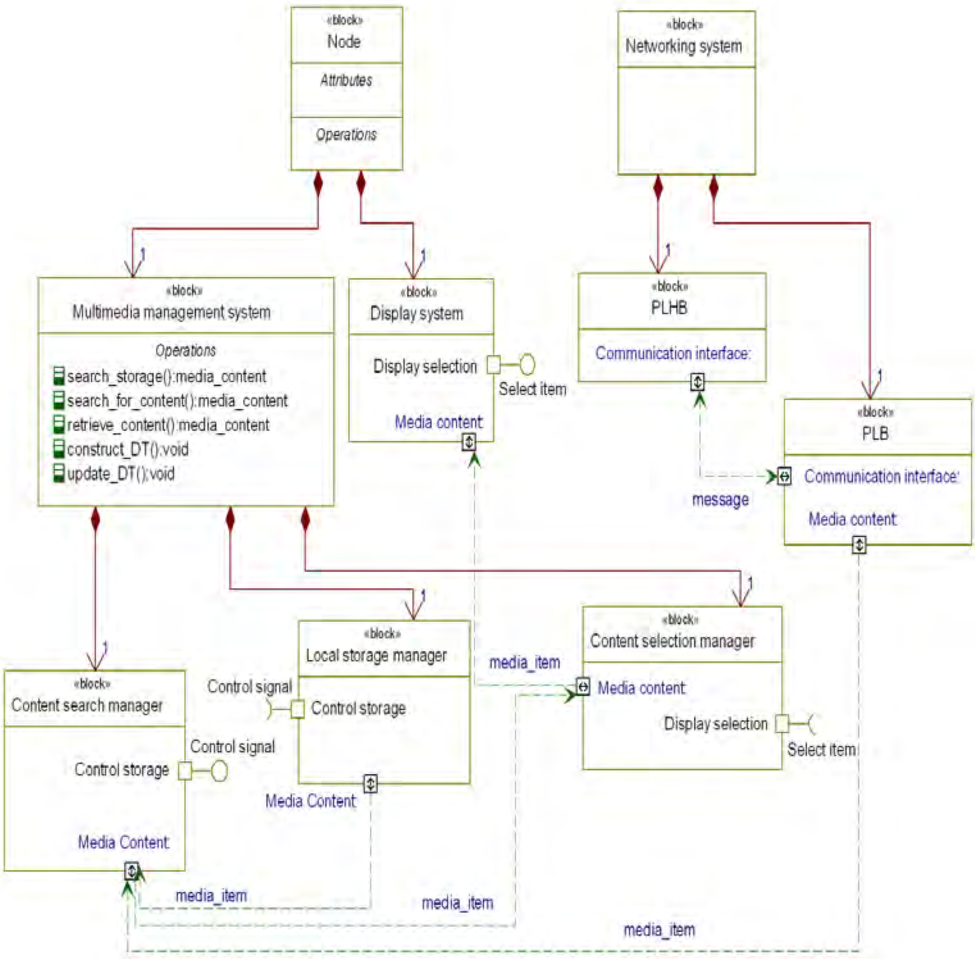


Fig. 11. Block diagram of control signals and flow items

Figure 12 shows three main constraint blocks; *Peer-to-Peer Transmission Rate*, *PLC Parameters*, and *Acceptance Criteria*. The *Peer-to-Peer Transmission rate* defines three formulas (as mentioned in (Loureiro & Anzaloni, 2011)). The PLC parameters define the PLHB maximum bandwidth, as mentioned in (Akl et al., 2010). The output of the two constraints are used to determine the validity of *Criteria 1*. *Criteria 1* is valid when the PLHB maximum bandwidth is greater than the rate of data transmission B. This means that the PLC network is able to handle the traffic generated to update the distribution table. *Criteria 2* defines the time taken to transfer data during startup (i.e., constructing the distribution table); this time should be less than a certain threshold defined as $T_{acceptance}$. Table 2 clarifies the meaning of symbols used in figure 12. The next step is to model the behavior of system components to acquire the expected services.

