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A SURVEY ON RECENT ADVANCES IN IPTV

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ABSTRACT

After the success of carrying voice over IP networks, the dream of an IP-based television is being turned into reality with the research and standardization efforts. Today, standardization organizations, researchers, as well as commercial companies are putting huge efforts to make Internet Protocol TeleVision (IPTV) successful. The achieved successes of IPTV are due to many factors, including mainly the advanced video coding techniques, the continuously increasing Internet bandwidth that end users have been enjoying and the mature wired and wireless networking protocols and architectures. Although IPTV still faces many challenges, many content providers as well as Internet Service Providers (ISPs) already started to deliver IPTV services to customers. Nevertheless, the way ahead is still long and more efforts are required. This paper surveys a breadth of research areas related to IPTV. It first discusses the general service architecture of IPTV services and diagnostics in these architectures. It then turns the attention to surveying encoding techniques that can serve as enablers for future IPTV especially Scalable Video Coding. Then, various IPTV distribution approaches including peer-to-peer and Content Distribution Networks are discussed. After that, major work on security and privacy concerns in IPTV is tackled. Finally, a discussion of the major work in wireless IPTV services is discussed with focus on LTE-based service offering. We believe such a survey will be very helpful for researchers who would like to educate themselves in the overall landscape of IPTV before digging deeper to address open research problems to bring IPTV closer to reality.

KEYWORDS

IP-based TV, P2P, LTE, SVC, Channel.

1. INTRODUCTION

Although IPTV has been existing for a while, it has recently attracted content and service providers. Part of this is probably due to the exponential growth in technology and the advancements and maturity of networking tools and protocols in addition to multimedia and video compression techniques that have changed many things during the past two decades. These changes rendered IPTV as a viable application. IPTV, therefore, continues to grow commercially.

Three main Internet services are requested by customers today: Internet access, voice over IP (VoIP) and IPTV. The combination of these services is referred to as “Triple-Play” service. Adding mobility to the Triple-Play brings up the “Quadruple-play”. Moreover, an IPTV service may deliver both live TV and VOD, where each of these classes has its own characteristics, and is handled differently by IPTV users or clients, which makes the IPTV system design a challenging process.

Two factors have helped IPTV advancement to a great extent: the Advanced Video Coding (AVC) standards; namely MPEG-4 and H.264 and the increased capacities supported by broadband Internet access [2]. AVC standards play an important role in alleviating the effects of the heavy burden that IPTV imposes on the backbone as well as access networks. On the other hand, the ever increasing data rates end users continue to enjoy complements to this role, as these data rates allow more demanding applications to be implemented in practice.

Concerning IPTV, the access network represents the bottleneck. Because recent access technologies, such as Long-Term Evolution (LTE), provide subscribers with high data rates, such technologies are strong candidates to support wireless and mobile IPTV. We, therefore, give LTE special attention in this paper, where we shed light on a number of subjects regarding carrying IPTV traffic over LTE access networks. Many researchers have proposed P2P IPTV architectures to complement IP multi-casting for streaming multi-media and providing TV channels to users. We discuss these proposals as well.

Video transmission over IP networks can be classified into four types [3]: IPTV (the topic of this survey), IPVOD, Internet TV and Internet Video. IPTV delivers content that is similar to broadcast or cable TV, consisting of a huge number of live channels (pre-recorded videos or shows can be delivered too), on a privately owned and operated network (e.g., U-verse by AT&T and FiOS by Verizon). Usually, users are required to subscribe to an IPTV service and own a special device called Set Top Box (or STB for short) to be able to view the content. Similar to IPTV, IPVOD may require a subscription (e.g., Netflix and Amazon) or, alternatively, a per video fee may be required or it can be supported entirely by advertisements. Unlike IPTV, IPVOD is delivered via the Internet, which is a public network. In addition, the delivered content in IPVOD consists of pre-recorded videos, like movies or episodes of shows, and not live channels. Internet TV is similar to IPTV in the type of delivered content, where both live channels and pre-recorded videos can be delivered. However, it is usually a free or an Ad-supported service that does not require an STB to be viewed, since it is delivered via the Internet. In contrast to Internet Video, all the previously mentioned services (IPTV, IPVOD and Internet TV) deliver professionally produced content, whereas the content in Internet Video is usually user generated pre-recorded videos. Internet video is similar to both IPVOD and Internet TV in that it is delivered through the Internet and can be supported by Ads.

With the above classification, we notice that the distinguishing feature of IPTV is that it is delivered on a private network, which has the following advantages:

1. Since IPTV is delivered on a private network, Quality of Service (QoS) can be easily implemented and managed. This is because all network devices are managed by the same operator, which allows for enforcing consistent QoS rules among the whole network. On the contrary, guaranteeing QoS is hard on the public Internet, and thus for IPVOD, Internet TV and Internet Video.
2. True multi-cast can be used, which relies on the Internet Group Management Protocol (IGMP) that allows duplicating packets in-network when they are near their destinations. This reduces the used network resources when compared to multiple unicast sessions, which is used for other types of video services.
3. Real-time Transport Protocol (RTP) over UDP (RTP/UDP) can be used, which is more suitable for multi-casting and streaming video traffic. RTP/UDP is usually not used in the Internet, because of high jitter and the problems encountered in passing firewalls.

It is worth mentioning that despite the above classification, we note that the boundaries between these four types of services are not very firm. That is, some of the available services do not clearly belong to any of the discussed classes; rather, they may borrow from the attributes of more than one class of service.

We identify the following four major areas where IPTV needs further development. First, enhanced security mechanisms with a special focus on user privacy need to be implemented. Second, channel switching delay needs to be efficiently minimized. Third, efficient distribution mechanisms (e.g., peer-to-peer, CDN-based, etc…) should be proposed and fourth, efficient compression mechanisms (especially those based on Scalable Video Coding) need to be devised. These problems become more challenging when considered in the context of real-time IPTV.

The rest of this paper is organized as follows: Section 2 outlines the major recent research directions in IPTV. Then, in Section 3 we talk about wireless IPTV. Section 4 gives the reader an insight into the open research areas and future research directions and concludes the paper.

2. MAJOR RESEARCH DIRECTIONS IN IPTV

In this section, we go over the major recent research directions in IPTV. Extensive research has been performed in the past few years on IPTV. This section provides a brief description of the IPTV service architecture and diagnostics, Scalable Video Coding (SVC), IPTV distribution and security.

