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IPTV: Delivering TV Services over IP Networks

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1.1 Overview

When we watch television, it is not possible to ignore the vast change that television service has undergone over time. In fact, television services have been experiencing several developments since the invention of the television. The first analogue colour television broadcast was started in 1951 via terrestrial broadcast with only a single channel (Fink, 1951; Baker, 1984). Then, another television service was delivered via cable (Dees et al., 2007). After that, digital TV emerged with the benefits of digital signal transmission and digital compression techniques. These benefits let TV service providers broadcast a variety of channels with high quality within a limited bandwidth (Joshi and Maskara, 2012; Picard and Siciliani, 2013). Furthermore, digital TV bridged the gap between the TV industry and computing industry as a result of the digital transmission of signals. More recently, Internet TV, also called online TV, has been delivering TV services over the public Internet without any commitment on the part of Internet service providers. The user must surf the website of the TV service provider and enjoy watching live and on-demand TV content (Simpson, 2013). YouTube is the dominant Internet TV provider, with 85% of the Internet TV consumption in the USA (Lee et al., 2013).

With the prosperous evolution of digital video formats and broadcasting as well as the advent of high-speed broadband networks, a new era of TV system has emerged known as IPTV, which can be defined as 'multimedia services such as television, video, audio, text, graphics and data delivered over IP-based networks that provide the required

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level of quality of service (QoS)/quality of experience (QoE), security, interactivity and reliability (International Telecommunication Union [ITU-T], 2006). In other words, IPTV is a television system that delivers its content to subscribers over a broadband network. The broadband network can be described as a communication network over which all the voice, data, video and text services are delivered to end-users instead of isolated delivery networks (Moore and Siller Jr, 2004). As high-speed broadband networks exploit the digital representation of content, IPTV offers a wide variety of channels with high quality and interactivity compared with other TV systems. In addition, IPTV gives a simultaneous transmission of auxiliary data (e.g., subtitles, electronic programme guide [EPG]).

IPTV has recently become a popular trend in delivering TV services due to the increasing number of broadband network users. Globally, many companies work as service providers offering IPTV services. In 2009, there were almost 600 commercial IPTV operators worldwide (Nordström, 2009). According to Multimedia Research Group Inc. (MRG, 2012), this number was more than 930 operators worldwide. In Malaysia, only two competitive IPTV service providers have been operating. HyppTV is an IPTV service provided by Telekom Malaysia (TM). TM launched its IPTV services in 2004 after migrating the service delivery to Malaysia's High-Speed Broadband (HSBB) network. The second IPTV service provider in Malaysia is Astro Byond launched in 2011 and has been transmitting through fibre-optic broadband. Astro Byond operates in partnership with Time Dotcom Berhad and Maxis.

1.2 Internet Protocol Television

Due to the expeditious improvement of IP networks, along with the significant growth of users' bandwidth, IPTV has become popular worldwide as a promising way of delivering TV-related services including live broadcasting, video on demand (VoD) and other continuous streaming services to end-users. The number of IPTV subscribers globally grew from 2.03 million in 2005 to 4.56 million in 2006 and reached 60 million in 2011. According to SNL Kagan, the number of IPTV subscribers reached 117.39 million by the end of 2014, and it is expected to reach 165 million by the end of 2017. According to Jacqui (2007), IPTV subscribers occupy currently more than a third of the TV-viewing market. In 2017, IPTV is considered one of the most recent technological advancements made by humans. Moreover, IPTV is widely recognised as a proven and popular way of providing TV-related services including live broadcasting, VoD and other continuous streaming services over IP-based networks alongside the Internet, telephony, gaming and other home-networking services. According to an ITU-T focus group (ITU-T, 2006), IPTV can be defined as 'multimedia services such as television/video/audio/text/graphics/data delivered over IP-based networks that manage to provide the required level of QoS/QoE, security, interactivity and reliability'.