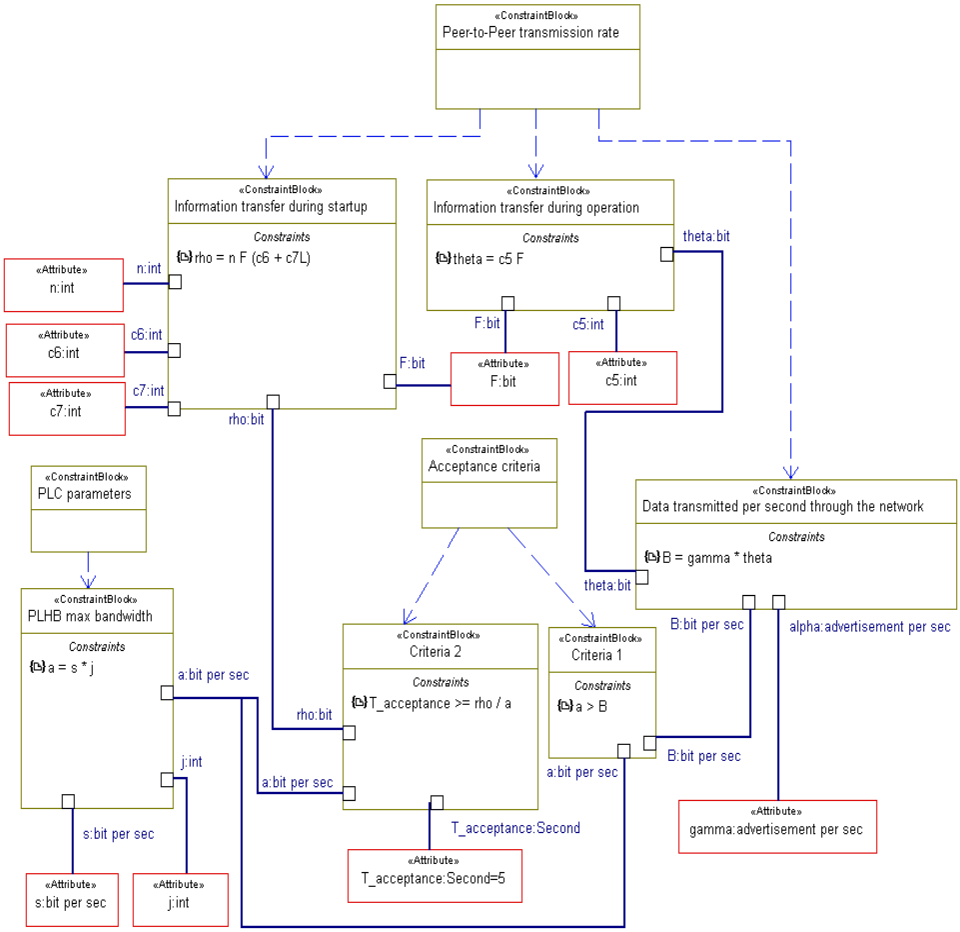


Fig. 12. Parametric diagram for system constraints

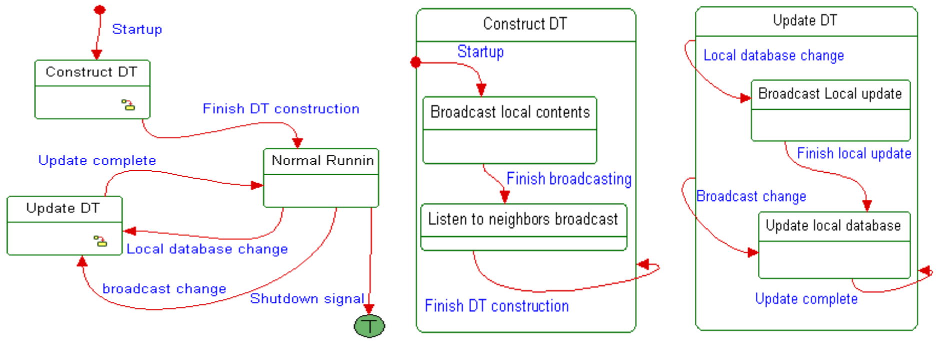
3.1.4 Behavior model

The behavior model is aiming at formalizing system behavior, and reconciling it with other requirements. In SysML, behaviors can be represented in different ways; they can be represented by *Activity diagrams*, *Sequence diagrams*, and *State machine diagrams*. We will show how they can give different views for different parts of the system.