2.1 Service Architectures

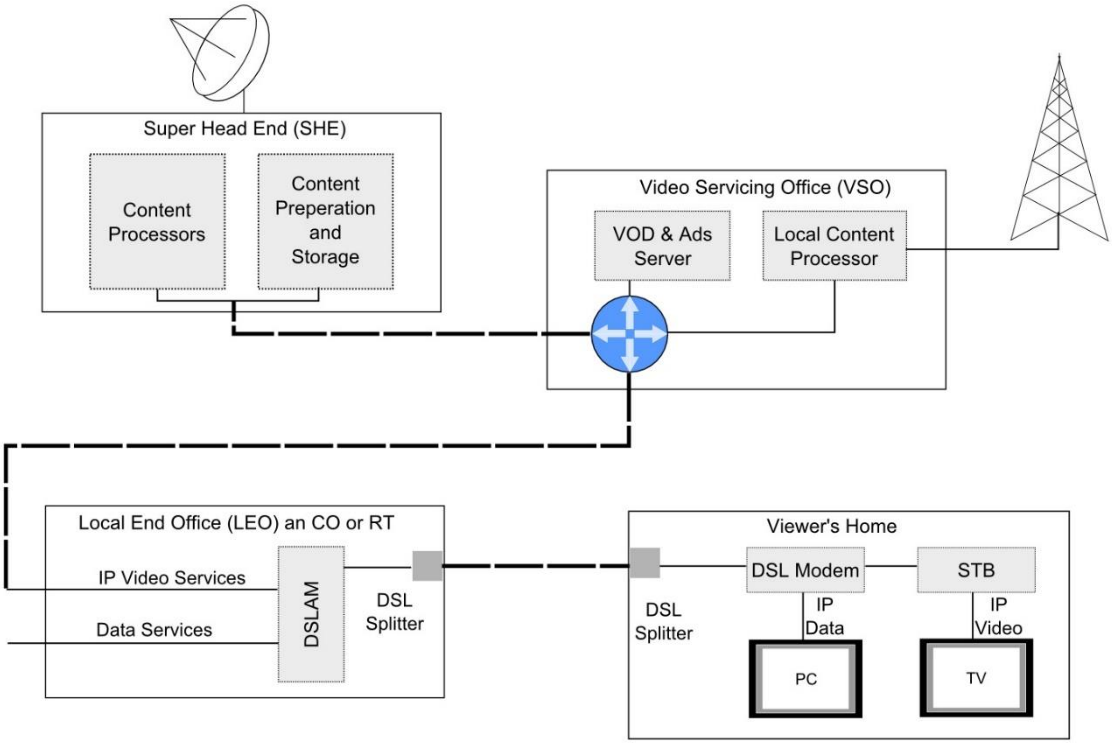

Figure 1. General IPTV Architecture [3].

The general IPTV system architecture is shown in Figure 1 [3]. The Super Head End (SHE) aggregates live content from different programming suppliers, and gathers and formats content intended for VOD (e.g., from videotapes or DVDs). The gathered content is then transcoded into a format suitable for transmission. The SHE labels and catalogues the gathered content and prepares its metadata (description, duration, etc…). After preparing the content, the SHE is responsible for transporting it to the Video Servicing Offices (VSOs). Note that in addition to content, the SHE is capable of processing Ads if they are to be sent to the whole IPTV system. Alternatively, Ads can be handled at the VSOs if they are focused towards a certain region. In addition for being responsible for the processing and the real-time delivery of content in a certain geographical region, the VSO can gather, prepare and deliver local content (e.g., local broadcast channels). The VSO creates IPTV streams and sends them to Central Offices (COs) or Remote Terminals (RTs). Moreover, the VSO handles VOD storage and provides video control capabilities (play, pause, rewind, etc…) for VOD, and interactivity support (making purchases or vote) for live channels. Another important task that the VSO takes care of is STB authorization to make sure that only paying users are receiving the content. Local End Office (LEO) that can be an OC or an RT is simply part of the existing infrastructure installed by telephone companies. It contains equipment to deliver IPTV over DSL lines. Basically, it contains one or more Digital Subscriber Line Access Multiplexer (DSLAM), which is sometimes called Video Remote Access Device (VRAD) that forwards each IPTV stream to its corresponding recipient. DSLAM can also support multi-casting using IGMP, which allows the replication of IPTV streams to end users.

Generally, there are two major service architectures for providing these services. The one-to-many service architecture is used by most of IPTV service providers as discussed previously. In this platform, the service provider specifies for each region one regional station for delivering on-demand IPTV services to subscribers. In other words, each subscriber is served by one pre-specified regional station. This paradigm has many shortcomings in that IPTV service providers are required to replicate devices massively in order to achieve reliability. Moreover, the nature of on-demand services suffers from temporal and spatial skewness, which leads to poor service quality at peak time as well as overall under-utilization of resources. Furthermore, such one-to-many service architecture may miss chances of reducing disk IO or fully utilizing memory-based cache. A collaborative IPTV for delivering on-demand services using many-to-many subscriber-to-station mapping is a viable solution to address these shortcomings. In this many-to-many architecture, a station serves subscribers from multiple regions and one subscriber is served by multiple stations [4].

2.2 Diagnostics in IPTV Architectures

The end-to-end diagnostic mechanisms in IPTV architectures are very useful for improving network performance and reducing customer complaints, which leads to lower operational expenditure (OPEX) costs [7]. The purpose of these diagnostics is to detect configuration problems, including port misconfigurations and element misconfigurations. Diagnostic mechanisms are also used to detect sub-optimal configurations that still allow the network to operate but result in poor network performance. Moreover, diagnostic tools are also useful for addressing congestion due to high traffic volume, server being overloaded and incorrect parameter settings.

The implementation of diagnostic tools can use either in-band or out-of-band mechanisms. In-band-based diagnostics use Operations, Administration and Maintenance (OAM) messages. In-band mechanisms typically collect small amounts of information from many nodes along a path in real time and are therefore considered fast mechanisms. Cross-product end-to-end diagnostics usually use in-band mechanisms. Telnet and Simple Network Management Protocol (SNMP) can be used to communicate diagnostic information out of band. Unlike in-band mechanisms, out-of-band network management system (NMS)-based diagnostics typically collect large amounts of information from fewer nodes and are slower. Table 1 lists some typical symptoms in IPTV architectures, their possible causes and the corresponding diagnostic tool used in each case. All these diagnostic tools may be implemented in-band or out-of-band [7].

Diagnostic tools usually depend on active diagnostic protocols, where some sorts of control messages are injected in the network, then received and processed. On the other hand, passive diagnostic techniques do not require any additional messaging, and thus, no extra overhead. To the best of our knowledge, such techniques are still unexplored for IPTV architectures.

2.3 Scalable Video Coding (SVC)

The scalability of SVC includes temporal, spatial and quality modes. Spatial scalability provides video with reduced picture size, temporal scalability provides video with reduced frame rate and quality scalability (also called Signal-to-Noise Ratio (SNR) scalability) provides video with reduced quality (or lower SNR) [8]. The scalability of SVC thus can lead to several benefits that substantially help in achieving ubiquitous IPTV including efficient methods for graceful degradation in addition to adaptation in both bit rate and format [9]. Moreover, the inherent scalability of SVC will bring many benefits to the wireless domain, since it enables true multi-cast and avoids the more costly solution of multiple unicast sessions. The standardized extension of H.264/MPEG4-AVC that includes scalable video coding specifies three profiles for SVC: Scalable Baseline, Scalable High and Scalable High Intra profiles [8]. The Scalable High profile, which supports spatial scalability (a key feature of SVC), was designed for broadcast and is expected to be used in IPTV [9].

