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Developing a Solution for Multimedia Home Networking

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ABSTRACT OF THE
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This paper analysis the solutions to home multimedia network, compare nowadays-popular home networking solutions, especially for the DLNA (Digital Living Network Alliance) standard. By comparing different features and implementations, our team developed a suitable mobile solution for multimedia home networking which takes advantage of both Airplay and DLNA protocols on Android platform. It started with a comparison of popular streaming technologies, Airplay, DLNA, Miracast and Chromecast. By analyzing the features and capabilities of those streaming technologies, we proposed a universal solution for multimedia home networking by supporting multiple protocols.
In the middle of the paper, I tested different multimedia solutions and implement an online channel proxy for our app "Streambels" to stream online channels like YouTube and Spotify and finally get a published Android application for Tuxera Inc. The application is already published in Google Play Store for 3 months, which generate a statistic report of how users use our app, so there is a short description of the user behavior, and how we could improve user experience by analyzing these data.
At the end of the paper there is a discussion on the future of Home network and DLNA.

Keywords: Home network, Multimedia, HTTP Streaming,
UPnP, DLNA, Miracast, Airplay

Preface

This document is my master's thesis of *Communications and Engineering Networking* at Aalto University. All research and development of this thesis was conducted at Tuxera Inc. in Helsinki from January 2013 to June 2014. Tuxera is a high-tech startup that develop kernel-level file system and multimedia solutions for leading software, hardware and electronics companies. Duration this project I worked together with my colleagues at Tuxera, I started to work on DLNA project for the first few months during which period I learned DLNA architecture and made a research about Digital Media Server solutions. After that I worked on an Android project to develop a universal solution for multimedia home networking.

Acknowledgements

First of all, I would like to thank the Streambels team at Tuxera, whom I worked together throughout the project. I would like to thank Karthik Ramakrishna, our lead developer. Every week he helped solving out problems with the project, no matter the question is theoretical or technical, he always answered my questions. As our project manager, Oscar Santolalla helped us with organisational problems we encountered and taught us to look at things from a end-user perspective as well. Sakari Tanskanen, our mobile developer helped us by integrating Chromecast and FireTV support to Stremabels. Nadir Javed, our quality assurance engineer helped us with the quality management and testing of potential bugs before releasing the product to end-users. Karolina Mosiadz, our PR helped to listen to user's ton's of feedback everyday and provide unique insights in improving Streambels. Hien Le, our UX designer helped us to develop a very handy user interface. And special thanks to Mikko Valimaki and Szabolcs Szakacsits who lead the company and gave me the opportunity to participate in this great project. Without them, I would not have been able to finish this report.

I thank my university supervisor Raimo Kantola, who helped me to develop a good thesis topic based on my project and helped me with initial problem description. I got great support from him with his critique and useful advice, especially during the middle and final peroid, when I wrote the report.

Finally, I thank everybody who supported me during my graduation work, especially my family, friends and house-mates.

Otaniemi, 25.5.2014

Peng Liu

Contents

Symbols and abbreviations

Symbols

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Abbreviations

DLNA	Digital Living Network Alliance
DMC	Digital Media Controller
DMS	Digital Media Server
DMR	Digital Media Renderer
HTTP	HyperText Transfer Protocol
RTSP	Real Time Streaming Protocol
DRM	Digital Rights Management

1 Introduction

People's life is digitalized, home multimedia devices like digital TV, smart phone, digital camera, tablet, PC, laptop and NAS (Network Attached Storage) are all equipped with great processing power and mass storage to handle multimedia information which records our daily life. In a typical home scenario, most of these devices are usually connected to a local network like Wi-Fi hot spot, so that allow music, pictures, videos and other content to be ported across different devices.

The problem of connecting all media devices in home networking and make them work together is getting more and more interesting because of the rapid growth of consuming electronic market. Although there are several widely used multimedia-streaming solutions in the market, these standards are not compatible with each other. What's more, and due to different implementation method, even devices using same standard are not always compatible with each other. This caused great inconvenience to end-users.

