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Optimization of TV Multicast Delivery

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ABSTRACT: *This paper focuses on user-centric mobileTV service considering the users' consumption style, the cost reduction of network resources and the enhancement of End-Users' Quality of Experience (QoE). We consider a nomadic access scenario where each user is able to access his mobile TV content AnyTime, AnyWhere and from Any Device (ATAWAD), considering the eMBMS (Evolved Multimedia Broadcast Multicast Service) diffusion. In multicast TV delivery, clients join/leave the multicast TV source of channels according to their requests. However, during Nomadic Access (NA), the multicast tree has to be reconstructed according to the new demands. This paper introduces a solution that adapts the multicast delivery for mobileTV service through optimizing the tree structure of multicast nodes in a dynamic manner according to the different context of the user and the network. The proposed solution optimizes the investment cost (CAPEX) of multicast sources (streaming points) and opens the way to an enhancement of the Quality of Experience (QoE) of End-User.*

Keywords: *MobileTV, Multicast, Nomadism, Cost Optimization, Quality of Experience, MOS, Service Virtualization*

1. Introduction and Background

Mobile TV market evolution is presenting new entertainment services and business opportunities for network operators, service providers and contents providers. Consumers are increasingly demanding instant access to TV and video content through mobile terminals, where smart phones and tablet devices are becoming entertainment devices. Mobile Operators aim to increase their market share through: i) increasing in the number of customers and reducing churn and ii) increasing revenues coming from non-voice content services (multimedia services, TV and Video). Content Providers are looking at ways to increase the use of mobile phones as a managed channel for content delivery, while Application Providers (Developers) are looking at developing, protecting, and monetizing mobile content assets. Devices Vendors aim to increase their mobile devices market share, monetizing devices as a content delivery/consumption platform, and increasing their non-device services revenues (as in the case of Apple services through iTunes). Platforms Vendors want to increase their content distribution services and aggregation platforms.

1.1 Mobile TV Service Consumption: Market Analysis

The mobile media population has grown 19 percent in 2011 to more than 116 million people in August 2011 [1]. Mobile usage for multimedia services can take three forms: "fixed" (not moving while consuming services), "nomadic" (moving not fast while consuming services, for example when walking), and "mobile" (service consumption when moving fast, passengers in vehicles or trains) [2]. It has been shown that mobile **data traffic will roughly double each year, increasing 66 times between 2008 and 2013 and almost 64 percent of the world's mobile data traffic will be video in 2013**. Figure 1 illustrates a forecast for the evolution of the global mobile data traffic until 2015 [3] which is expected to grow at a Compound Annual Growth Rate (CAGR) of 92 percent from 2010 to 2015. According to a study done by Orange (France Telecom), laptops, notebooks and tablets devices are among the majority of devices contributing to the increase of the global mobile traffic which is expected to increase the global mobile traffic to around 1500 Terabytes per month in 2015 (compared to an increase to 400 Terabytes expected from Smartphones in 2015).

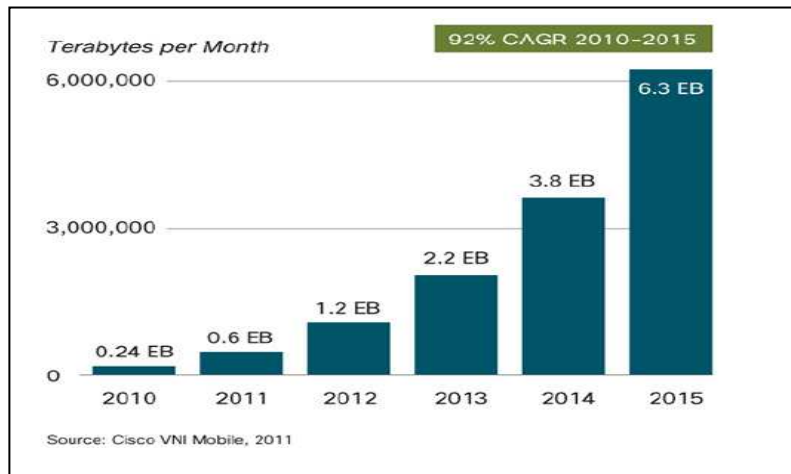


Figure 1: Overall Mobile Data Traffic (2010-2015) [Cisco Visual Networking Index: Global Mobile Data Traffic]

Mobile video content has a much higher bit rate than other types of content and is expected to generate much of the mobile traffic growth through 2015, where 4.2 Exabytes of the 6.3 Exabytes global mobile traffic will be due to video traffic. Figure 2 shows a forecast for the evolution of the mobile video traffic by 2015 [which is expected to generate 66 percent of the world's mobile data traffic].