Table 1. Typical symptoms in IPTV architectures, their possible causes and the corresponding diagnostic tool used for each case. All these diagnostic tools may be implemented using in-band or out-of-band mechanisms [7].

Symptoms	**Possible Causes**	**Diagnostic Tool**
A multi-cast channel is not received at home	1. An Internet Group Management Protocol (IGMP) join issued by the user for a given channel was dropped due to overflow. 2. The IGMP proxy function did not work. 3. The multi-cast forwarding database was updated incorrectly. 4. The multi-cast forwarding database was overflowed.	Multi-cast link trace (MLINK)
Lack of connectivity to a given channel	The user may not be allowed to access the network resources. This includes bandwidth availability and current bandwidth usage for a given channel and a specific stream type.	Information access line (iLINE)
Degradation of quality for a certain service	Alteration of packet priorities. Priority misconfigurations will result in an operational but sub-optimal network that may not trigger an action from network administrators. Priority misconfiguration may cause only transient problems and can remain undetected for a long time.	Priority trace (pTrace)
A user loses connectivity to some or all IP services	Dynamic Host Configuration Protocol (DHCP) misconfiguration.	In-band (lease query) mechanisms or NMS-based Diagnostics

SVC supports the transmission of video in layers; a base and one or more enhancement layers. Users receiving the base layer can decode and display video of base quality. Decoding more layers enhances video quality. This allows video transmission to receivers with different capabilities where each receiver can decode a number of video layers (based on its needs and capabilities) from a video stream that has several layers. This is more efficient than sending different video streams to meet the different receivers' needs.

The aforementioned features of SVC can be very helpful for IPTV. Specifically, applying SVC in the context of IPTV can significantly improve content portability, optimize content management and distribution, achieve a smart management of access network throughput and improve QoS and QoE [9]. The scalability of SVC helps in improving content portability in that the user can watch a video content on devices with different capabilities like TV, PC, smart phone, etc… even if this video content was not downloaded on that device, keeping in mind that these various devices differ from each other in terms of display area, processing capabilities, mobility and power consumption. In terms of optimizing content management and distribution, the scalability of SVC serves different subscribers at the best of their connection bandwidth (for example, half HD or full HD). Moreover, the scalability of SVC helps in managing the throughput of the access network in a smart way, because the adaptation of SVC simply drops selected IP packets and adapts the video bit rate to achieve the suitable user experience. SVC plays an important role in improving QoS and QoE by reducing channel zapping time and improving content navigation in the case of VoD IPTV. In addition, the graceful degradation feature of SVC aids in congestion control, as well as in handling access network constraints [9].

The architecture of SVC in H.264/SVC consists of several layers, where the original H.264/AVC video stream is called the base layer. The scalability of SVC is achieved by adding additional enhancement layers to the base layer for the purpose of increasing frame rate, picture size and quality (SNR). H.264/SVC employs inserting Instantaneous Decoding Refresh (IDR) frames into the video stream in order to enable random access. The simulcast technique [10] works by including a companion stream that has more IDR frames at lower quality as illustrated in Figure 2 [10], where black rectangles represent IDR frames and arrows represent inter-prediction. The main video stream shown in Figure 2 (a) has full quality and slow switching, while in Figure 2 (b) it has lower quality and faster switching. The two video streams in IPTV are independently encoded and independently transmitted. The low-quality companion stream works as channel-switching acceleration in that the screen of the end user when he/she changes the channel is first displayed. The regular SVC configuration [10] combines in one scalable video stream both the main and the companion streams, where the companion stream is encoded as the base layer and the main video stream is encoded as the enhancement layer. This regular SVC configuration can reduce bandwidth in the core network. However, it puts a burden on the access network in terms of bandwidth requirements, because the base layer is still to be transmitted to the user's STB if no channel change occurs.

Because of impairments and network conditions like congestion, packets of IPTV are liable to errors and loss, which badly influences the video quality. Error concealment for SVC in IPTV systems is therefore necessary. The four error concealment methods that have been adopted for SVC are: temporal direct, frame copy, motion and residual upsampling, as well as base layer reconstruction and upsampling [11]. The first two methods are intra-layer error concealment methods, while the last two are inter-layer error concealment methods. Implementing error concealment techniques at the decoder increases the decoder’s complexity [12]. The work in [3] proposes a per-packet prioritization mechanism that assigns a high priority to important frames, such as IDR frames, P-frames and B-frames. This mechanism provides resiliency against transmission errors for such important frames.

Other related research topics include proposing resource management mechanisms for scalable transmission control to optimize resource allocation for SVC-based mobile IPTV service [13]. The proposed system properly trades resource consumption and utility gain and maintains a given level of service coverage for each layer of the scalable video-encoded stream.

2.4 IPTV Distribution

To provide customers with IPTV Services with High QoS, there are two different architectures for the distribution of servers in the network [15]: centralized and distributed. The pros and cons for each approach are summarized in Table 2.

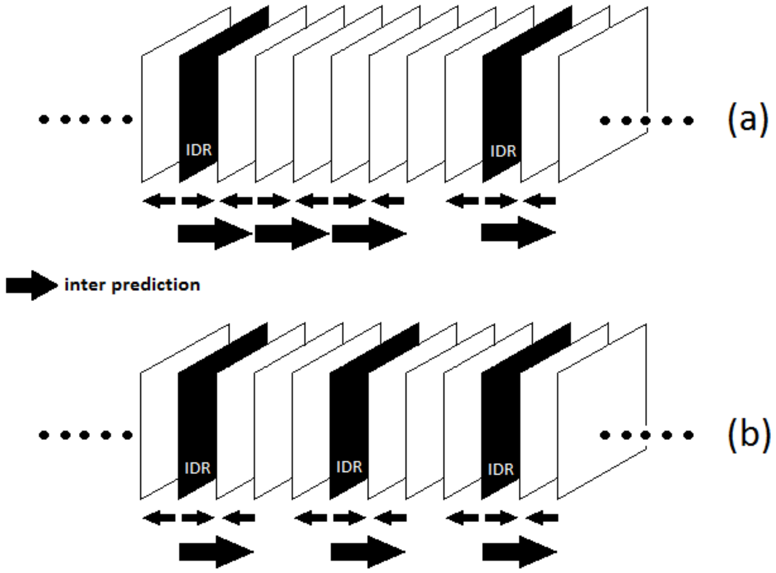

Figure 2. The simulcast of H.264/SVC: (a) Main video stream, (b) Companion video stream.