Figure 13(a) shows the state machine representing the states of the decentralized technique. When the system startup, the *Construct DT* state is initiated, and each node starts to broadcast the information of its local video contents. Neighboring nodes receive this information and construct their *Distribution Table (DT)*. The DT contains tuples that consist of a unique video file identifier accompanied with the IP address of the node storing this file. When the construction process completes, the *Normal running* state begins, and nodes start to run normally and exchange video contents. The *Update DT* state is fired in two cases. First, when a node

Symbol	Meaning
rho (ρ)	Total amount of information (bytes) transmitted during construction of DT
n	Total number of peers
F	Messages sent between two nodes
$c_5..c_7$	Constants
theta (θ)	Total amount of information (bytes) transmitted during normal operation when one peer advertise one local database change
B	The amount of data per second transmitted through the network
gamma (γ)	Advertisement per second
L	Number of video files stored in a local storage
a	PLHB maximum bandwidth
s	Maximum bandwidth of a single PLB
j	Number of PLBs
$T_{acceptance}$	Maximum delay needed to complete the transmission of ρ or θ

Table 2. Constraints symbols



(a) First level state machine (b) Second level of "Construct DT" state (c) Second level of "Update DT" state

Fig. 13. State Machine Diagram

has a change in its local video contents, it updates its local DT and broadcasts the change to allow other nodes to update their local DT. Second, when it receives a *broadcast change* from neighboring nodes. When the update process finishes, the *Normal running* state is fired by an *Update complete* signal. The system closes when a shutdown signal is detected. As any SysML diagram, a state can decompose into more detailed levels. This is indicated by a small icon at the right bottom corner of the state. The sub-levels are shown in figuers 13(b) and 13(c) to present a deeper presentation of *Construct DT* and *Update DT* states, respectively.

Each system state has its own *Activity diagram*. It includes the actions needed to fulfill the state, the signals required to initiate the state, and signals to fire a transition to another state.

Figure 14 shows the behavior of state *Update DT*. It is initiated by receiving a signal indicating a change in a local file; then an update of a local database is performed, followed by broadcasting an update signal to neighboring nodes. If a *broadcast change* signal is received, the node checks if it is a new message from a neighbor or it was its own broadcast message. It

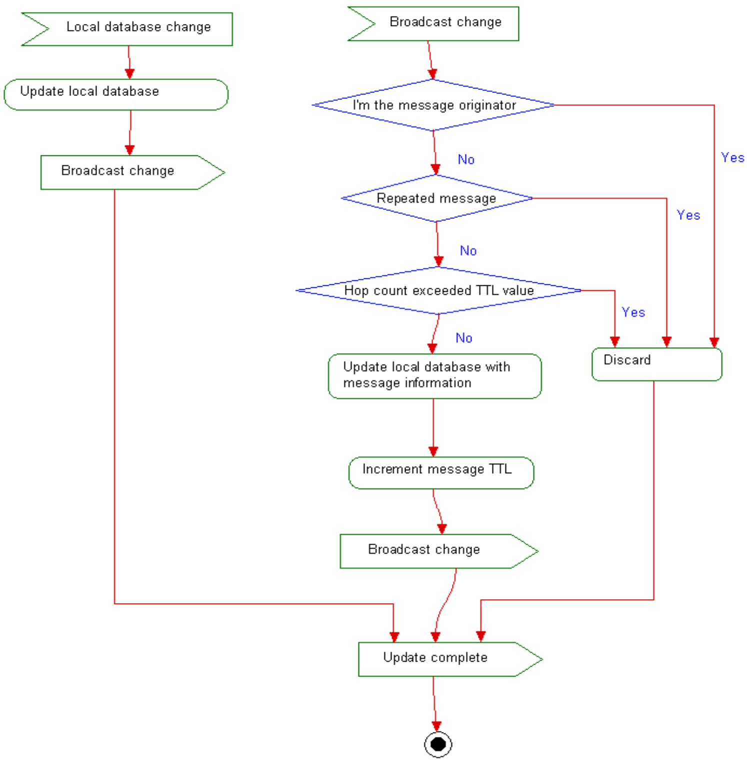


Fig. 14. Activity Diagram

updates its local database, rebroadcast the message, and send an *Update complete* signal to fire a transition to the normal running state.

3.2 System evaluation

We are interested in checking the proposed configuration (i.e., distributed table and PLC network) with the criteria shown in Figure 12 to see if it is feasible or not. According to the values indicated in (Akl et al., 2010) we can calculate the maximum bandwidth supported by each PLHB

$$a = s * j = 3480 * 20 = 69600 bit/sec = 0.06638 Mb/sec = 8.496 KB/sec \tag{3}$$

As shown in (Loureiro & Anzaloni, 2011), when $\gamma = 20 adv/sec$ and $n = 200 peers$, then

$$B = 0.1 Mb/sec \tag{4}$$

This can be interpreted as having 200 passengers, where 20 of them are performing an update to their DT. Since we will compare the value of B with the maximum bandwidth of PLHB, then we are assuming the worst case where all advertisements are initiated at the same PLHB segment.