DLNA, Airplay, Miracast are three major multimedia home network digital living solutions. Airplay is only used between Apple products; it provides various features, including tunes play for music, airplay for video and photos and screen mirroring. Miracast (previously called Wi-Fi display) is proposed by Wi-Fi Alliance, and in recent years it gets more and more popular, from version 4.2.2, Android has officially added support of Miracast. On the other hand, DLNA is most widely deployed solution so far, with 2.2 billion installations. It was proposed by several industrial leading electronic manufacturers and network operators like AT&T, Broadcom, Cisco, Google, Huawei, Intel, LG Electronics, Microsoft, Nokia, Panasonic, Samsung, Sony and Verizon.

These standards are proposed by different device manufactures, due to completing consideration , they are not compatible with each other. It usually happens that end-users have several multimedia-devices that are using different protocols; sharing media between those devices become a headache.

So it is quite interesting to study and compare those multimedia-streaming technologies and develop a more easy-to-use multimedia home networking solution for modern advanced home networking.

2 Background

Home networking has been a hot topic for quite a few years. Thanks to the rapid development of electronics and computer science, home networking devices are getting more affordable and more powerful that people would have at least several multimedia devices that can be connected to network.

Early research in home networking area has been made mainly on how to implement home networking infrastructures, like the cable connection, wireless connection, optical connection etc. So far, it turns out that IEEE 802.11 protocol stack is most successful and most widely deployed home networking infrastructure.

Nowadays, a typical scenario is that a wireless route connected to Ethernet cable or optical cable from network operator, while other devices connect to the same local network created by the wireless router. A wireless AP is using 802.11 b/g/n/ac protocol, utilize 2.4 GHz or 5 GHz frequency channels and provide a 100+ Mbps network connection. This bandwidth is sufficient enough for transmitting High Definition (1080p) videos.

Different device manufactures choose its preferred multimedia-sharing protocols. The development of multimedia-sharing protocols has also experienced a long research period. Since late 1990s, UPnP protocol has been developed for home networking usage. At that time, XML is popular and widely used by different network applications. UPnP is also designed to make full use of XML. UPnP is independent of media and device, and it is running on TCP/IP stack, so it can be easily applied to modern network devices.

In June 2003, Sony established the Digital Living Network Alliance (DLNA), a nonprofit collaborative trade organization. The DLNA standard is based on widely used UPnP protocol but it added some restrictions on media formats and some compatibility requirements. Device hardware and software can be certified by DLNA organization to prove that it should work with other devices that also passed this certification.

In 2010, Apple quitted DLNA and developed its own multimedia home networking solution, called AirPlay. By adding screen mirroring, authentication and RTP music streaming, Apple tried to make a more advanced home network sharing system and create a unique user experience between Apple products. It indeed attracts people's interest, and the user experience of Apple's product is much better than other similar products in the market.

Two years later, Wi-Fi alliance released its Miracast technology, and participated in pushing new standard in wireless home networking. The Miracast uses Wi-Fi direct technology, so that it doesn't require a wireless local network, instead, a peer-to-peer connection is created between the sharing and receiving devices. After its releasing, some major software and hardware companies soon accept the new standard. Google, for example integrated Miracast support into its Android operating system, and provide screen-mirroring feature to other Miracast receivers.

The competition is far from the end, in 2013, Google released a 35-dollar dongle, using its Chromecast protocol, Chromecast makes it possible to watch YouTube and Netflix video directly on TV with such a device. Laptop and mobile devices with

official YouTube App or Chrome browser can control the dongle through the local network in home. The home networking has been pushed to cloud, since YouTube and Netflix content are directly downloaded from Internet, mobile devices just act as a controller of picking interested contents.