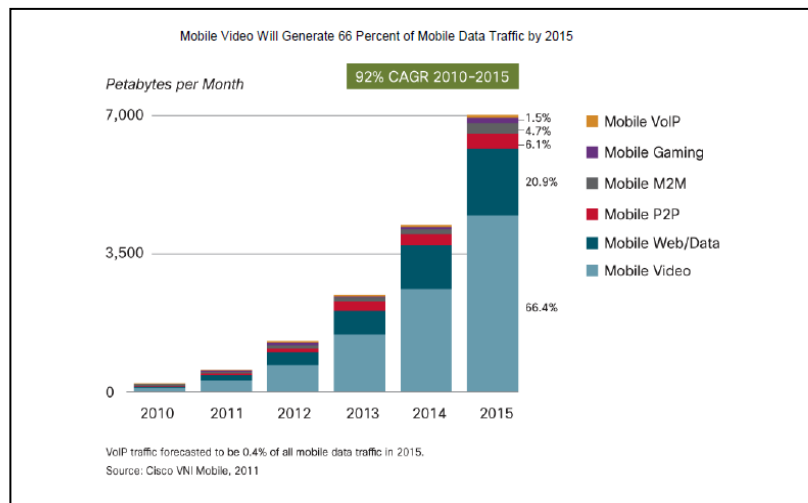


Figure 2: Video Mobile Data Traffic (2010-2015) [Cisco Visual Networking Index: Global Mobile Data Traffic]

1.2 Mobile TV Video Distribution

The most common distribution means of Mobile TV are cellular networks and more recently WiFi networks. Mobile TV distribution was initially largely focused on cellular networks. Network capacities are upgraded when required to sustain the TV data growth in order to maintain a high network Quality of Service (QoS). Some technologies have emerged for broadcasting content over cellular networks, including Multimedia Broadcast Multicast Service (MBMS), Integrated Mobile Broadcast (IMB), and Evolved MBMS (e-MBMS) for Long Term Evolution (LTE) networks. These technologies are currently either not mature yet or not widely deployed.

Multimedia Broadcast Multicast Services (MBMS) [4] delivers multimedia content to several users at the same time and are adapted to TV broadcasts (live events, for example) but not suited for video on demand (VoD). Evolved MBMS (e-MBMS) [5] has emerged to support multimedia broadcasting over LTE networks and has a similar concept and high-power requirements as MBMS. The eMBMS is equivalent to MBMS however for LTE offering higher capacity and allows the resources sharing between the unicast and multicast where a transition takes place between unicast and multicast function of the number of audiences of the same channel within the same cell. Even though MBMS and eMBMS technologies are standardized, they aren't deployed in practice because no terminals support them owing to the absence of business models that can work among broadcasters, MNOs, and terminal vendors.

In this paper, we focus on eMBMS and we propose a solution to enhance this technology through adapting the multicast delivery (as presented in Section 3).

1.3 Mobile TV Standards

Different mobile TV standards have been developed by various countries. Some of these standards include DVB-H, DMB, S-DMB and MediaFLO. In this section, we discuss different mobile TV standards [6] taking into account features such as audio/video codecs, transmission schemes, power saving techniques, frequency bands, etc.

Digital Multimedia Broadcasting (DMB) is a digital radio transmission technology that is seen as the next generation digital broadcasting service for indoor and outdoor users. DMB was developed by the Electronics and Telecommunications Research Institute of Korea in 2004 based on Digital Audio Broadcasting (DAB) standard. DMB uses the same video encoding scheme as DVB-H namely, H.264. However, DMB uses a different audio encoding technology, MPEG-4 Bit Sliced Arithmetic Coding (BSAC). It also uses MPEG-2 Transport Stream (TS) as the transport format. While DMB does not have the function of time slicing, it deals with a lower bandwidth of 1.54 MHz for keeping the tuner power low.

Satellite Digital Multimedia Broadcast (S-DMB) is a mobile satellite system which provides a communication medium in areas where terrestrial coverage is not available. S-DMB is suitable where terrestrial networks have not been deployed. S-DMB provides a high data rate broadcast service to any 3rd Generation Partnership Project (3GPP) standardized Class 3 handsets (250mW). The system operates in the International Mobile Telecommunication 2000 (IMT-2000) frequency band allocated to Mobile Satellite Services and is based on a dedicated high power geostationary satellite.

T-DMB is a **Terrestrial Digital Radio Transmission System** for broadcasting multimedia to mobile units. T-DMB adopts H.264 for video coding and MPEG-4 Part 3 for audio coding and multiplexes them into the MPEG-2 transport stream. In T-DMB, Differential Quadrature Phase Shift Keying (DQPSK) modulation is used over OFDM channel access, which alleviates channel effects such as fading and shadowing.

