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Recent Advances and Challenges in Human-centric Multimedia Mobile Cloud Computing

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Abstract— **The increasing usage of cloud computing, along with the proliferation of mobile devices and the demand for multimedia services, are changing the life style of users and creating new opportunities to providers and clients. Multimedia data will account for up to 90% of all Internet traffic in a few years, where most of the content will be created, shared, and accessed by mobile smartphones/tablets (carried by humans or placed in vehicles). However, this novel mobile multimedia era imposes new challenges for the networks, content, terminals, and humans, and must overcome problems associated, for instance, with high congestion, low scalability, fast battery consumption, and poor user experience. This paper discusses recent advances and challenges in human-centric mobile multimedia cloud computing approaches. On the one hand, Internet cloud will ubiquitously enrich multimedia mobile environments with more advanced and powerful features, including high processing and memory, scalability, availability, and adaptability. On the other hand, mobile devices will efficiently cooperate with each other to form mobile clouds that offload the Internet clouds from tasks that the latter cannot perform in a timely or efficient manner, including video and resource sharing. Both Internet and mobile clouds will be efficiently used to adapt/optimize multimedia flows to a single user or a group of users according to the current network conditions, context-awareness, content characteristics, device capabilities, and human experience.**

Keywords: Mobile Cloud Computing; Human-centric Networks

I. INTRODUCTION

The evolution of wireless access technologies, mobile devices, and protocols together with the constant demand for video applications has created new human-centric multimedia scenarios. Thousands of users will produce, share, and consume video services on smartphones and in a ubiquitous manner, ranging from provider-generated entertainment videos to user-generated disaster or surveillance real-time flows.

The vision of human-centric multimedia places the users in the centre of mobile multimedia content services, where the video delivery process must be accomplished and optimized according to the human experience (Quality of Experience – QoE) [1] and context-awareness. Mobile multimedia systems will require instant adaptation of content and resources according to the human preferences, experiences, or/and interests due to increasing situational dynamics, such as mobility and bandwidth scarcity. In case of MANETs, the fast battery consumption of smartphones/tablets is also another key problem to be minimized for users consuming multimedia data.

The integration of human-centric multimedia networking into Internet cloud computing environments allows mobile users to have new media experiences that are not possible from their mobile smartphones/tablets [2]. The cloud can be configured to perform a set of important tasks and services for mobile multimedia users and networks, ranging from assessing the video quality level and load balancing to multimedia transcoding and redundancy/error correction schemes [3-4]. Thus, the user experience in consuming human-aware videos is increased, while the cloud "virtually" extends the capacity of mobile devices, such as battery, memory, and processing.

Even with the aiming of Internet clouds, mobile users can still suffer from congestions, frequent disconnections and low video quality experience. For instance, many devices can upload or download the same/similar content (at the same time) from the Internet by using overloaded (and possible high cost) 3G, LTE, or Wi-Fi networks. However, they could cooperate with each other and only one (or few) mobile device could interact with the Internet cloud and request video flows to be locally shared with all neighbours by using Wi-Fi direct, bluetooth, or even IEEE 802.11p/WAVE in case of vehicular networks. Since wireless devices are constantly sensing the environment and sharing scarce resources, they could cooperate with each other in maximizing the usage of network resources and human experiences. These mobile terminals can form Mobile Clouds that offload the Internet [5].

Mobile clouds can be dynamically composed of wireless devices located in same area, sharing the same preferences, contexts, and/or videos. Thus, mobile clouds can increase the accuracy of networking protocols or services (enriching with sensing information), while reducing communication delay, spectrum costs, and extending the range of mobile applications. The integration of mobile clouds with Internet clouds must be seamless and will bring many benefits for both users and network/content providers [6]. The Internet cloud can enhance mobile devices/clouds by performing high complex or too energy consuming procedures, such as real-time video quality level assessment or human-centric video transcoding [7].