Almost at the same time, September 2013, Spotify, a new startup music service company has also taken part in making its own home networking solution, called Spotify Connect, it provides an interface for speakers in home access its huge music database, and directly browse and stream using mobile application. Home networking has been pushed towards cloud and Internet.

Since so many companies would like to develop their own devices and even their own protocols. The market is a bit mess, devices are not compatible with other devices, users have to buy new device to have services from those companies like Netflex and Spotify. There is great need of creating some thing that can connect those devices in home and make them work together.

Streambels project is just created for this need, fill the gap between different protocols and connect devices in home networking environment.

Available solutions in the market(COMPARISON OF MIRACAST, CHROMECAST, DLNA & AIRPLAY)

Market comparison

1. History

   - DLNA is proposed by several leading consumer electronic manufactures based on UPnP technology, from early 2000s on, over 2.2 billion devices has shipped with DLNA solutions, making it possible to sharing audio and video seamlessly different smart devices. DLNA alliance had two annually meetings a year to discuss the marketing and developing related issues, making it a more and more accomplished standard.
   - Airplay, on the other hand, is proposed by Apple Inc. in 2010, before that actually Apple is a part of DLNA alliance, by proposing Airplay, it enables more advanced features than DLNA, such as whole screen mirroring, RTP audio streaming, authentication etc.
   - Miracast is a quite new technology, it is formerly known as Wi-Fi Display, and proposed in 2012 by Wi-Fi alliance. Different from Airplay and DLNA, it is not based on home AP, but using Wi-Fi direct instead. It provides a screen-mirroring feature just like Apple Airplay Mirroring, and now it becomes quite popular among manufactures and software ventures. Google has launched its Android 4.2 with native support of Miracast, the latest Kitkat Android 4.4 has been certified to the Wi-Fi Alliance Wi-Fi Display Specification as Miracast compatible. There is a strong trend that this standard with soon be very popular in multi-screen sharing market.

- Chromecast or Google cast is another new trend in market, Released in 2013, a piece of 2.83-inch (72 mm) dongle hardware is becoming a hot topic recently, with 35$ price, it has been ranked as the most popular device in its category. The standard is proposed by joint effort form Google and Netflix, and as they are Internet companies, the standard is actually based on Cloud, the content is directly streamed from YouTube and Netflix to the Chromecast dongle. And applications running on mobile platforms are just acting as a control point. It also provides features like browser mirroring, with a Chromecast plugin, a Chrome browser can stream its tab to the big screen TV. In a foreseeing future, the standard could become more and more popular.

2. Share on the market, popularity

   - DLNA is one of the first proposed solutions for multimedia home networking, so it is so far the most accepted solution, chart below shows the growth of DLNA-certified device sales. In 2018, the sales will reach 7.32 billion, nearly the totally population of earth.
   - Airplay is bundled with Apple products, with great sales of Apple TV, Airport Express, Mac, iPhone, iPad, iPod, many family has just use Apple's product for everything. Thus Airplay becomes the easiest way to build home networking solution, and maybe the only solution for those Apple users, since a lot of speaker manufactures implement their own Airplay receiver on their Airplay compatible speakers. And indeed it provides enough easy to use features to fulfill daily usage.
   - Since bundled with Android operating system, Miracast has experienced a fast growth in the past two years, many TVs built in the Miracast support to accept peer-to-peer Wi-Fi direct connection.
   - Chromecast dongle is really cheap device that everyone wants to try, it can easily upgrade old TV to "Smart TV", and since Google has provided good content support for it, it is soon accepted by huge amount of users. Except for Google play online sales, it also ranked top 3 best selling devices recently.

Technology feature comparison

1. Meida format support Airplay and Chromecast has very limited media format support since they are only limited device types, so far Chromecast has only 1 device released. Apple TV now has 3rd generation box, but the media format support has not changed so much, the main improvement is the 1080p high resolution video support. On the other hand, DLNA has specified mandatory media formats in its specification, the "must have" formats only include MP3 and LPCM for music, JPEG for images and MP4 for video. Since Miracast is a screen mirroring technology, all formats can be played on device can be streamed.