2.4.1 P2P IPTV

It is expected that P2P IPTV will be more prevalent than client-server IPTV in the future. The main reason for this is that P2P scales better. Currently, P2P IPTV is only deployed in China. UUSee Inc. [66] is a principal P2P live streaming provider in China [67]. Nonetheless, intensive research has been conducted on this topic. In P2P IPTV, peers contribute their resources such as CPU and upload bandwidth and at the same time upload (they act as content providers) and download real-time video streams, which adds no additional infrastructure cost as the community grows larger. This has been reflected in practice, where it has been noticed that the traffic generated by P2P IPTV applications has recently increased significantly [16]. A similar conclusion has been drawn in [17], where the authors argue that IP multi-casting would be the best solution for streaming TV content of popular TV channels that are greater in number than the active multi-cast groups. However, for less popular channels and using unicast connections, P2P produces comparable performance in terms of scalability, bandwidth utilization and quality. The authors in their study took into account the findings in [18] which show that the popularity of TV channels follows the Pareto principle, where only a small portion of people who watch TV channels are interested in watching the vast majority of TV channels. Similarly, picking the end-to-end content blocking as a QoE parameter, P2PTV outperforms the IPTV as the total number of users increases [19].

P2P IPTV was originally proposed as a solution for the scalability issue of streaming multi-media content at lower costs. The scalability for video distribution using the P2P approach is achieved by dividing the video into several chunks prior to distribution. These chunks are then shared among peers [20]. In P2P IPTV, an overlay network is created for each channel to connect the viewers (peers) of that channel, who receive, view and redistribute the content of the channel [21]. Some of the most famous IPTV services that employ P2P video streaming include PPLive, PPStream, SOPCast and TVants. However, there are several concerns regarding the success of P2P IPTV, including the stress that P2P imposes on ISP networks, because of the overwhelming traffic that P2P may pump into core and access networks, in addition to security concerns as it opens the appetite for malicious attacks [22]. Moreover, one of the issues that has been considered as a limitation of the P2P applications is having users (peers) being inside Network Address Translated (NATed) networks. This is an issue that can be faced by any commercial IPTV service provider. The NAT issue has been investigated in [23] with two categories of peers: the first category includes peers inside Lancaster University, the majority of whom are behind NAT. The second category represents off-campus peers, who had poor sharing and in general performed poorly, because they were unable to contact their on-campus peers and therefore started to starve of content quickly. The authors were able to resolve this problem by increasing the piece availability to external peers.

There are two different approaches for streaming IPTV using P2P architectures: the mesh-pull approach and the tree-push approach, where the mesh-pull succeeded in achieving commercial deployments. The P2P IPTV architecture followed in [24] for IP Multi-media Subsystem (IMS) employs a centralized control layer in addition to a P2P-like media layer at the peers, who act as forwarding nodes of multi-media streaming. The architecture in [25] integrates P2P distributed systems into Telco's STB at home to support advanced rewind functionalities and large number of live channels. Bikfalvi et al. [17] proposed a hybrid IPTV system that combines IP multi-casting and a P2P overlay unicasting to provide TV channels to large number of receivers as shown in Figure 3 [17].

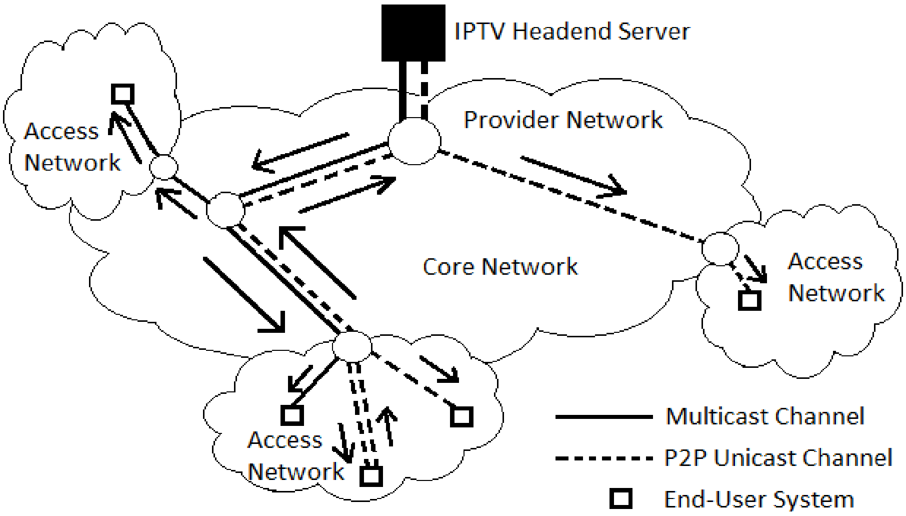

Figure 3. Multi-cast and unicast hybrid IPTV systems [17].

Decreasing channel zapping is one of the most important challenges in IPTV in general and P2P IPTV in particular. When employing P2P networks for IPTV, a delay is incurred when switching from one channel to another. Each IPTV channel is an overlay network. Switching from one channel to another is done by moving to another overlay network. This transition incurs a delay that ranges from seconds to minutes.

As a solution to the channel zapping problem, other channels' (adjacent channels') data can be sent along with the current channel data. When the user switches to an adjacent channel, the switching occurs with no delay [26]. In [27], another solution to the channel zapping problem is provided by sending I frames of the adjacent channels along with the video frames of the current channel, so that when the user switches to an adjacent channel the additional I frames are used instead of waiting for the normal I frames [27].

The channels' data transmitted with the current channel are supposed to have high probability for being selected by the user. Adjacent channels are selected in such a way that the likelihood that the user switches to theses channel is high. Depending on the popularity of channels (less delay incurred when switching to a popular channel than that incurred when switching to a less popular channel) [28].

Hei *et* al. [29] conducted a measurement study of PPLive and concluded that the internet infrastructure is sufficient for a large scale IPTV system. On the other hand, there are some P2P specific issues that need to be resolved, so that a P2P IPTV system becomes more attractive. Slow start due to startup delay caused by tens of seconds of buffering before playback helps overcome the fluctuation of the video connections' rates. Also, dedicated infrastructure may become necessary to support higher data rates at peers that have upload capabilities that are less than the download capabilities. The dedicated infrastructure consists of nodes that have high upload capacity. Variance in playback times at the different peers is another issue that needs to be considered.

Other P2P IPTV related topics include providing peer selection algorithms that offer reliable media streaming transmission as well as satisfactory user QoE [30], studying the overlay characteristics of large-scale P2P IPTV systems and identifying differences between PPLive multi-media streaming overlays and P2P file-sharing overlays [31], providing channel zapping (surfing) distributed mechanisms to reduce channel zapping time in P2P IPTV that involve switching to another P2P overlay network [21], as well as designing data scheduling schemes for storage-constrained mesh-based P2P IPTV systems [32].

Despite all the research conducted on P2P IPTV, there are still many challenges that need to be addressed, especially as prices of infrastructure CDN-based IPTV is getting lower [33]. The inherent heterogeneity of the Internet and user nodes makes it impossible to find a solution that would be suitable for all cases. Some of the main challenges that face P2P IPTV are fairness, availability, stability and including incentives in a P2P IPTV system (tit-for-tat is not suitable, especially for real-time IPTV). Also, one cumbersome situation when it comes to P2P IPTV is dealing with flash crowds, where a huge number of users become interested in an event all at once (e.g., a live event) [33].