The major advantages of IPTV are addressability and interactivity (GlobeComm, 2006). In a fast-paced world, subscribers love to watch what they want when they want to, instead of scheduled channel broadcasting. IPTV grants this facility to subscribers by allowing them to choose only the channel they want to watch. Unlike most of the legacies of TV systems, IPTV takes advantage of the two-way communication in IP-based networks to let end-users enjoy the unlimited interactivity feature. By means of the interactivity feature, users can subscribe/unsubscribe to any channel or programme anytime without any intervention from the service provider. Besides, IPTV offers a wide variety of high-definition channels, along with the streaming media on demand (VoD) and the simultaneous transmission of auxiliary data (e.g., subtitles, EPG) as well. Consequently, IPTV has recently become a popular trend in delivering TV services. Globally, there are many companies offering IPTV services to end-users. Likewise, telecommunication companies (network providers) have entered a hectic competition to increase their customer base and profit by delivering IPTV services (Fati et al., 2014). In 2012, there were almost 900 commercial IPTV operators worldwide (Nordström, 2014). According to MRG (2014), this number was more than 1000 operators worldwide.

Amidst such hectic competition, the key concern of service providers is to provide high-quality services at lower costs. Thus, the challenge facing service providers is to build content delivery networks that use resources efficiently and diminish costs. However, designing such delivery networks is not an easy process. This is because IPTV content is huge in size and have an unsteady watching pattern. Therefore, the delivery network design process is required to pay more attention to content characteristics, user behaviour and resource utilisation. Hence, the target in this chapter is to explore the challenges that hinder IPTV delivery networks and the current research directions that are looking at resolving these challenges in light of content characteristics. Section 1.3 presents a brief historical overview on how the TV industry has been evolving over time to let IPTV become the most recent and dominant TV technology.

1.3 Evolution of TV to IPTV

Television services have experienced several developments since the invention of television. In the 1930s, TV broadcasting started with a linear schedule. Such TV services were disseminated over ether to roof antennas. Broadcasting was national with central control of scheduling (Takayanagi, 2003). According to Dees et al. (2007), the first analogue colour television broadcast was started in the 1950s via ether (terrestrial broadcast), and later via cable. Terrestrial and/or cable broadcast are/is still the primary means of delivering broadcast services, and have a considerable market share in many countries (EBU, 2011).

With the advent of digital video formats and digital broadcasting, a new era of television has begun via cable, terrestrial or satellite broadcasting. Digital television, proposed in the 1990s, has some advantages over the analogue one (Valentin, 2004). For instance, digital television can provide more channels with better picture and sound quality. Moreover, digital broadcasting induces the possibility of simultaneous transmission of auxiliary data (e.g., subtitles, EPG).

Due to the vast growth of broadband networks, the current trend is to turn into an 'All-over-IP' concept, wherein most service platforms will be unified into a single IP-based platform (Sabella, 2007). For instance, the existing IP-based networks deploy many services apart from high-speed Internet surfing. These services include IP-telephony (voice over IP), IP-surveillance, IP home appliance and IPTV. In the 2000s, the first IPTV service started broadcasting commercially over IP-based networks (Davies and Delany, 2005; OECD, 2007).

Inasmuch as high-speed broadband networks utilise the digital representation of content, IPTV offers a wide variety of channels with high quality and interactivity as compared with other TV systems. In addition, IPTV gives a simultaneous transmission of auxiliary data (e.g., subtitles, EPG) along with many enjoyable services.

Insofar as both IPTV and Internet TV use IP-based networks as a platform, it is worth mentioning that IPTV is completely different from Internet TV. In Internet TV, the user must connect to the Internet and then access the entertainment website (e.g., YouTube.com) to watch or download video streams without any telecom operator's responsibility. In contrast, IPTV delivers the video streams to a set-top box (STB), connected to a TV set, via IP-based networks under the full responsibility of a telecom operator. In the case of IPTV, the telecom operator is responsible for network, service continuity, QoS, content, right management and user experience. In that sense, users should subscribe to watch live and on-demand media services in a manner similar to that of current cable/satellite TV systems (Karantanis, 2009).

1.3.1 IPTV Services

IPTV providers mainly provide two streaming services: live channels and VoD. The live channels are broadcast to all subscribers using the multicast streaming technique. The user joins the multicast tree of a particular channel when he or she switches to this channel. In contrast, a dedicated connection is established between the user and streaming server for a unicast stream. Another direction in multimedia broadcasting is P2P broadcasting, which is utilised to alleviate the load on the servers by sharing the multimedia between the different set-top boxes directly. The different multimedia broadcasting techniques are not discussed in this chapter.