Digital Video Broadcasting- Handheld (DVB-H) is a European standard designed to use terrestrial TV infrastructure to deliver multimedia service to mobile devices. Since DVB-H only specifies the behavior below the IP layer of a mobile TV system, other service layer standards over DVB-H are required for describing, signaling, delivering, and protecting IP-based mobile TV services (e.g., streaming and file downloading services). Currently, two similar service-layer standards are

available over DVB-H, and they are the Open Mobile Alliance (OMA) Mobile Broadcast Services Enabler Suite (BCAST) standard and the DVB IP DataCasting (DVB-IPDC) standard.

Media Forward Link Only (MediaFLO) is a technology proposed by Qualcomm that uses a limited number of high-power transmission towers. MediaFLO uses OFDM transmission with approximately 4K carriers with either Quadrature Phase-Shift Keying (QPSK) or 16-Quadrature Amplitude Modulation (16-QAM) for the modulation of the carriers. MediaFLO provides multiple types of encoding schemes such as H.264, MPEG-4, and RealVideo. MediaFLO supports a multiple-level error correction system and an efficient coding which provides efficiencies of 2 bps per Hz to allow 12 Mbps with 6 MHz. MediaFLO uses the OFDM to simplify the reception from multiple cells, and the handsets receive the same packet from multiple cells which can improve the reception.

Integrated Service Digital Broadcasting-Terrestrial (ISDB-T) is similar to DVB-T and is used in Japan to provide digital service to TV sets and handheld mobile devices. It systematically integrates various kinds of digital content, each of which may include High Definition Television (HDTV), Standard Definition Television (SDTV), sound, graphics, text and so forth. ISDB consists of various services. In an ISDB-T network, signals for both fixed and mobile reception services can be combined in one transmission via the use of hierarchical layers. Transmission occurs as a continuous flow by minimizing delays in signal acquisition when the user switches from one channel to another.

1.4 ATAWAD TV Service Access

Mobile TV service is based on real time video streaming over IP. Operators propose the service in a ‘managed’ manner and guarantee the delivery and the bandwidth requirements for service quality and customer satisfaction. Delivering the same service under roaming policies for mobile and nomadic users is a new trend to allow mobile TV access Anytime/Anywhere/Anydevice (ATAWAD).

The structure of classical IPTV networks as explained in [7, 8] consists of an access network and a core network. This structure is slightly modified for users accessing mobile TV under the eMBMS model. In both approaches, multicast protocols are the key element in communication through mainly Protocol Independent Multicast - Sparse Mode PIM-SM [9] protocol for multicast routing. PIM-SSM (Source Specific Multicast) [10] can also be used for high optimization. Network operators search for dynamic solutions to cope with clients’ mobility and nomadism with the guarantee of video quality. This is mainly through adapting the multicast topology according to clients’ behaviour and considering the cost reduction. Operators then need to reconstruct multicast trees to match the clients’ needs and networks resources optimization. In this context, we propose in this paper a dynamic reconstruction of the multicast spanning tree topology.

Figure 3 illustrates the global architecture for ATAWAD TV Access including Nomadic Access (NA) for TV Service. This architecture extends the classical IPTV service access in the UP-TO-US project [11] to allow for mobile and nomadic TV access considering the ATAWAD principle. Layer1 in this architecture highlights the local access of TV service based on any device through context aware recommendation system based on the user location in his personal sphere. Layer 2 represents nomadic TV access based on the same principle of layer 1. Layer 3 represents nomadic TV access in hotels based on software Set-Top-Box (STB) to simplify the access and allow service portability. Layer 4 is represents mobile client and handover process for terminal mobility.

We differentiate between the home network and the visited one in TV access as follows:

Home Network (HN): refers to the user local home network where he resides with his Set Top Box (STB). This STB is installed by an operator in a physical location (cable, fiber) inside the home.

Visited Network (VN)/Nomadic Network (NN): refer to any access network different from the user home network. It could be with the same operator, outside the user local home (mobile or nomadic) or through any other operator (roaming).