2. Networking technologies used

   A short technology specification comparison is made to help better understanding the existing solutions, table 1 below shows the main technology used for different popular solutions.

Table 1: Technology used

	Device discovery	Control Protocol	Streaming protocol
DLNA	SSDP	UPnP	HTTP
AirPlay	Multicast DNS	HTTP	HTTP/RTSP
Chromecast	DIAL	Chromecast	HTTP
Miracast	Wi-Fi direct		Wi-Fi direct

Apart from those basic technological details, some standards also offer advanced features compared to other solutions. For example, screen mirroring is an interesting feature that many standards offers. Table 2 below shows what advanced features each standard provides.

Table 2: Advanced feature comparison

	DLNA	AirPlay	Chromecast	Miracast
Screen mirroring	No	Yes	No	Yes
Multiple connection	Yes	No	No	No
Authentication	No	Yes	No	Yes

According to the comparison, each standard have its own features and uses different protocols to communicate. But there are common features supported by most standards, such as HTTP media server is used quite much to handle video and photo streaming. UPnP device discovery protocol SSDP is used quite a lot for device discovery.

Since there is some similarity that is used by most standards, there is possibility to make some application that include all these standard architecture and work with those protocols. Making an Android application to connect those devices becomes a doable work.

Technology specification

UPnP device architecture

The UPnP device architecture [2] includes seven parts below:

1. Addressing
   UPnP devices have a DHCP client and searches for a DHCP server when connected to the network. An UPnP device firstly scans for the DHCP server and then requests an IP address when the DHCP server is found. Otherwise, if there is no response from DHCP server, the device uses automatic IP address. It randomly chooses an address in the 169.254/16 random and tests it using ARP probe to determine if it is already used. The same procedure repeats until an unused address is found. After first IP address is set, it then will periodically check for DHCP server, when a server responds, it will use the assigned addresses and stop using the address generated by Auto-IP after a period of parallel use to complete interactions in progress. If there is DNS server in the network, it can also use domain names instead of the numerical IP address.

2. Discovery
   UPnP devices advertise their services to network using UPnP discover protocol, which is based on Simple Service Discovery Protocol (SSDP). An UPnP control point also searches the existence of UPnP devices in the network using SSDP. The discover message contains a few specific attributes of a device and its services, these attributes include device type, unique identifier and a pointer to more detailed information. The device send multicast several NOTIFY message to a pre defined address and port to advertise its availability. A control point will listen to this standard multicast address of and get notifications when new devices are available in the network. An advertisement message has its lifetime, so devices in the network will periodically send NOTIFY message before the previous message expires. When the device or servers becomes unavailable or shut down intentionally, previous advertisements are canceled by sending cancellation messages, otherwise, the advertisements will eventually expire on its own. Control point can search for devices actively by multicasting an SSDP Search message. Other devices in the network will respond to the search message by unicasting directly to the requesting control point.

3. Description
   The discovery message contains URL to the description information. A control point can send HTTP GET request to the URL to get detailed UPnP description of the device. The description includes a device description and several service descriptions.

   A device description includes vender related information such as model name, serial number and manufacture name. A device may have many services, for each service, the device description lists the service type, name and URL to the detailed service description, control and eventing. A device description may also include embedded devices and a URL to a presentation page.

   A service description includes a list of actions that servers can accept, arguments of each action, and a list of state variables. The state variables reflect

the device's status during runtime.

The description is in XML syntax and is based on standard UPnP device template or service template, which is defined by UPnP forum. The template language is written in XML syntax and is derived from an XML schema language, so it is machine-readable and automated tools can parse check easily.

By using description, vender has the flexibility to extend services, embed other devices and include additional UPnP services, actions or state variables. The control point can be aware of these added features by retrieving device's description.