In addition to live and on-demand streaming services, IPTV also supports a variety of information and control functions, such as user notifications and content guide (CG). Open IPTV Forum (2009a) summarises the services that are provided by IPTV as follows:

- *Scheduled/linear TV services*: Live TV and/or audio channels are broadcast according to a predefined schedule. End-users can enjoy watching these live services and/or recording them. For privacy and security purposes, these services can be protected using appropriate encryption techniques.
- *Content on demand (CoD)/video on demand (VoD) services*: This category of services allows users to watch on-demand content (videos). In other words, end-users can select an individual video from a list of available videos. Once the end-user issues a request, he/she can watch or download the requested content.

- *Personal video recorder (PVR)*: This service enables users to record scheduled TV programmes using local-based storage (PVR) or network-based storage (nPVR). End-users can play the recorded content according to their convenience.
- *Notification* service: This service allows end-users to be informed of scheduled TV programmes (i.e., the starting time of a scheduled programme), emergency alerts or pre-configured reminders.
- *Communication service*: This service allows users a caller ID or short message services (SMS) on screen, and also to chat with others while enjoying IPTV services.
- *Information service*: This service provides end-users information on their subscription, management or the available content. This information may be delivered to either all or specific users.
- *Advertisement* service: This service enables advertisements to be delivered to end-users. These advertisements can be customised based on the locations and preferences of end-users.

In addition, the European Telecommunications Standards Institute (ETSI) reports a diverse collection of IPTV services including personal channels, user profiling and personalisation, service discovery, communications and messaging, notifications, interaction between users, targeted advertising, user-generated content and content recommendation (for further details, the reader can refer to ETSI TS 183063).

1.3.2 IPTV Standardisation

To make IPTV a popular and a standard platform worldwide, standardisations are conducted. IPTV standardisation aims to achieve the following purposes: interoperability, investment confidence and cost reduction (Fleury, 2006). For instance, end-users will often want to access diverse content belonging to different service providers stored in a heterogeneous network. To let such heterogeneous IPTV components interoperate smoothly, IPTV standardisation is required. Many organisations are involved in the process of standardisation of IPTV services (Gaber and Sumari, 2012; Gaber, Sumari and Budiarto, 2012). These organisations include Digital Video Broadcasting Project (DVB), International Telecommunication Union (ITU-T), European Telecommunications Standards Institute (ETSI), 3rd Generation Partnership Project (3GPP), Open Mobile Alliance (OMA), Internet

Engineering Task Force (IETF), Alliance for Telecommunications Industry Solutions (ATIS), Cable Television Laboratories, Inc. (Packet Cable), Open IPTV Forum and Home Gateway Initiative (HGI).

1.3.3 General Architecture of IPTV

The general IPTV architecture explains the different shareholders of IPTV and the relationships among them (Mikoczy and Podhradský, 2009; Open IPTV Forum, 2009b; Lee et al., 2009). Figure 1.1 depicts the IPTV architecture and the involved domains.

- *Content provider domain:* This domain, similar to film production companies, collects content from different resources (or even produces content) and encodes them to a predefined media coding. Content providers own the intellectual property rights for contents belonging to them, and have the right to sell them to others (e.g., service providers) through appropriate rights management and protection mechanisms.
- *Service provider domain:* This domain purchases content from different content providers, packages them as services and then distributes those services to end-users via the delivery network. Delivery networks are responsible for retrieving, protecting,