2.4.2 VN-based Networks for Delivering IPTV Services

The current solutions for delivering IPTV services is by using a backbone or IP overlay-based content network. However, these solutions suffer from limitations in terms of guaranteed service delivery, cost effectiveness, flexible control and a scalable network infrastructure. The virtual network (VN) is a promising alternative, which allows multiple service providers to share the infrastructure by dividing the physical network structure of infrastructure providers (InPs) into several slices and associating them with different service providers. The main advantages of applying VN for delivering IP services can be summarized in the flexibility and control that VN offers to IPTV service providers in addition to security and reliability, since multiple VNs are isolated from each other even if they coexist on a shared substrate network [34]. Delivering IPTV over VNs requires leasing servers and links from an infrastructure provider and then replicating content according to the demand. The work in [35] integrates these two problems and proposes a genetic algorithm as a heuristic.

There are, however, two major challenges that must be worked out when considering VN for IPTV service delivery [34]. The first is the need for a well-designed virtual network topology (VNT) to ensure that services can be efficiently delivered from the servers to the customers. VNT must be efficient, cost effective and reliable to overcome any virtual node or link failure. The second challenge is the handling of a VN allocation failure problem by infrastructure providers using an efficient VNT reconstruction algorithm.

2.4.3 Content Distribution Networks (CDNs)

Commercial video distribution services (VoD and Live IPTV) over CDNs have been around for a while, like Akamai video streaming service and Limelight streaming service. In addition, Netflix, Amazon and AppleTV are examples of commercial IPTV service providers assisted by CDNs. The massive, highly distributed infrastructure that CDNs own enables them to serve the video content from a lightly loaded location nearby end-users. Since these commercial CDNs deploy sophisticated measurement and quality path selection mechanisms, they are able to avoid points of congestion in the network, and therefore, provide high quality streaming services. Furthermore, video distribution over CDNs eases the burden on the core of the network posed by the high bandwidth demand of the IPTV application. In terms of research, Yin et al. [36] proposed a hybrid architecture that combines P2P distribution with CDN-based distribution. The proposed architecture benefits from the reliability and quality of CDNs and from the inherent scalability features of P2P systems when the total demand exceeds the capacity of the CDN. The authors also reported on the performance of a commercial hybrid CDN and P2P IPTV service. The authors in [37] showed that the unique characteristics of video transport; namely the high bandwidth requirement and the design of Akamai's CDN streaming service can leave the system susceptible to intentional service degradation (by an attacker). Therefore, the authors demonstrated the importance of careful design of these services to avoid possible attacks.

2.5 Security and Privacy

When considering security in IPTV, many important issues should be considered. The authors of [42] argued that to let end users enjoy content in new ways without any security hurdle, IPTV security must be architected and implemented correctly. This is possible by providing a cost-effective security and allowing service providers to explore and innovate new business models, as well as customer experiences. There are a number of security requirements for the transmission of any form of data on the Internet in general and for the transmission of IPTV traffic in specific. These requirements include the following [43]:

1. Confidentiality, which means to allow legitimate users only to recognize the transmitted data and to prevent attackers from getting such information as the source of data, destination, time, length and traffic characteristics of communication channels. To achieve confidentiality, the transmitted data must be encrypted.
2. Integrity; that is to protect data, either stored on an information system or being transmitted, from being falsified. To achieve integrity and notice any illegal data modification, electronic signatures can be employed.
3. Authentication, where during the transmission of data, the sender should be able to confirm the identity of the receiver and the receiver should be able to confirm the identity of the sender. Authentication is in general hard to achieve. A form of user ID and password can however be used.
4. Access control, which means to grant access to data and network resources to authorized users only. To control access to network services, intrusion detection systems and firewalls can be used to counter attacks of unauthorized users.

Authentication, Authorization and Accounting (AAA) is a standard developed by the IETF working group to provide secure network access, user authentication and accounting [43]. The Conditional Access System (CAS) is used to control users' access to charged broadcasting services. DVB CAS [44] is the standard developed in Europe and ATSC CAS in the USA [43]. The Digital Right Management (DRM) is used in Internet-based environments to manage intelligent property of digital contents [43]. The time-constrained management rights provided by DRM include the right to read, distribute, edit and copy [45].

Content protection is required to enable subscribers to use the content they have acquired in accordance with the rights they have been granted. To protect content and services of IPTV, a number of security aspects need to be addressed, including identification, authentication, authorization, key distribution, content encryption, right's expression, renewability and revocation, content export, compliance and robustness [46].

Possible security attacks in IPTV include subscriber and STB impersonation attacks, replay attack, stolen verifier attack, smart card loss attack, man-in-the-middle attack and attack on perfect forward secrecy [47]. Moreover, providing IPTV through IP networks may result in illegal control, illegal content distribution, service theft, access of unapproved users, sniffing, tapping, Denial of Service (DoS) attack, War Dialling attack, Rogue Device attack and harmful software infection [43].

Secure IP Multi-cast allows the secure transmission of IPTV services to groups of receivers. Nevertheless, when users switch between groups (channel zapping situations), the existing solutions do not optimize the signalling generated by the IPTV, because new cryptographic material is retrieved by the zapping user [48]. Moreover, Secure IP Multi-cast neglects access control and network management [49]. IPTV services use one key for each video channel. For perfect forward and backward secrecy, key distribution for secure group communications applies key refreshing techniques when group members join and leave (when a group changes) [49].

Subscriber authentication schemes for mobile IPTV users require individual-level user authentication to provide personalized, tailored services for mobile users. These authentication schemes are different from the existing IPTV authentication schemes that provide the same IPTV services and access levels to the whole family members using a set-top box (STB)-level authentication [50]. Secure key exchange with mutual authentication between STB and smart card is required to avoid smart card cloning and McCormac Hack attacks [47].

The provision of secure authentication mechanisms is a fundamental security requirement of IPTV. The traditional protection scheme's like Conditional Access System (CAS) [51] and Digital Rights Management (DRM), may fail in IPTV, because IPTV provides interactive on-demand services [50]. Moreover, mobile IPTV requires individual-level user authentication in contrast to the authentication schemes that are currently used in IPTV and provide the same services to the whole family members using a set-top box (STB). Existing IPTV authentication schemes are either password-based, RFID-based or Universal Subscriber Identity Module (USIM)-based [50].

According to the ITU-T IPTV Focus Group [52], there are five types of security threats facing IPTV:

1. Content security threats, which include interception, unauthorized viewing and unauthorized reproduction or redistribution.
2. Service security threats, which include violating copyrights of the programs which IPTV service platform provides to the subscribers, masquerading/spoofing IPTV service provider, malicious threats aimed at the IPTV servers and theft of the subscribers' information.
3. Network security threats, which include intentional threats to the network equipment or resources, security threats to multi-cast techniques used in IPTV bearer network and malicious attacks on nodes in content distribution network.
4. Terminal device security threats, which include illegally accessing clear content by tampering device hardware or software, illegally accessing keys or other secret information in devices using software cracking or hardware tampering, device malfunctioning by software and hardware methods, unauthorized applications, the failure of terminal equipment, unauthenticated terminal devices connecting to the home network and unauthorized use by subscribers.
5. Subscriber security threats, which include theft of the subscribers' information and end user's privacy by malicious programs.