4. Control
   A control point can ask services in a device to invoke actions by sending control messages. The control process is a form of remote procedure call: a control point sends the action to device's service, and when the action has completed on the remote device, the service returns the results or errors of the action.

   The control messages are expressed in XML using the Simple Object Access Protocol (SOAP) and sent by HTTP request. The action results are also received by HTTP responses. The action may cause state variable change and those changes will be reflected in the eventing messages.

5. Eventing
   UPnP service description defines a list of state variables, which updates at runtime. The service publishes those changed state variables in the form of event messages, and a control point can subscribe to this information.

   A control point can subscribe the event notification by sending a subscription message to the subscription URL specified in the device description and provides a URL to receive the event messages.

   Since there is no mechanism to subscribe to a subset of evented state variables, all subscribed control points will receive all event messages regardless of why the state variable changed.

   When the subscription is accepted, the device gives a unique identifier for the subscription and the duration of the subscription. The device will also send an initialize event message, which includes the names and current values for all evented variables.

   The event messages are GENA NOTIFY messages, sent using HTTP with a XML body, which specifies the names of one or more state variables and new values of those variables. Once the state variable changed, the event message is sent immediately sent to control point, thus the control point can get timely information and could display a responsive user interface. The control point then send HTTP OK message to acknowledge device that the event message is received. The event message also contains a sequence number that allows the detection of possible lost or disordered messages.

The subscription must be renewed periodically to extend lifetime and keep it active. The renew message which contains the subscription identifier is sent to the same URL in the subscription message. When the subscription expires, the device will stop sending eventing message to the control point, and any attempt to renew the expired subscription is rejected.

A subscription can be canceled by sending an appropriate message to the subscription URL.

6. Presentation
   Many UPnP devices provide a presentation URL to "web" interface for users. User can access the presentation URL by a standard web browser. Control point send an HTTP GET request to the presentation URL to get a HTML page from the device, and display the page in a web browser, thus provide a more user-friendly interface for control and view the status of device.

   The presentation page is totally specified by the device vender, but it must be an HTML page. UPnP architecture does not define the details of presentation page, but it should be user friendly and have some basic functionality.

DLNA architecture

DLNA is a pretty old standard in industry compared to other home networking solutions, so it is widely used by many manufactures, the newer home networking solution is also influenced by DLNA and followed similar technologies. In this paper we focus on the DLNA standard architecture so we can have an overview of how a home networking solution will look like.

Three basic functional entities are defined in the UPnP AV architecture: Media Server, Media Renderer and Control Point. A physical device can consist of a combination of any of these functional entities. A typical example is DLNA Media player is a combination of a Control Point and a Media renderer.

A simplified DLNA application use scenario[1] can be seen as below:

The first thing in UPnP network communication is Simple Service Discovery Protocol(SSDP)-based device discovery. A SSDP multicast message is send when a new device is added in the network. A control point will listen to these multicast messages. When the control point receives the SSDP message, the control point sends request for the device's description and services using the location provided in the SSDP discovery message. Later the control point can invoke the services action command using SOAP.

In media sharing scenario, the control point will browse the information about the Content Directory Service (CDS) provided by the Media Server. A browse/Search action can be invoked to navigate through the content stored in the Media Server device. When selected the media content from Media Server, a Media Renderer AVTransport::SetAVTransportURI will be sent by control point to Media Renderer. Finally, the Play command is invoked by control point to Media Renderer, and the transfer begin afterwards. The media streaming happens directly between Media Server and Media Renderer using HTTP.