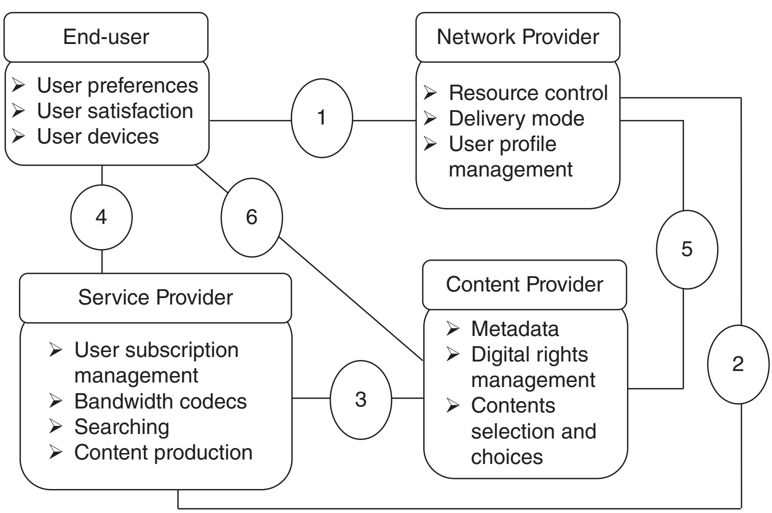

Figure 1.1 IPTV domains (Lee et al., 2009).

storing, distributing and delivering contents to the end-user domain through the network provider domain.

- *Network provider domain:* In this domain, end-users and service providers are connected via a shared underlying platform to interact with each other. This platform consists of a variety of backbone and access networks according to the running network technologies. User authentication, charging and billing mechanisms should be provided to service providers.
- *End-user domain:* This domain consists of related service terminals that allow the end-user to benefit from IPTV services. These terminals are connected to the network provider domain and receive IPTV services from the service provider upon subscription.

According to Lee et al. (2009), a number of reference points (RPs) should be defined among the IPTV domains. Such RPs, denoted by numbers in ovals in Figure 1.1, should control the relations among those domains. For instance, RPs 1, 4 and 6 show how the end-user interacts with the network provider, service provider and content provider, respectively. Similarly, the interactions of the network provider with both the service provider and content provider are represented by RPs 2 and 5, respectively; whereas RP 3 depicts the relationship between the service provider and content provider.

With reference to Figure 1.1, the need for a unified platform that collaborates content providers, service providers, network providers and end-users is highly recommended to guarantee the integrity and consistency between different shareholders. This unified platform is called an 'IPTV delivery network'.

1.4 IPTV Delivery Network

The advent of IPTV has opened new avenues for content providers, service providers and network providers. Service providers benefit by distributing their content, which is produced by content providers, to end-users. The network providers profit by delivering the content over their network from the service provider to end-users (Lee et al., 2010). Service providers have two distribution options to deliver IPTV services to end-customers. The first option involves building their own private delivery network infrastructure, which is expensive and requires extra effort for standardisation. The second option involves delivering their services using shared infrastructure. Shared delivery networks are substrate networks where surrogate servers that act transparently on behalf of the origin server are placed across the network closer to the end-user for performance improvement. Contents from different service providers can be replicated from the origin server to surrogate servers (Xu, 2009). A famous example of shared delivery networks is the content distribution network (CDN).

1.5 Evolution of the Delivery Network

In their early days, video streaming services were provided by massive central data centres, as depicted in Figure 1.2a. Once the number of incoming requests increases, this architecture suffers from the design flaw known as 'single point of failure' (SPoF) (Cho et al., 2008; Meng, Liu and Yin, 2010). In addition to SPoF, the other main shortcomings of this architecture are prolonged delay and network congestion (Golubchik et al., 2001; Mir, 2011; Nair and Jayarekha, 2010). A scalable model called 'server cluster' or 'server farm' is built by arranging multiple servers together such that the burden/load can be distributed among them. This model is also augmented by a request dispatcher (e.g., layer-4 or layer-7 dispatchers). This dispatcher examines the