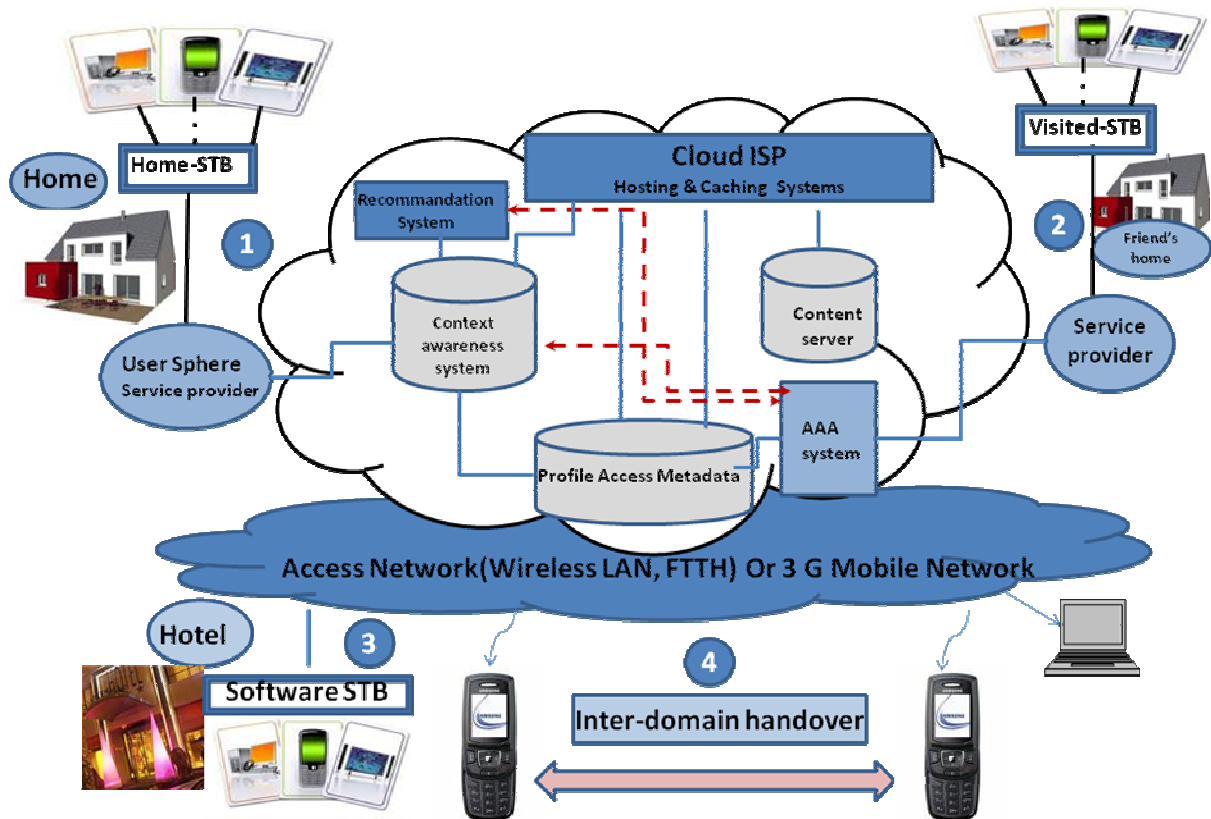


Figure 3: ATAWAD TV access

Since multicast is the base for modern live TV, operators search for dynamic solutions to cope with the clients mobility and nomadism. This behaviour is confronted with the guarantee of video quality implying changes in the multicast topology. Network operators then need to multicast the required TV channels in a customized manner by adapting their multicast trees to the client behaviour and also to minimize the access cost. To do this, there are two ways:

- Clients build Virtual Private Networks (VPN) with their home networks to obtain their videos. This solution is not scalable when the number of clients increases and with the existence of multi-domains (many hops). Also, it is not efficient in video applications for delay and performance issues.
- Operators should reconstruct multicast trees to match the clients' needs. This solution has more benefits in terms of network scalability and resources optimization. It matches our objective where we propose a solution to reconstruct the multicast spanning tree topology.

In our proposed solution we consider three optimization criteria: i) **CAPEX cost: Capital Expenditure** is the essential and fixed investments in main infrastructure, ii) **OPEX cost: Operational Expenditure** is the running cost for long term operation, and iii) **Revenue:** operator benefits from adaptation of the diffusion mode.

2. Adaptation of Mobile TV Content Delivery

Content Adaptation is an important step in mobile TV delivery and can be done by the operator, the service provider or the client itself. However it is little bit complex in this later case and requires more capabilities for the current generation of end devices. So, network operators and services providers are mainly responsible for content adaptation according to the whole context information in the system.

2.1 Context-awareness along the delivery chain: Context types in Mobile TV

It is noticed that traditional content adaptation, recommendation and personalization systems consider only network coverage (for example, EDGE, UMTS, HSDPA...), subscription and the used device (for example, 3GPP device, iPhone, Windows media...) criteria while the general context information is missed (terminal capacity, network status, user's location...etc). To offer a coherent and efficient content adaptation, there is a need to consider additional context information in Mobile TV systems.