These types of security threats are illustrated by the Security Threats Model shown in Figure 4 below, which also illustrates the relationships between these threats [52].

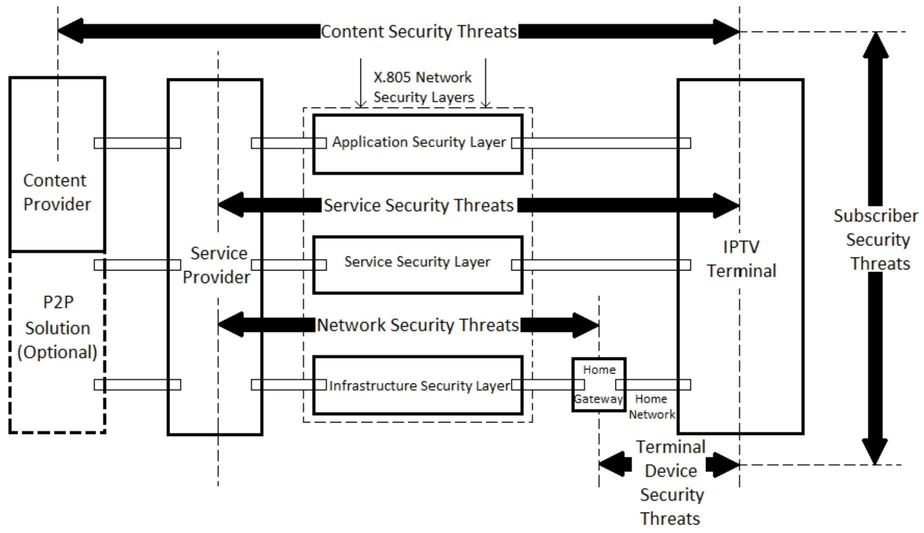

Figure 4. Security threats model [52].

Privacy protection is another important security aspect that must be enforced in order to achieve a secure IPTV. The recommender service is employed by service providers to attract and satisfy customers by collecting information about the user preferences and selecting the items that might be of interest to customers in the future. Currently, the recommender services are implemented in a centralized fashion using a collaborative filtering technique, a smart machine learning technique that can recommend new items for users by collecting preference data for all the users in one place [53]. This, of course, may violate the privacy of users.

3. IPTV OVER WIRELESS NETWORKS

IPTV services can make use of the wireless broadcast advantage. Unlike transmissions on wired networks, wireless transmissions are broadcast by nature. Therefore, an IPTV client actually receives the channel he/she requested in addition to all other channels broadcast in his/her proximity to neighbouring clients. This characteristic can help in improving the channel zap times as suggested in [54] for LTE-based networks.

Recently, multi-Gigabit wireless personal area networks (WPANs) utilize the 60 GHz millimeter-wave (mmWave) communication technologies. For mmWave-based WPANs, directional antennas are preferred over omni-directional antennas. This is because of the small wavelength of mmWave communication systems. The attenuation of mmWave signals in the air is much faster than lower frequency signals. Furthermore, it is possible to concurrently allow P2P transmission and exploit spatial multiplexing using directional antennas [55]. This has the potential of guaranteeing the QoS requirements of IPTV and improving resource utilization efficiency.

3.1 Mobile IPTV

The H.264/MPEG4-AVC video codec has been implemented in STBs, Flash and QuickTime players, and is expected to be included in mobile devices [9]. Scalable High Profile of SVC will not probably be supported in mobile IPTV, because interlaced coding is not used in the mobile space due to the high implementation complexity [9].

ITU-T classifies IPTV architectures into Next-Generation Network (NGN)-based and non-NGN-based architectures [36]. Figure 5 shows a typical mobile IPTV architecture, where both IPTV sender and receiver can be mobile. Moreover, mobile IPTV users are allowed to provide content to other mobile and non-mobile IPTV users. The network architecture could be non-NGN, NGN IMS or NGN non-IMS based.

Point-to-Point (PTP) is usually employed in mobile communications. Unfortunately, PTP may quickly cause exhaustion in the network resources represented mainly by the bandwidth. Therefore, to restrict the limitations imposed by the bottleneck that exists at the last mile from the mobile grid backbone in terms of data rates and the amount of communication, Point-To-Multipoint (PTM) using broadcasting and multi-casting techniques is advisable, putting in mind that interests in certain TV contents like sports and news is common by many mobile users [36].

In a typical situation, it is possible that many home devices request IPTV services simultaneously. Using a single Access Point (AP) will not be adequate to provide a full coverage at home. One possible solution is to use several APs, which might lead to interference among devices at the same house and within neighbourhood. This will result in more collisions and increase the packet loss ratio to an unacceptable value. To manage the wireless transmission of IPTV services at home, two possible approaches can be used: distributed and centralized architectures. Since home networks are centralized by nature (home network is connected to ISP via a single gateway), the centralized approach seems more appropriate for home networks [36]. In light of this, several commercial products implementing the centralized architecture are available today, including OmniAccess series from Alcatel-Lucent, RFS series from Motorola, Lightweight AP and WLC from Cisco, just to mention some.

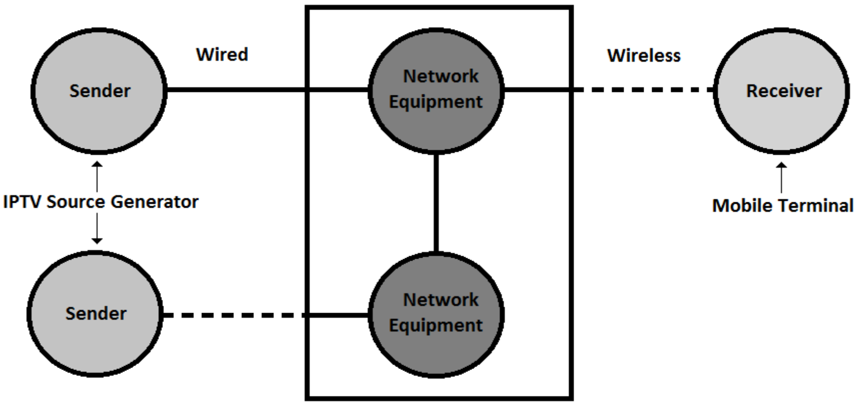

Figure 5. A general architecture of mobile IPTV.