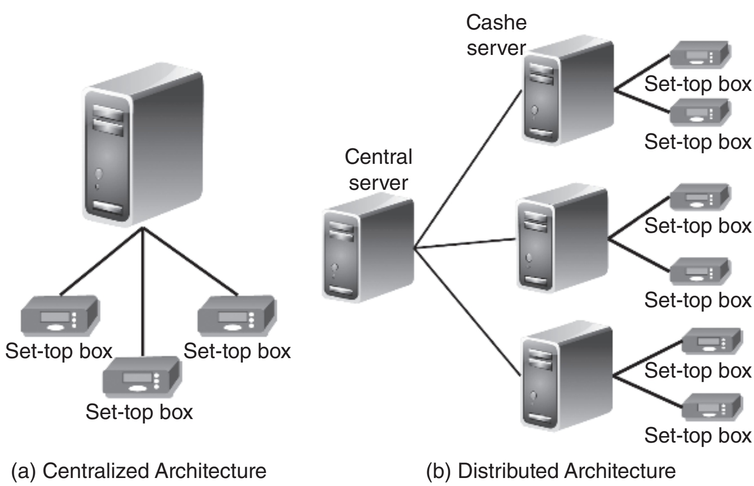

Figure 1.2 Central and distributed delivery network architecture.

requests and then distributes them among the cluster (Pathan and Buyya, 2007). To alleviate the problems of prolonged delay and network congestion at the central server or server cluster, content can be cached in different local servers, as depicted in Figure 1.2b, to place the content as close as physically possible to the end-users. Although cache proxies are allocated to different areas in the whole network to tackle the problems associated with the centralised architecture, SPoF still remains a severe flaw at each cache server (Meng, Liu and Yin, 2010).

Caching or replicating content from the main source to local servers leads to the concept of CDNs. A CDN is considered a modernistic way of allocating replicas of content among several distributed servers to improve the performance and scalability of the provided services (Borzemski and Zatwarnicki, 2008; Pathan, Buyya and Vakali, 2008; Passarella, 2012). Akami, Digital Island, Radar, SPREAD, Amazon and Globule are famous examples of popular CDNs that are deployed worldwide for website hosting. According to Pathan and Buyya (2007), the new generation of CDNs has moved to multimedia streaming including IPTV services, yet are commercially unavailable currently as this is still in the research stage.

On the other hand, the hierarchical architecture is proposed aiming at improving the reliability and QoS offered. In this architecture, the streaming servers are organised hierarchically, with a main data centre at the root, as shown in Figure 1.3. Under this architecture, if a local server at any level suddenly stops, the streaming requests will be redirected to a server at a higher level. A streaming request may travel from the leaf to the root in case of content unavailability at the cache levels. The growing number of levels and servers improves the QoS. However, this exponential growth leads to higher storage cost (i.e., further replicas must be stored for each popular content). This higher storage cost increases the cost of the provided service, which, in turn, may lead to user dissatisfaction.

A promising architecture for IPTV delivery networks called 'cloud-based architecture' has appeared in the works of Meng, Liu and Yin (2010) and Li and Wu (2010). The iCloud architecture (Meng, Liu and Yin, 2010) overcomes SPoF by aggregating the servers into service groups, as depicted in Figure 1.4, based on a proximity-aware rule where the adjacent servers are grouped in a single service group.

A second architecture, called 'peer-service area architecture' (Li and Wu, 2010), divides the delivery network into many service areas, as

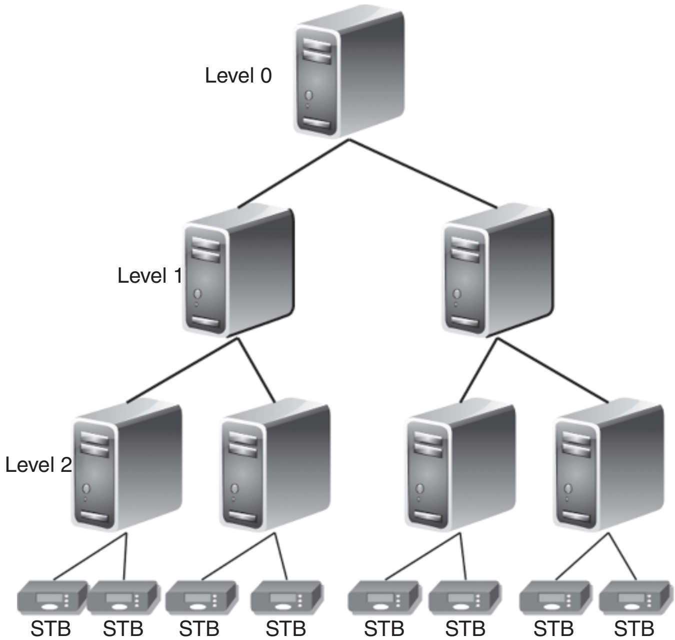

Figure 1.3 Hierarchical delivery network architecture.