Context-Aware Mobile TV service along the delivery chain allows the Mobile TV system to gather in a dynamic and real-time manner the different context information related to the users, devices, network and content, throughout the whole Mobile TV delivery chain. We define four types of context information:

- i) **User context:** Includes information about the user which could be static (user profile, his preferences...) and dynamic (user location, available networks in his proximity...).
- ii) **Network context:** represents the characteristics of the access link being used for accessing/delivering audiovisuals content (jitter, packet loss, delay, available bandwidth).
- iii) **Device context:** User can access the multimedia content through various devices which may have different capacity (device's screens size, CPU, supported format (codec, protocols), supported network technologies...).
- iv) **Content context:** Information about the content itself (type of content, used codec, content format, language...).

On the basis of this information Context-awareness along the delivery chain is promising in enhancing the Mobile TV system through appropriate and accurate service adaptation, recommendation and personalization to increase customer satisfaction and loyalty.

2.2 Enriching Quality of Experience

Quality of experience (QoE), or quality of user experience, measures how users will directly perceive a quality parameter (playback time, rebuffering rate, page load and view duration...). QoE measurement helps also the Content Providers to know consumer satisfaction from the service and then reduces the churn, promotes new services and improves the ARPU (Average Revenue Per User).

To measure how user perceives the quality, QoE is measured through three main means: i) **Objective means** based on network parameters (e.g. packet loss, jitter, delay, available bandwidth, congestion notification from routers...), it is based on network related parameters that need to be gathered to predict the users' satisfaction. ii) **Subjective means** based on the quality assessment by the users giving the exact user perception of the service. This method for QoE measurement is the most fundamental methodology for evaluating QoE, techniques are based on surveys, interviews and statistical sampling of users and customers to analyze their perceptions and needs with respect to the service and network quality. Several subjective assessment methods suitable for video application have been recommended by ITU-T [12] and ITU-R [13]. The most famous metric used in subjective measurement is the MOS (Mean Opinion Score), where subjects are required to give a rating between 1 to 5 (1 means bad and 5 excellent).

3. Multicast TV Delivery Optimization

Actually, there are two famous Multicast service models used in live TV delivery:

- **SSM:** Source-Specific Multicast. In this model, the terminal subscribes to a multicast group to receive data sent to the group by a specific source (only one source for the tree) which means specific source to specific group (S,G) [10]. Therefore, with SSM the network is able to build a separate distribution tree for each multicast source.

- **GSM:** Group-Shared Multicast. In this model, each node in the multicast group could send/receive videos to/from any member in the tree (many sources of traffic in the trees). This type traditionally called Any Source Multicast (ASM) as explained in [14].

The delivery optimization is based on a multicast tree with optimal costs and optimal QoE. We show hereafter a method to derive such a tree.

3.1 Overview on Spanning Tree Algorithms

Engineering the content delivery in a large operator network is crucial. That is why we can find a specific business for cache provisioning (AKAMAI for example) specialized in such optimizations. Adding the mobility aspect explained before introduces new difficulties in the network engineering. We need to move the content close to their mobile consumers. Otherwise, the network suffers from large congestion and the user is unsatisfied from the end to end QoE.

We extend the Spanning tree Algorithms as a mean for optimizing the network delivery architecture for both content delivery networks and live TV for live multicast diffusion. We introduce to the Spanning Tree Algorithms based on the parameters previously explained including economical (Capex, Opex) and QoS parameters. We have proposed in [15] the introduction of the virtual node concept to the spanning tree. This virtual node is added as shown in Figure 4 as follows:

- We represent the physical topology of the network including links and nodes. The nodes represent servers and streaming head points (Figure 4.A).
- We add a link between the virtual node to the physical nodes if we can relocate the service in the physical nodes. The link value represents the parameters previously explained (i.e. costs and quality) (Figure 4.C).
- The result is a new graph with an additional virtual node (node 7) and some new links.
- The spanning tree algorithm is applied to that topology.
- The result is a new multicast architecture, optimized with new costs. All we have to do is remove the virtual node and obtain the relocation of servers in the network (we remove node 7 from Figures 4.D and 4.E).

As shown in Figure 4-A, the network is represented by a simple topology of 6-nodes with interconnection links. After running the Minimum Spanning Tree (MST) algorithm to define the shortest paths between nodes on the assumption of node 6 as a network root, we have the output minimum spanning tree structure as shown in Figure 4-B. The weights on the arcs represent the metric values or link costs between nodes.