Differently from existing works [7-11], this paper will discuss recent advances and challenges coming from the integration of Internet and mobile clouds for Human-centric Networking (HCN) systems. HCN mobile cloud computing schemes will offer new opportunities for users, content-generators and network administrators and will overcome the current multimedia-networking (or even content and information-centric) paradigm, where coding, transmission and adaptation operations are performed only based on a set of video and network parameters, such as bit rate and packet loss rate. HCN will allow the creation of an efficient, powerful and rich human media collaborative environment.

By exploiting the computing, storage, social interactions, and sensing capabilities of an integrated Internet and mobile cloud environment, many multimedia applications can be executed on low resource mobile devices and in a human-centric fashion (according to network, device, content, and human characteristics). However, some key questions must be analysed for the future human-centric mobile multimedia era as follows: Do we really need human-centric approaches in multimedia networking? How to integrate Internet cloud and mobile cloud in human-centric systems? What can be expected for human-centric multimedia mobile cloud computing environments? Privacy, security and performance issues are out of the scope of this paper.

The remainder of this paper is organized as follows. Section II discusses the need of human-centric multimedia approaches and how human-centric schemes can improve the multimedia era. Section III presents an overview about Internet and mobile cloud computing. Human-centric multimedia mobile computing research challenges and open issues are introduced in Section IV. Conclusions are summarized in Section V.

II. Do we really need human-centric approaches in multimedia networking?

Multimedia services over wireless networks are becoming a part of our personal and professional lives and have been used for sharing many types of content, ranging from user-generated to entertainment live videos. According to Cisco, more than 10 billion mobile devices are projected to be in use by 2016, and 71% of all mobile data traffic is expected to be videos by that time as well. Videos will represent over 90% of the global IP data by 2016. The multimedia market will continue to expand over the next several years with mobile video services, for instance, total revenues only in France's multimedia market will rise to $1.96 billion in 2016. The multimedia industry believes that mobile video consumption is growing at such a fast pace, that it is comparable to an unstoppable train. Get on board or get knocked down!

The evolution of the Internet over the past decades has aimed to provide network-centric traffic differentiation, resource reservation and Quality of Service (QoS) support for multimedia content. However, QoS proposals are only suitable to indicate the impact of network performance on the delivery of multimedia services, such as bandwidth, packet loss rate, and packet delay rate. QoS schemes alone are not enough to assess and control the quality level of multimedia applications, because they fail to capture subjective aspects of multimedia content related to human perceptions. With this goal in mind, many researchers, standardization bodies and industries have been studying Quality of Experience (QoE) approaches [2], where the user experience can be measured and integrated into networking components to improve the overall performance of multimedia systems. However, QoE and networking schemes must be extended with context-awareness, content adaptation, cloud computing, and human-based models to provide a better application, service, and resource utilization for multimedia human-centric systems.

Following the success of recent research topics, such as Content and Information Centric Networks (CCN and ICN) [12], HCN has been seeing as a key paradigm to improve the usage of network resources, while also ensuring a better human experience in consuming/sharing video applications. HCN can be used to improve the dissemination of videos in fixed and wireless CCN/ICN or even in the traditional host-to-host communication Internet. In HCN scenarios, content creators and network providers should be able to adapt, share, and deliver video flows according to different (cloud) network conditions, devices capabilities, environmental characteristics, and human-centric models and metrics. For instance, HCN must improve the system performance and user satisfaction by taking context, network, and human-awareness into account in the video creation/transmission/access decision-making process, such as the user experience, preferences, interests, human visual system requirements, video motion and complexity levels, frame type and importance, network impairments, and mobile device characteristics.