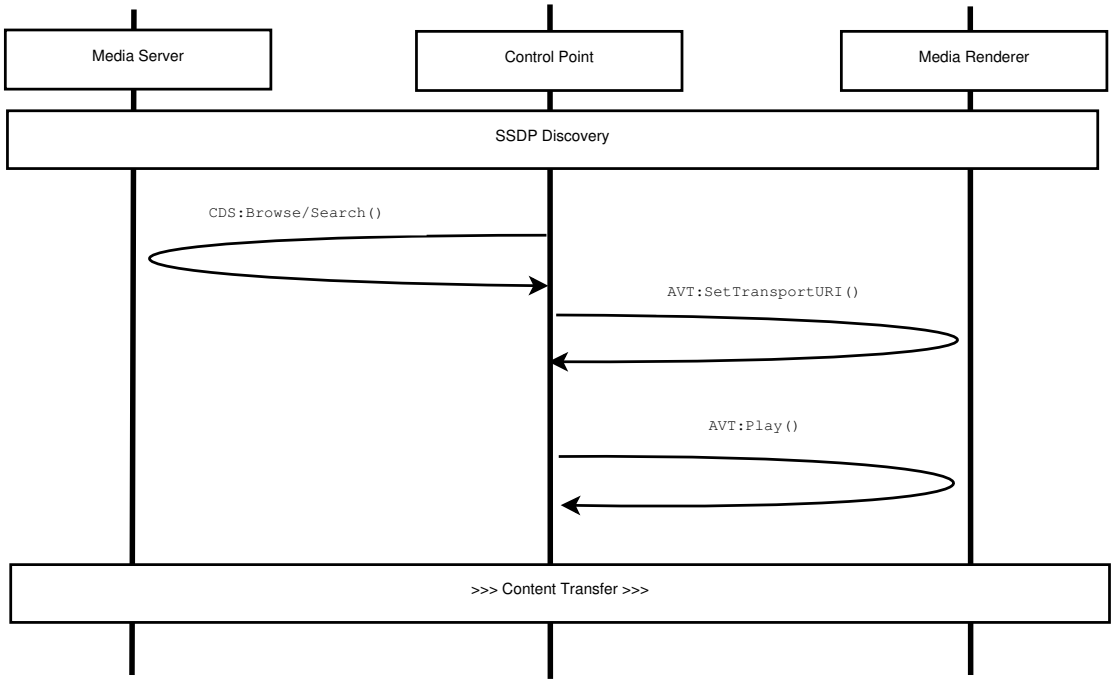

Figure 1: DLNA use scenario

An overall DLNA architecture can be described below:

1. Architectures and Protocols

Table 3: Key Technology Ingredients

Functional Components	Technology Ingredients
Connectivity	Ethernet, 802.11 (including Wi-Fi Direct) MoCA, HPNA and Bluetooth
Networking	IPv4 Suite
Device Discovery and Control	UPnP* Device Architecture v1.0
Media Management and Control	UPnP AV and UPnP Printer:1
Media Formats	Required and Optional Format Profiles
Media Transport	Media Transport
Remote User Interfaces	CEA-2014-A

The DLNA architecture is built on UPnP protocol, which is discussed in already2. In networking layer it uses IPv4 suite, on top on that, UPnP device architecture and UPnP AV architecture is used to control and manage media devices. DLNA guideline also addresses the media format compatibility and media transport interoperability issues to make devices interoperable with each other.

2. Media Format Profiles
   DLNA organization defines the media formats used by DLNA home networking standard. There are three types of media in DLNA standard.

   (a) Music
   Minimal requirement is LPCM format, which is PCM raw data, this format is not compressed so it does not require heavy CPU usage, but on the other hand, the bandwidth consumption is considerably bigger than other formats.

   MP3 is most popular music format in music category, it is compressed format, so it will require some CPU power to encoding or decoding, but on the other hand, the bandwidth consumption is less and suitable for low bandwidth networking.

   AAC is kind another kind of compressed audio format and it becomes popular since it is Apple's iTunes's default media format. It has similar characteristics to MP3.

   (b) Photo
   The minimal requirement in DLNA guideline is JPEG format, and sometimes the only suggested format, since its proven quality and compress ratio.