In Figure 4-C, we insert node-7 as a virtual node to act as a root position between nodes-1, 2, 3, 5 and 6 with same assumption of nodes weights. After that, we run the same MST over the new virtual topology and have the output shown in Figure 4-D. The VN creates new sub trees; one with the old root node-6 and another with new root node-2 and last one with node-5. In Figure 4-E, we have different sub trees (only two) as we change the virtual link weights/costs. The final step is to remove node 7 (Virtual Node) to obtain the divided trees. Those output trees will be analyzed in terms of cost reduction as shown in Section 3.3.

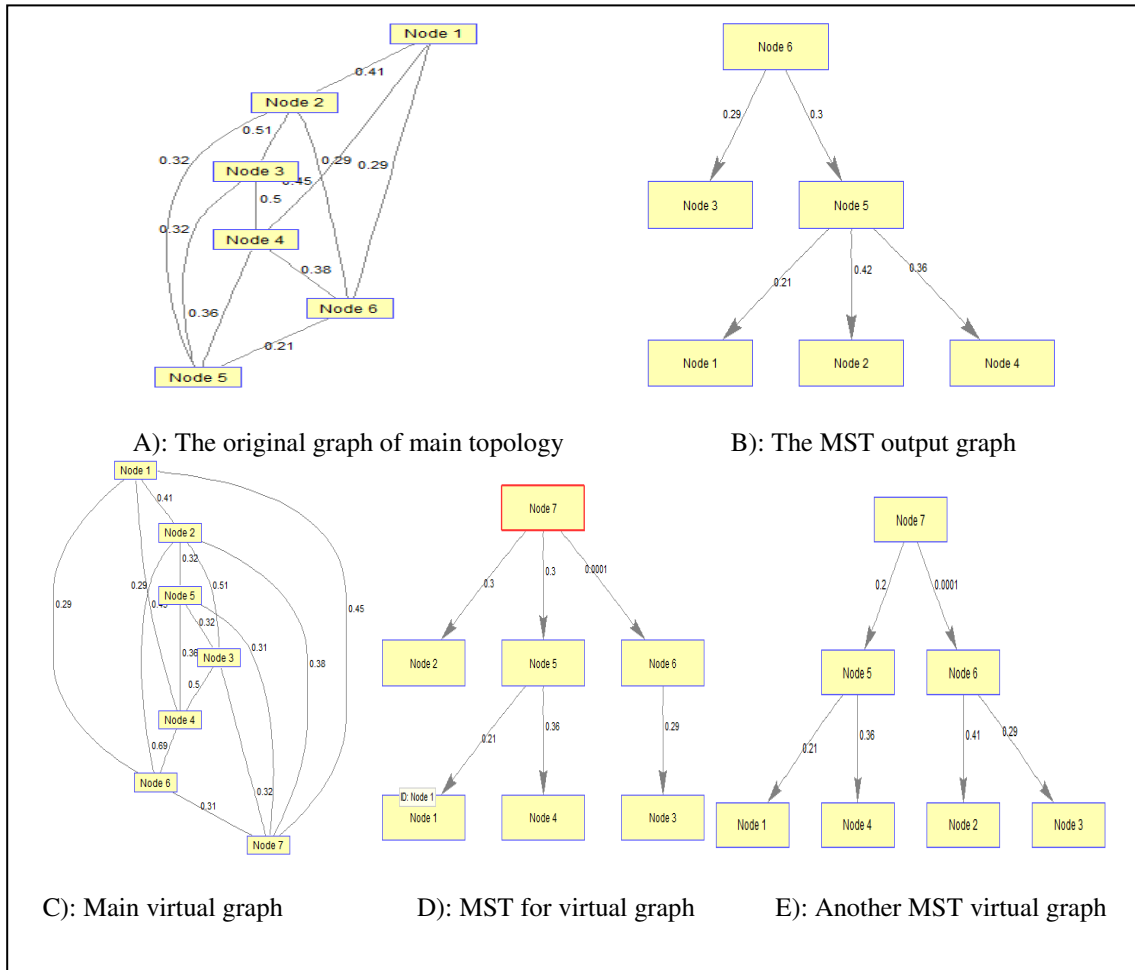


Figure 4. Main and virtual topology by inserting VN (node-7) and different MST outputs according to changing the weights of links between VN and proposed ones

3.2 Mapping QoS on links to end-to-end QoE

In this section, we open the way for enhancing Quality of Experience (QoE) by adapting the spanning tree technique described earlier and choosing the appropriate tree.