3.2 Long Term Evolution (LTE)

LTE is the fourth-generation cellular network that has proven to provide high-speed wireless and mobile Internet. Multi-media multi-casting, streaming and downloading in LTE networks are provided through evolved Multi-media Broadcast and Multi-cast Services (eMBMS) [56]. Using LTE for live broadcast (live events or TV channels) is not available commercially yet. The closest LTE got to being used for live broadcast is in a few trials to broadcast in-stadium live events to the audience in the same stadium [57]. Some service providers, e.g., Verizon (USA) and Telstra (Australia) [58], are planning to use LTE for video broadcast in the near future, but this is not done yet, since the market is favouring OTT content [59]. Ericsson is the first to propose a complete solution to broadcast video over LTE, and in its vision, this will be enabled by HEVC (High Efficiency Video Coding), MPEG DASH (Dynamic Adaptive Streaming over HTTP (DASH)) and eMBMS [60]. Nevertheless, LTE should be capable of serving VOD due to its high supported rates. For example, the minimum bandwidth requirement for Netflix is 0.5 Mbps, while the recommended bandwidth by Netflix, for HD and Ultra HD, is 5Mbps and 25Mbps, respectively [61], which should be satisfied by LTE.

It is important to assess the performance of LTE and to measure the amount of success that has been achieved in the deployment and use of LTE networks. In a recent study, the authors of [62] performed a thorough performance evaluation of LTE and reached a number of interesting findings. The LTE network topology is shown in Figure 6 [62]. The typical LTE network shown in Figure 6 shows that the end users use User Equipments (UEs) to get access to the 4G LTE. The Radio Access Network (RAN) connects UEs to the Core Network (CN). The RAN consists of a number of Evolved Node B (eNB) or base stations. The authors collected data at the Monitor. The role of Performance Enhancing Proxy (PEP) is to split the end-to-end TCP connections between the UE and the server port 80 or 8080 into two connections: the first is between the UE and the PEP and the second is between the PEP and the server. The split is transparent to the UEs. The PEP compresses data and acts as a cache, which leads to improved performance.

LTE has been attracting more users because of the significantly higher bandwidths and lower delays compared to the 3G networks. Nevertheless, the authors of [62] found that many TCP connections underutilize the available bandwidth significantly, which incurs additional energy consumption and makes data downloads take longer delays. The authors found that the main cause of this underutilization of bandwidth is that some applications are energy and LTE network unfriendly. The authors also found that the majority of LTE traffic (in terms of byte count) is multi-media (video, audio and graphics). They found that user consumption of multi-media and the dominance of video have been significantly increasing compared to previous studies. They also found that LTE outperforms WiFi in many cases and substantially outperforms WiMAX.

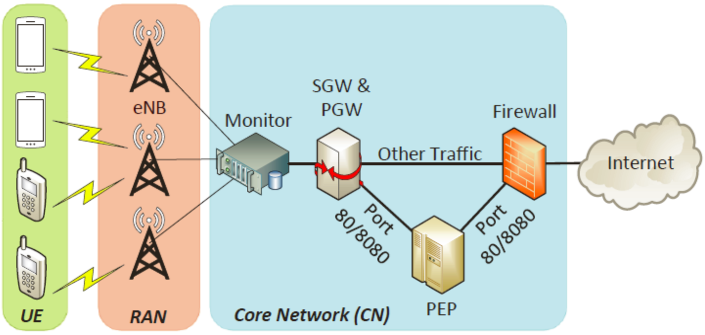

Figure 6. The LTE network topology used measurements in [62].

Employing SVC can be very helpful for IPTV over LTE networks. SVC proved to be successful in reducing packet loss and bandwidth requirements of video multi-casting in LTE with acceptable video quality. SVC also provides graceful degradation of video quality for users in the cell edge, where users near the base station are served with all the three temporal layers (containing I, P and B frames) and the base temporal layer (containing I and P frames) is only sent to users far from the base station [63]. Authors showed 18% reduction in bit rate with SVC compared to simulcasting using H.264 without SVC. In [64], the authors proposed a dynamic AMC and scheduling approach for MBSFN-based SVC video transmission in LTE networks. The authors showed that the proposed scheduling can considerably save radio spectrum.

Power is an important issue in the transmission of video over LTE networks; lower transmission rates help increasing sleep mode power conservation [56]. The capacity of poor receivers affects the eMBMS performance. Existing power settings increase the transmission power for the purpose of better covering poor nodes, which leads to more power consumption and interference. There are two approaches to reduce power consumption in LTE. The first approach multi-casts multi-media using layered video (i.e., through SVC), where the base layer is transmitted using high power at low rate and the enhancement layers are transmitted using lower power and higher transmission rates. The second approach depends on power-efficient multi-casting in the various layers like cooperative and opportunistic routing (network layer), scheduling (MAC layer) and multi-cast beamforming (physical layer). Therefore, power efficient SVC multi-casting should consider power savings in group, channel assign and schedule [56].

For future research, these subjects must be profoundly studied in the case of mobile users in LTE networks, as mobility can cause substantial CQI fluctuations. More efforts are also required to explore the interactions between radio, network transport and application layers. Moreover, new energy-efficient resource management policies and transport protocols are needed. Finally, it is critical to optimize the LTE network for IPTV.

4. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

The increased data rates provided to end users and overwhelming the world with numerous smart devices, like mobile phones and other handheld devices that can access the Internet from anywhere at any time, have turned providing television over IP networks into reality. There are, however, many unsolved issues in the realm of IPTV, especially if it is required to support wireless and mobile IPTV. The complexity and challenges increase while integrating High Definition TeleVision (HDTV) into IPTV. In this paper, we provided an extensive review for the recent research efforts in the field of IPTV on areas like IPTV services, P2P IPTV, SVC and IPTV, security and wireless and mobile IPTV.

Despite all the advancement, in video coding techniques, we believe further study is still needed on how to efficiently encode real-time video because of the SVC’s encoder complexity [14]. SVC is a promising solution for providing TV services over IP networks [8]. The technical complexities of the design of SVC features for the consumer end devices will decrease over time allowing commercial deployment.

The work in [4] addressed three issues; request dispatching, content placement and controlling collaboration scope to ensure QoS. We believe that there are still other issues that need to be addressed in many-to-many service architectures. For example, how would such a system perform with real-time live traffic? Also, although network coding [5] has been applied to P2P IPTV (e.g., [6]), the many-to-many service architecture is different. Utilizing network coding in such many-to-many service architectures, which have replicated redundant data, may bring throughput, reliability and cost advantages. Finally, as suggested in [4], algorithms for high definition video delivery in many-to-many architectures still need to be evaluated.

With respect to CDN-based IPTV distribution, there are three main challenges. First, the need to optimize CDN deployment to reduce cost will always be an important challenge. This is due to the continuously increasing demand on IPTV, intense competition in the content delivery market and to the constant need to upgrade and maintain network hardware. The second challenge is end-user miss-location, which is mainly caused by assigning end-users to CDN servers based on the location of the DNS resolver that served the user, which in many cases gives an inaccurate view on user location. Third, since CDNs have limited network knowledge, inappropriate user assignment may lead to overloading network bottlenecks [38]. The above challenges can be addressed through the collaboration between ISPs and CDNs, where [38] and [39] are first steps towards this approach.

In addition, energy-efficient IPTV or Green IPTV should receive more attention. Current IPTV providers’ multi-cast TV channels as close as possible to the user are needed to reduce the delay perceived by the user as much as possible. However, not all channels have viewers all the time. Therefore, selective multi-casting channels may reduce the consumed energy, especially for high definition channels [40].