   (c) Video
   The minimal requirement in DLNA guideline is MP4 format, but the detailed audio and video codecs are also specified in DLNA media format guidelines.

   In a device-to-device usage scenario, the media server may store tons of different formatted media. The communication between two devices should follow the same encoding mechanism. Normally the media server takes the responsibility to transcode the media to certain format defined by DLNA media format profile guideline.

3. Link Protection
   DLNA Link Protection is defined as the protection of a content stream between two devices on a DLNA network from illegitimate observation or interception.

   Content protection is an important mechanism for ensuring that commercial content is protected from piracy and illegitimate redistribution. Link Protection is a technique that enables distribution of protected commercial content on a home network, thus resulting in greater consumer flexibility while still preserving the rights of copyright holders and content providers.

4. DRM Interoperability Solutions (DIS)
   DIS is intended to be used to enable the secure transfer and use of protected commercial content among different implementations on network media devices. The content could be protected by different content protection technologies, which are described as DRMs in short.

5. Device Profiles
   A Device Profile is a collection of DLNA capabilities and features within a DLNA device. For a device to be compliant with a Device Profile, it has to conform to all of the guidelines listed for that Device Profile.

   In practice, Device Profiles reference existing optional or recommended DLNA guidelines, that enable certain features, and makes those DLNA guidelines mandatory within the context of a Device Profile. A Device Profile can also provide some additional guidelines that complement or modify existing DLNA guidelines for a feature.

   A particular type of DLNA Device Profile is the Commercial Video Profile (CVP). A CVP Device Profile is an extension of the DLNA guidelines that will allow content from service providers and multichannel video programming distributers to be distributed on the DLNA network. DLNA Commercial Video Profiles (CVPs) are defined as Device Profiles that consistently enable commercial content that enters the home network through a gateway device via an interface to a commercial content service provider. Since different regions of the world have different requirements for commercial content, there are multiple CVPs defined.

Other protocols

Airplay has its own specification, and it is not open to public, but on Internet there are hackers make unofficial specification. The Service discovery is based on multicast DNS, the discovered device include receiver's IP address and port number

1. Video streaming
   The video streaming uses typical HTTP streaming technology, the controller set the streaming URL to Apple TV or other airplay receiver. While the URL is set, Apple TV start to download video from the server using the URL and starts playing while buffered enough data.

2. Photo streaming
   The image streaming uses HTTP put message to send image raw data to Apple TV or other devices, when the whole image is received, the image is then rendered on screen.

3. Music streaming
   Airplay music streaming is a bit different from video and image streaming, the technology used is RTSP streaming, it is more "push like" protocol, the RTSP streaming server push UDP packets to receiver. However the RTSP protocol Apple used is not standard RTSP, it uses its own implementation.

Chromecast and Fire TV on the other hand uses DIAL protocol for device discovery, the protocol is proposed by Google and Netflix so the YouTube and Netflix application has already build in with DIAL device discovery. The streaming part uses

HTTP streaming, which means controller can directly set the streaming URL and the receiver will start downloading automatically.

Miracast is quit different on technology perspective, instead of connecting on the same local network, a Wi-Fi peer to peer connection is created, so Miracast is not limited to pre configured network infrastructure.

Test footnote [1]

[1] test footnote ei more text.

3 Developing a solution for multimedia home networking

We developed an Android application that has integrated with a simple media server, Airplay/DLNA/Chromecast device discovery, and Airplay/DLNA/Chromecast streaming control point.