It is important to mention that delivery selection alone may not be sufficient to enhance user satisfaction. It only helps mobile users to select the best tree. Recall from the last section that we can improve the diffusion tree by bringing content closer to consumers. After this process, we arrive to a set of possibilities where users can retrieve contents. To enhance users' satisfaction, we focus on tree selection and look at the Quality of Service (QoS) offered by each tree in order to achieve good user perception for the consumed content.

The QoS value for each link can be calculated as the the sum of the network parameters multiplied by a weight for each attribute (bandwidth, delay, jitter, packet loss). For example, a VoIP application may favor the bandwidth and the delay while for the video streaming the bandwidth and jitter has more importance. This is reflected by assigning higher weight for different parameters based on type of application.

We consider the different attributes between each two nodes and then compute the corresponding QoS based on what we previously explained. The end-to-end QoS is characterized by the minimum (QoS (link)).

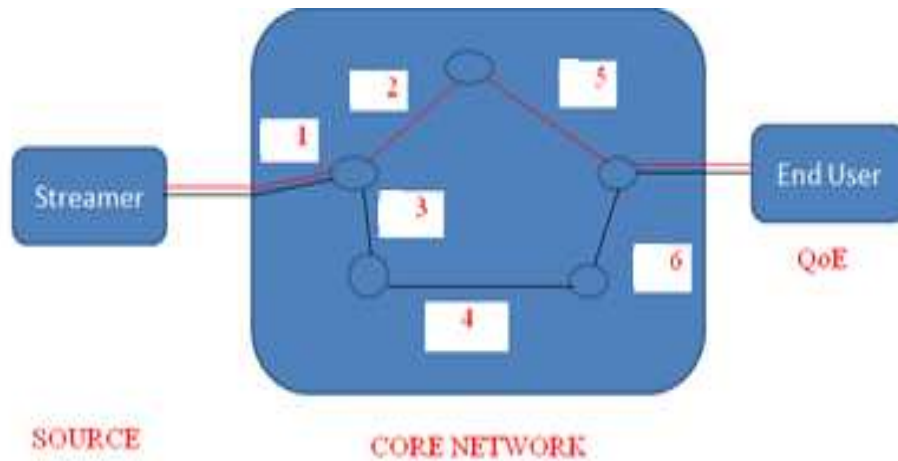


Figure 5. Mapping QoS to end-to-end QoE

As shown in Figure 5, to gather the content, the terminal has two choices: route (1, 2, 5) or (1, 3, 4, 6). The method computes the QoS for route in the tree and selects which one has the maximum score and the corresponding route in the tree will be the chosen distribution path that will guarantee better QoE. Consequently, we succeed in reducing the transmission cost through the enhanced MST and the selection of the streaming source that maximizes the QoE.

3.3 Evaluation and Results

We evaluate the proposed algorithm based on the virtual links cost (i.e. weight) between VN and the other potential nodes (nodes to act as new streaming points). Then, we study the evolution of the new tree with respect to the weights as:

- The VN has equal weights to the proposed nodes [from 0 to 1 step size 0.1]
- The VN has different weights to the proposed nodes [from 0 to 1 step size 0.1]

The equal base assumes that the costs are equal for all the new roots. The total virtual resource is equally divided between the new roots. For non-equal base, we assume different costs on new roots has different base of resources which means different cost.

We change the weights/costs on virtual links and prove that all the results give always an MST with total costs less than the original one.

Actually, the proposed costs or weights on virtual links depend on the network state (number of mobile clients, bandwidth, global QoE). This state is dynamic so the costs vary and the process is not detrimental but, could be considered as stochastic.

Moreover, the prediction of network state and nodes capacity changes according to users joining/leaving the delivery process. Hence, we will suppose different topology scenarios and assign different costs/weights on virtual links between 0 and 0.9 on equal and non-equal bases. In the following three figures, we simulate three scenarios with different number of nodes.

We run the MST taking into consideration the VN as a new root for the virtual topology and check the second level under the virtual root that actually represents the real roots for the generated trees. We then remove the virtual root. We recalculate the MST costs for the new trees and compare them with the original MST costs.

We plot in Figure 6, the total spanning tree cost gain compared to the original tree. We can see that all generated trees give MST costs less than or equal the original one as shown in Figure 6.A,B and C for 6, 16 and 25 nodes respectively. As it is known from MST complexity, time consumed by MST algorithm to build the final trees may be long. We improved the algorithm convergence time as shown in Figure 6.D with a non-heuristic method [15].