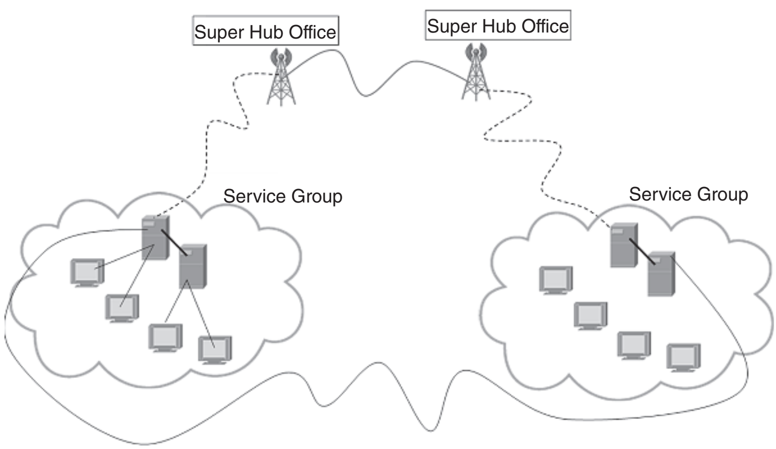

Figure 1.4 iCloud network architecture (Meng, Liu and Yin, 2010).

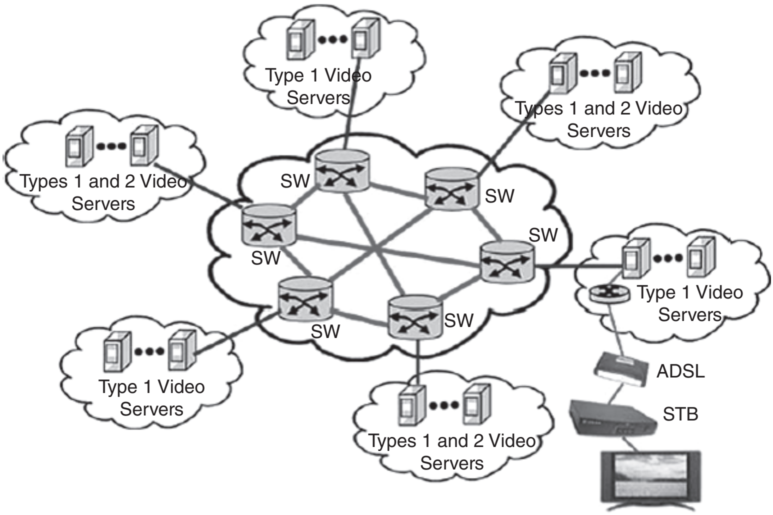

Figure 1.5 Peer-service area architecture (Li and Wu, 2010).

shown in Figure 1.5. According to Li and Wu (2010), two types of servers serve each service area: 'Type 1' servers allocate the popular content, and 'Type 2' servers allocate the unpopular content.

The customer belongs to only one service area and can request any video from any server within the service area. If a subscriber requests a non-existent video in his/her service area, this request will be redirected to the nearest service area that contains this video.

Li and Wu (2010) point out that this architecture can satisfy the QoS requirement and reliability. Thus, this architecture is considered particularly suitable for delivering IPTV services. Moreover, the peer-service area architecture can overcome the challenges mentioned by Meng, Liu and Yin (2010); it overcomes SPoF by allocating more than one server in a service area. Moreover, interconnecting the different service areas allows the requests to be redirected from one service area to another. The purpose of such interconnection is to ensure QoS and exploit cost-sharing among these service areas. The peer-service area architecture lacks request distribution and content replication mechanisms. Thus, this architecture suffers from a load imbalance problem.