A simplified version of our implementation is shown in the figure 2 below:

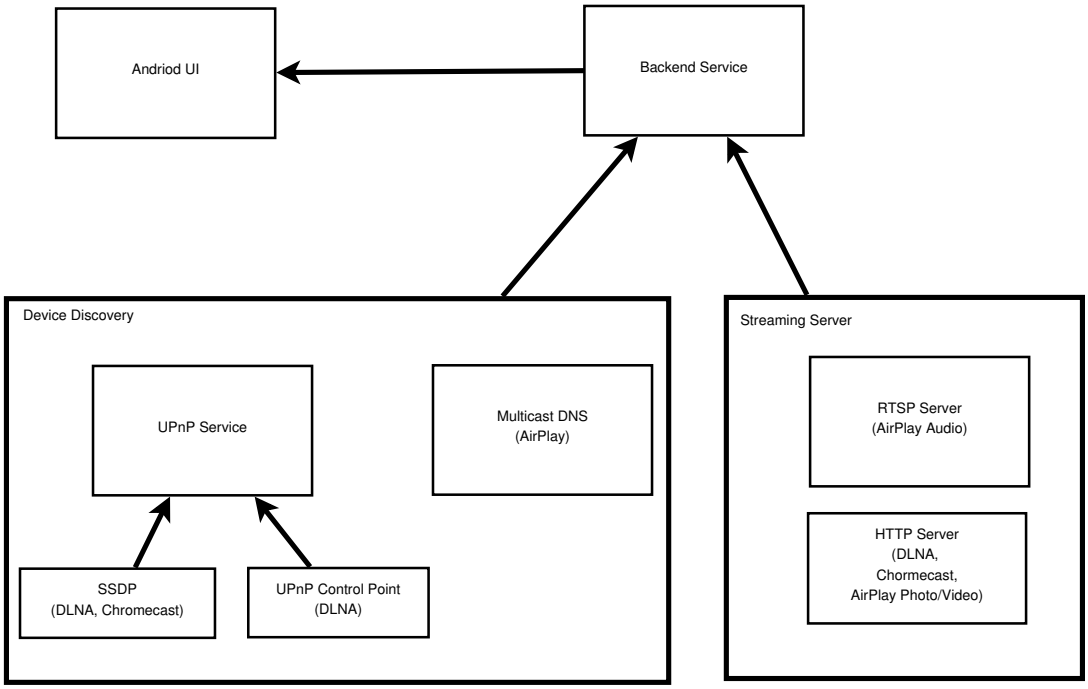

Figure 2: Simplified flow chart

As we know that Airplay and DLNA works differently and have different features, but according to the previous study, we could combine some use cases of both protocols. We are developing an Android application that can handle most multimedia devices in a typical home networking. Feature list:

- Firstly the app is a multimedia player, it can play music, photos and videos on SD card locally on Android phone
- It can stream local content to Apple TV, Airport express and Airplay-enabled speakers.
- It can stream local content to DLNA media renderers, which has a huge device base.
- It can stream local content to Chromecast devices.
- It can browse content from the DLNA media servers, a typical source is a Network Attached Storage (NAS). And play the media locally on the Android device.

– It can browse content from the DLNA media servers and stream it to DLNA media renderers.

– It can browse content from DLNA media servers and stream it to Airplay enabled devices using a different protocol.

– It can proxy online channels' content to DLNA and Airplay enabled devices. (Currently YouTube and Facebook videos are supported, but integration to Spotify is still in progress).

4 Results

- Totally more than 290000 downloads
- Used by people from 201 countries
- 8000+ daily active users
- 1,241,074 visits to home page
- Average rating 3.9, 3521 user gave rates
- Online for 3 months

User study

- What information we can get back from users
- User behavior/ statistics
- Improve the application accordingly
- Strategies for decision making

Write result here.

5 Discussion

Write discussion here. Development of a universal streaming SDK is essential for different manufacturers and on-line content providers.

[3] [4] [5] [6] [2] [7] [1] [8]

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A Appendicy

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$$d \wedge F = 0. \tag{A2}$$

B Appendicy

Figure B1: Title

Table B1: table title

11	12
21	22

$$T_{ik} = -pg_{ik} + wu_iu_k + \tau_{ik}, \tag{B1}$$

$$n_i = nu_i + v_i. \tag{B2}$$