Furthermore, $\rho = 3371.3KB$ at $n = 200$, so we can deduce its value at $n = 20$, where

$$\rho = (3371.3 * 200)/20 = 337.13KB \tag{5}$$

From 3 and 4, we find that $a < B$, so it does not fulfill the first acceptance criteria in Figure 12.

From 3 and 5, we calculate the time (T) required by the PLHB to transfer the data needed to construct DT is

$$T = \rho/a = 337.13/8.4969 = 39.681sec \tag{6}$$

This is not an accepted value because it must be less than $T_{acceptance}$ (i.e., 5 seconds).

Since both criteria are not fulfilled, then we can say that under this configuration, it is not feasible to use the decentralized technique with this PLC network. The available solutions for this problem are:

- To enhance the performance of the decentralized technique to have a less value for B and T
- To enhance the performance of the PLC network to handle more traffic
- To change the value of $T_{acceptance}$ to allow the system to accept more delay.

To achieve these changes, the designer has to change the behaviour diagrams. He also may change or add or remove some components in the block diagrams. Obviously, $T_{acceptance}$ in parametric diagram needs to be changed if the third solution is considered. If possible, some requirements may be altered to minimize the constraints imposed on the design.

3.3 Discussion

IFE is a large system with various components and parameters, especially in an aircraft environment with strict regulations. SysML provides a solution to model and verify such system. The modeling process starts by defining all parties involved with the system and gathering their requirements; this step helps to have a design that complies with their needs. These requirements are presented in a requirement diagram to show consistency, and relations between requirements and constraints. Moreover, it shows system components that are responsible for satisfying the requirements. System components are modeled using block diagrams. The block diagram shows the relations and connections between different components, define the items flowing between them, and the services they provide or need. The behavior of these components is modeled through different diagrams, where each of them represents a different view of the desired behavior. The behavior diagrams show how components can satisfy needed requirements. During the design of these models, parametric diagrams are considered to model system constraints.

The design process life cycle is not a sequential one; this means that at any step, changes can be done to a previous step. For example, during the behaviour diagram design, changes can be done to block or requirement diagrams. However, changes to requirements must be done after the approval of stakeholders. At the end of the design process, all components and behaviours must fulfill all requirements and constraints.

4. Conclusion

Since the very beginning, IFE systems were targeting passenger comfortableness. This target was the main intention to develop services dedicated to passengers. As time goes, business requirements changes, so IFE systems start to reveal another dimension of services to support crew members and airline companies in order to facilitate crew tasks and increase airline revenue. Recent technological advancements helped designers to offer various designs and services. However, this variations increased system complexity and former design techniques become less efficient.

SysML is offered as indispensable tool for modeling complex systems. It can formalize all parts of the system, so that bug tracking, and future enhancements become more manageable. In this work, we showed the design steps for a part of an IFE system and how it can be modeled. Through SysML capabilities, we were able to integrate two different techniques; the Distribution Table for a peer-to-peer network, and the PLC network. These proposals were done by two independent research teams. However, SysML modeling allowed us to verify if these proposals can be used together in the same system or not, and if not, what are the possible available solutions.

5. Future focus areas for IFE systems

IFE systems are still in their development phase and different topics are still under research. In this section, we propose some ideas to be integrated in future designs. Although IFE system development made a great leap in the past years, but there are still various issues that need further research. These developments range from enhancing current systems to adding new components and services. As technology improves, more advanced devices can be used to enhance current components such as increasing network bandwidth, using more accurate contactless sensors, wireless devices, and lighter components. There is no limit for new services that can be added to IFE systems. Nowadays, a passenger who takes different connections to his destination may not be able to continue his selected IFE content even if he is using the same airline. An attractive service is to allow him to continue unfinished IFE content when changing to the next connection, so he can enjoy the selected service for the whole trip regardless of any flight change. Another service is to create a personal profile through which he can customize his favorite contents before taking the flight, so he does not waste time for selecting items during the flight, and his profile can be used for future travels. For health services, automatic pop-up reminders can be used to stop passengers from being stick to the entertainment content. Using 3D displaying devices can introduce a new sensation to IFE entertainment. Furthermore, hologram images can be used to present safety instructions instead of crew members.

6. References

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