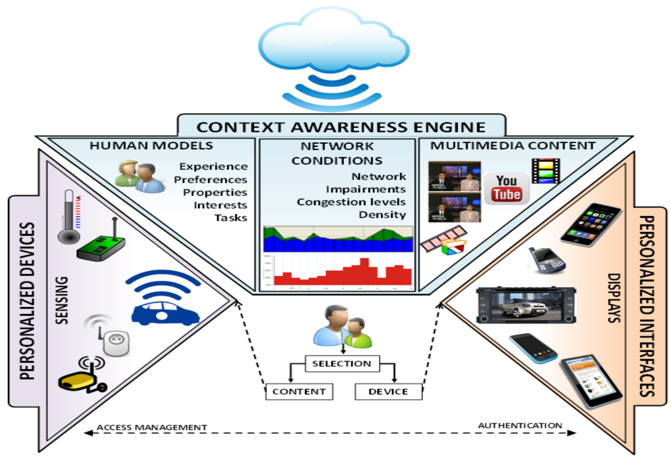

Figure 1. Human-centric multimedia networking scenario

Fig. 1 shows a human-centric mobile multimedia environment composed of three main modules, named Personalized Devices, Personalized Interfaces, and Context-awareness Engine. Regarding personalized mobile devices (smartphones, tablets, notebooks, and also vehicles), they do not rest only on the computing resources (such as for the Internet clouds) but on the sensors they carry, including cameras, light sensors, and location schemes. For instance, environment monitoring and surveillance services using video cameras and sensors are increasingly important functions in human-centric scenarios, where users cooperate with each other to improve surveillance and monitoring missions. Moreover, different devices have different display sizes and resolutions, as well as memory and processing capabilities. Videos can also be distributed based on the available resources in mobile devices to improve the usage of network resources and increase the user satisfaction.

Human-centric approaches must also be enriched with a context-aware engine. Advanced models can describe the human experience in consuming real-time videos, preferences allowing systems to dynamic adapt the content/resources according to the human needs, properties of the human visual system, and interests can be used to configure filters and improve the system performance. Understanding and modeling user behaviors, experiences, feelings, and psychological aspects when consuming and sharing multimedia data are key issues for HCNs. Human-based data can be collected from social networks, social interactions, and/or any context management systems, such as [13-14]. Information about the current and future network conditions, including packet loss and delay rates, quality of the wireless links, congestion levels, available buffers, and system density (sparse or dense), are essential to improve HCN decision-making engines and networking algorithms, protocols, and mechanisms (from data link to application layers).

Multimedia content characteristics are also key information for HCN systems, where spatial (edges and colors) and temporal (movement speed and direction) activities, frame types, intra- and inter-frame dependence, CODECs, Group of Picture (GoP) lengths and partners, bit rates, resolutions, and region of interests must be considered in assessment, control, and collaborative HCN procedures. For instance, depending on the video motion and complexity levels (e.g., a small moving region of interest on a static background or fast-moving sports clips), the impact of a packet lost in the human visual system can be annoying or not [15]. The information on video characteristics can be collected from deep packet inspection schemes, off-line signal processing analysis, or described in a Media Presentation Description (MPD) as proposed in MPEG DASH standard. This information is extremely important for content and networking procedures in HCN systems as presented in [15] for in-service assessing the video quality level and in [16] for mobility with QoE support.

The integration of personalized devices, interfaces, and context-awareness into HCN requires extra processing, memory, collaboration, and communication efforts from users, content-generators, mobile devices, and networking systems. Thus, Internet cloud together with mobile cloud will enrich HC multimedia mobile environments with more advanced, cooperative, and powerful features, including high processing and memory, scalability, availability, and adaptability.

III. Moving from Internet Clouds to Mobile Clouds

According to ABI Research, by 2015, more than 240 million business customers will be leveraging cloud computing services through mobile devices, driving revenues of $5.2 billion. The size of the mobile cloud market is poised to reach over $45 billion in a few years. Therefore, new approaches for mobile cloud computing must be discussed and implemented to improve the performance of cloud and HCN systems.