Another research direction that needs further exploration is implementing IPTV services over Information Centric Networks (ICN). ICN-based IPTV is yet to be explored because of the challenging nature of ICN architectures [41].

User’s privacy remains a big issue in IPTV. A possible future direction to privacy preserving IPTV as suggested by [53] could include utilizing game theory in the implementation of recommender service.

The most important aspects of the IPTV security system remain the need to provide cost effective state-of-the-art security with an ability to recover from a compromised system and the need to provide a competitive open and interoperable security infrastructure with flexible capability to allow service providers to innovate and explore new business models and consumer experiences. Furthermore, while [53] has proposed a privacy-preserving multi-agent based recommender service, the security of such services needs to be studied carefully. For example, a breach of security of these services may render the service useless (by for example submitting a large number of fake user ratings) or may defeat the goal of these services by being able to trace a rating back to the originating user.

The other open issue that needs to be addressed as a research direction in IPTV security to achieve content service protection [65] is transcodable encryption. That is to decrypt the protected content and re-encode the decrypted content without considerable performance overhead at the end user side.

To reduce the huge bandwidth requirements of multi-media contents, video compression techniques must be employed. Since these compression techniques are lossy in nature, degradation in the perceptual video quality is possible. Therefore, more efficient error control mechanisms are required for better QoS and QoE in IPTV. It is also required to implement error concealment techniques that do not increase the decoder’s complexity [12].

Channel zapping remains an issue that must be dealt with for successful IPTV deployment. Channel zapping time should be as short as possible. If the channel zapping time is too long, the quality of experience will be affected, which leads to user dissatisfaction. It is required to come up with fast channel switching SVC configurations that reduce bandwidth on the access network and facilitate backward compatibility [10].

Following the work of [9], we believe that more effort should be put to implement Context-Adaptive Binary Arithmetic Coding (CABAC) and EB slices decoding into mobile devices [9]. Additionally, the devices available today for providing wireless IPTV services are relatively expensive, which makes them not affordable by home users in most cases. Therefore, more research is required to address this issue. Other related topics include dynamic scheduling algorithms [37], as well as rateless channel coding and data-partitioning [36].

Concerning mobile IPTV, future research directions include the derivation of MPLS-based NGN architectures to support QoS, traffic engineering and VPN IPTV mobility requirements, correlating networking resources, terminal capability, and user profile for mobile IPTV streaming applications, integrating SVC coding technologies into mobile IPTV services and devising display procedures for mobile IPTV users that are both viewer centric and context aware [37].

We believe that an evaluation of current service deployments is necessary. It is also important to research new encoding schemes for wireless devices exploiting SVC. Finally, we argue that unlimited data plans might not be affordable now, but it is expected to be affordable in the future, which permits the utilization of the full power of IPTV over LTE networks.

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APPENDIX A: ACRONYMS

Table 2. List of acronyms used in this paper.

Acronym	Description	Acronym	Description
AP	Access Point	NGN	Next-Generation Network
AVC	Advanced Video Coding	P2P	Peer to Peer
CABAC	Context-Adaptive Binary Arithmetic Coding	PC	Personal Computer
CN	Core Network	PEP	Performance Enhancing Proxy
CQI	Channel Quality Indicator	PTM	Point-To-Multipoint
eMBMS	evolved Multi-media Broadcast and Multi-cast Services	PTP	Point-To-Point
eNB	evolved Node B	QoE	Quality of Experience
GBR	Guaranteed Bit Rate	QoS	Quality of Service
HDTV	High Definition TeleVision	RAN	Radio Access Network
IDR	Instantaneous Decoding Refresh	SHE	Super Headend
IMS	IP Multi-media Subsystem	SNR	Signal-to-Noise Ratio
IPTV	Internet Protocol TeleVision	STB	Set Top Box
ISP	Internet Service Provider	SVC	Scalable Video Coding
LTE	Long Term Evolution	UE	User Equipment
MBS	Multi-cast and Broadcast Services	VoD	Video on Demand
MPEG	Moving Pictures Expert Group	VSO	Video Serving Office
NAT	Network Address Translation	WiMAX	World interoperability for Microwave Access

ملخص البحث:

بعد النجاح الذي أحرز في نقل الصوت عبر شبكات بروتوكولات الإنترنت، تحوّل حلم التلفاز القائم على بروتوكولات الإنترنت إلى واقع عبر جهود البحث المكثفة. واليوم، تبذل مؤسسات التقييس والباحثون والشركات التجارية جهوداً ضخمة لإنجاح التلفزة المبنية على بروتوكولات الإنترنت. وترجع النجاحات التي تحققت في هذا الميدان إلى العديد من العوامل، التي تتضمن بصورة رئيسية التقنيات المتقدمة في مجال تشفير الصور، والازدياد المستمر في عرض نطاق الإنترنت الذي يمكن للمستخدمين النهائيين الاستفادة منه، إلى جانب البروتوكولات والمعماريات الناضجة المتعلقة بالتشبيك السلكي واللاسلكي. وعلى الرغم من أن التلفزة المستندة على بروتوكولات الإنترنت لا تزال تواجه العديد من التحديات، فقد بدأ العديد من مزوّدي المحتوى ومزوّدي خدمات الإنترنت بتقديم خدمات التلفزة القائمة على بروتوكولات الإنترنت للزبائن.

إلا أن الطريق لا يزال طويلاً والحاجة ماسة إلى المزيد من الجهود. تبحث هذه الورقة في مدى واسع من مجالات البحث المتعلقة بالتلفزة القائمة على بروتوكولات الإنترنت. فهي تناقش أولاً البنية الخدمية العامة لخدمات التلفزة القائمة على بروتوكولات الإنترنت و المسائل التشخيصية المرتبطة بها. ثم تحوّل الانتباه إلى مسح تقنيات التشفير التي يمكن أن تكون أساساً للتلفزة المبنية على بروتوكولات الإنترنت في المستقبل، وبخاصة تشفير الصور القابل للتدريج. بعد ذلك، تناقش الورقة طرق توزيع مختلفة للتلفزة المبنية على بروتوكولات الإنترنت، بما في ذلك شبكات التوزيع من نوع نظير إلى نظير و شبكات توزيع المحتوى. ثم تتناول الورقة العمل الرئيسي في مجال المسائل المرتبطة بالأمان والخصوصية، وتبحث أخيراً في مجال الإنجازات الرئيسية في ميدان خدمات التلفزة المستندة إلى بروتوكولات الإنترنت في الشبكات اللاسلكية، مع التركيز على تقديم الخدمات المبنية على التطور في المدى الطويل.

ونعتقد أن مثل هذا المسح سيكون ذا فائدة كبيرة للباحثين الذين لديهم الرغبة في تثقيف أنفسهم بصورة إجمالية في مجال التلفزة القائمة على بروتوكولات الإنترنت قبل أن يتعمقوا في معالجة المشكلات البحثية المفتوحة؛ من أجل تقريب التلفزة المبنية على بروتوكولات الإنترنت أكثر فأكثر من الواقع.