1.5.1 IPTV Delivery Network Characteristics and Challenges

The advent of IPTV has created great opportunities for different parties to participate and benefit. These parties include content creators, broadband network owners and service brokers. The connection between these parties is depicted in the functional IPTV architecture. The general IPTV architecture consists of four domains – namely, content provider, service provider, network provider and, finally, the end-user (Open IPTV Forum, 2009a,b; Mikoczy and Podhradský, 2009). The service provider buys content from the content provider and then distributes it to end-users over a shared delivery network provided by the network provider. In such shared delivery networks, many providers contract with the network provider to allocate their contents and to handle incoming requests. In this situation, all that the customers need is a subscription that allows them to enjoy the provided services belonging to different providers via a special STB device.

IPTV, as a promising technology, is growing rapidly in terms of subscribers and revenue to become the standard means of delivering home and business entertainment content (Yarali and Cherry, 2005). Thus, telecommunication companies (network providers) are in fierce competition to increase their customer base and profit by delivering IPTV services (Yarali and Cherry, 2005; Lee, Muntean and Smeaton, 2009). The key concern of service providers in this hectic competition is to provide high-quality services at minimum costs.

However, there are many elements that influence the process of building an IPTV delivery network. The choice of network architecture is one of the most important elements. In fact, the IPTV delivery network has been witnessing several developments starting from centralised architecture, which delivers content using a single main server. After this was replaced by server farms or clusters, the hierarchical architecture that distributes content into a set of cache servers arose. In addition, the distributed architecture is proposed to replicate content into a set of servers distributed in different places. The most recent and promising development is the peer-service area architecture (Li and Wu, 2010). In this architecture, the delivery network is divided into a set of interconnected service areas with a cluster of servers for each. Li and Wu (2010) argue that this architecture satisfies most QoS and reliability requirements.

Peer-service area architecture also can overcome the challenges that hinder other architectures – such as SPoF, cost-sharing and QoS (Meng, Liu and Yin, 2010). According to Gaber and Sumari (2012), load imbalance can occur because of improper content allocation and inaccurate request distribution that ignores the attributes of nodes. In peer-service area architecture, content is allocated among two types of servers without replications. Allocating the popular content without replication lets the servers become hotspots. Moreover, peer-service area architecture lacks appropriate request distribution techniques to distribute the load among different servers. Based on these limitations, peer-service area architecture suffers load imbalance and requires some enhancements to overcome the problem.

The second element contributing to building the IPTV delivery network is load balancing, which is considered one of the most important performance metrics of the IPTV system. Load imbalance means that some servers are heavily overloaded while others are relaxed. This problem degrades the QoS for IPTV services. Load imbalance usually happens as a result of inadequate content allocation and improper request forwarding, which is caused by not considering the non-uniform request access patterns of both content and users. Thus, replication and request dispatching techniques are designed to alleviate the load imbalance problem in IPTV systems. 'Replication' here refers to the even duplication of popular content among servers, aiming at reducing the overload. In fact, replication and request distribution strategies have become good choices to reduce overload on the backbone delivery network, improve performance and efficiently satisfy customer needs (Cranor et al., 2003).

On the other hand, cost reduction is a cause of concern for service providers. Hence, cost reduction is another important element that should be considered during the designing of IPTV delivery networks. In delivery networks, many service providers may share resources and compete to deliver good-quality services. However, IPTV content is characterised by its huge size and rapidly changing effective period. IPTV systems also suffer sudden peak workloads. Allocating large amounts of resources to cope with sudden workload leads to low resource utilisation at non-peak hours. On the other hand, not considering the peak workload leads to user dissatisfaction during peak hours. Thus, resource allocation and replica placement problems are important issues that should be considered mutually. In other words, resource allocation and replica placement should be integrated (Laoutaris, Zissimopoulos and Stavrakakis, 2005). Such integration can help reduce the wastage of resources by allocating the resources according to the necessitated replication scheme. As a result, the total cost can be reduced.