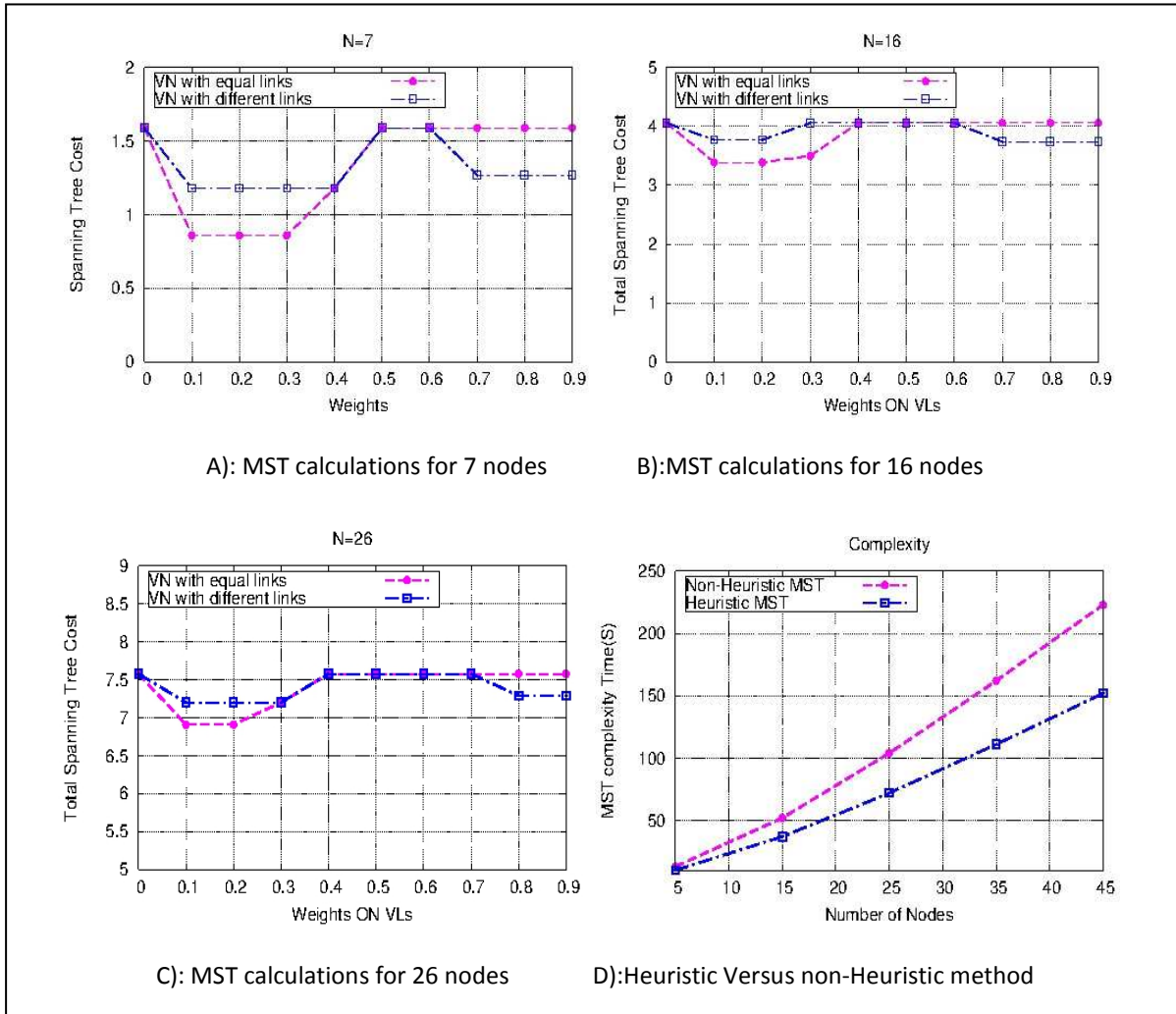


Figure 6. Simulation results based on topology structure and MST algorithm complexity

5. Conclusion

The great advancement in personal devices including smartphones and personal devices have completely revolutionized the way we live and entertain ourselves. Mobile TV has been attracting a lot of attention recently because of the tremendous revenue potential for all the players involved in its generation, distribution, management, and use. Despite the increasing demand of such a service from mobile users, the speed of adoption has been slow since many technical challenges still need to be solved. Among these challenges are the deployment cost for network operators and the QoE guarantee for users. In this paper, we present a market analysis for mobile TV, describe several related standards and technologies, then present a new solution for optimizing the live TV multicast diffusion for mobile users over eMBMS technology. The proposed solution

extends the Minimum Spanning Tree (MST) algorithm through considering cost reduction and QoE guarantees. The proposed solution is evaluated through simulation and the obtained results show the achieved gain. As a future work, we tend to consider more QoE metrics and implement the solution in a real platform.

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