1.6 The Key Issues of IPTV Delivery Networks

Despite the great benefits of delivery networks to both service providers and content consumers, designing efficient delivery networks is not a trivial task and presents potential problems that must be resolved. Delivery network composition, content distribution and management, resource allocation and request redirection are the main issues that must be considered while building the delivery network. Delivery network composition includes delivery network placement and determining server specifications and interaction among servers. Content distribution and management includes content selection and distribution based on demand and cache/replica management. Resource allocation chooses the type and size of resources that are required for each surrogate server. Request redirection includes the techniques used to distribute the requests among servers, aimed at maintaining load balance and avoiding traffic congestion (Pathan and Buyya, 2009; Xu, 2009). According to Neves et al. (2010), these problems can be solved by considering them as optimisation problems. The optimal solutions to these optimisation problems can be found based on the given objective functions, which represent one or a combination of business goals. These business goals must be achieved to satisfy the acceptable level of QoS, and must include scalability, service availability, reliability, responsiveness, security and load balancing (Pathan and Buyya, 2009; Xu, 2009; Sierra-LLamazares, 2009).

One of the concerns of the present thesis is load balancing. In shared delivery networks, allocating content among the servers without considering their load status and/or performing inaccurate requests dispatching could lead to load imbalance. Therefore, the load imbalance problem can be solved in two steps. The first step is to replicate content according to its expected load among servers to balance the expected load. The second step is to evenly distribute the incoming requests across the servers to maintain load balance across the video servers. During literature review, these steps are widely investigated. In addition, allocating content efficiently will resolve

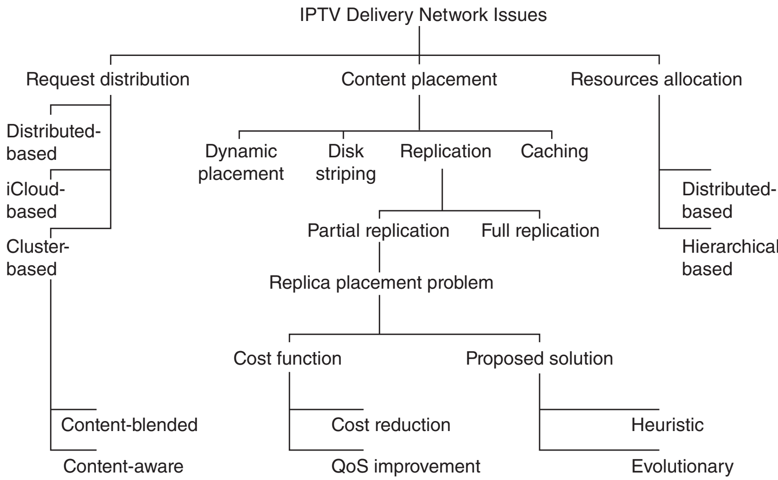

Figure 1.6 IPTV delivery networks issues taxonomy.

the resource allocation problem. Figure 1.6 depicts the taxonomy of the issues related to IPTV delivery networks, including request distribution, content placement and resources allocation problems.

1.7 Conclusion

In recent years, IPTV has been delivering live and on-demand TV services over high-speed IP-based networks. As these high-speed broadband networks exploit the digital representation of contents, IPTV offers a wide variety of channels with high quality and interactivity as compared to other TV systems. Thus, IPTV has been growing rapidly in terms of subscribers and revenue. Telecommunication operators have engaged in stiff competition to deliver IPTV services to their customers. However, service providers need to increase the viewing rates of their content, and customers need to watch a wide variety of high-quality channels/content.

From the service provider's viewpoint, the challenge in IPTV systems is to build delivery networks that exploit the available resources efficiently and reduce service costs. However, designing such delivery networks is affected by many factors, including choosing the suitable network architecture, balancing load, managing wastage of resources and reducing costs. Furthermore, IPTV content characteristics, particularly size, popularity and interactivity, play important roles in balancing the load and avoiding the wastage of resources for delivery networks. Accordingly, the focus of this chapter is to formulate and evaluate the load status of IPTV contents aiming at building content-aware IPTV delivery networks.

Building a delivery network for allocating large volumes of interactive content characterised by fluctuating popularity and non-uniform request patterns is challenging. Ignoring such characteristics can lead to load imbalance and affect the system's performance. Therefore, modelling the status of content according to the characteristics of IPTV content is very important in designing IPTV delivery networks. Such modelling helps to balance load by distributing incoming requests based on the anticipated load of both content and servers.

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