The mobile cloud computing is being defined as the combination of cloud computing and mobile devices. The mobile devices are considered as clients and sensors, which provides interface for human interaction and/or collecting data. Today smartphones and tablets are used for accessing email, posting pictures on social networks, sharing videos, and crowdsourcing traffic congestion [17][18]. The idea for offloading computing to the Internet cloud from mobile devices overcomes obstacles related to performance and reliability, allowing the usage of new HCN services and applications.

Although mobile devices provide end-users a new way to access the Internet cloud, the system architecture of the client - datacenter model is not new. From the systems perspective, there is not much difference between accessing the Internet cloud through wired or wireless networks. The two major differences between mobile and non-mobile clients are (1) Hand-held devices are more convenient data collectors (e.g., camera, motion) and are generally equipped with Global Positioning System (GPS); (2) Wired network provides cheaper and faster network access for desktops. In both scenarios, the Internet cloud is the powerful time-sharing system that provides massive computing power and storage, while end-users share the same hardware inside datacenters across the Internet [19]. In mobile cloud systems, which have the similar time-sharing idea, all devices are distributed in the mobile network and can share resources and content.

A mobile cloud can be defined as a group of mobile devices that collaborate with each other to provide powerful services. Mobile clouds can be situated at the edge of networks. All data collection, process, and storage schemes are performed on mobile devices. Mobile clouds are better than the Internet clouds in two major areas: bandwidth consumption and localization. Consider the scenario, where every mobile device in the city is sensing the Wi-Fi spectrum around itself and submits the collected data to the data center to build a real time spectrum map. Such application requires significant amount of bandwidth for all devices to submit data, especially a large amount of multimedia content. Namely, the bandwidth consumption scale linearly to the number of participating devices. On the other hand, if devices collaborate and exchange sensed-data and generate aggregated-data, the bandwidth required could be significantly reduced. Another example is the video surveillance application. Suppose that the police department is looking for a specific target and requests mobile devices to submit their videos from the last hour and with QoE support. It would be more efficient, however, for each device to search for the target and then upload only the search result with a high quality level. Mobile cloud can be easily applicable in VANETs. Energy consumption is the fundamental problem in mobile networks, and a vehicle is a perfect power source for mobile devices. Instead, new challenges arise, especially for human-centric multimedia networking scenarios, such as accessibility, bandwidth, and QoE assurance.

When mobile nodes form a cloud, it is possible to download content more efficiently. Currently, when each mobile user downloads a set of content, he or she pulls data directly from the source through the Internet, which can increase the packet loss rate and decrease the richness of the human experience for video applications. When multiple mobile users request the same content, there is no collaboration between different devices, and the same content has to be transmitted through the wireless medium multiple times and consumes extra wireless bandwidth resources. Under the structure of a mobile cloud, individual wireless devices, or even vehicles, request data through mobile clouds. Mobile clouds assign the downloading task to the device with the best capability (e.g., wireless link) to download the video. The downloading video is then transcoding into different video sizes and qualities. With the support of mobile clouds, the data are only requested once from the Internet to the mobile cloud to save resources and reduce costs. After that, the content is shared to neighboring devices by taking human experience, device capabilities, and content characteristics into account.

Mobile clouds improve HCNs by managing networks, devices, and content from their participants. To form a cloud, the first step is to have devices connected to each other directly through Wi-Fi, LTE direct, or WAVE. Once connected, vehicle propagate their available resources to their neighbors. This includes devices information, network impairments, and content characteristics. In addition, the metadata for existing content could be published to the mobile cloud. Finally, when the device receives any data, there is a human feedback system that tracks the experience of the received content, allowing mobile clouds to enrich HCN with more powerful features.

IV. Human-centric Multimedia Mobile Computing Research Challenges and Open Issues

Mobile cloud computing is one of the fastest growing segments of the cloud computing paradigm and will change the multimedia human-centric era. However, there are still important challenges that need to be addressed in future human-centric multimedia mobile cloud computing areas. For this paper, the challenges and open issues are grouped into cross-layer human, content, and network/device management schemes (covering approaches from link to application layers), where both Internet and mobile cloud computing systems will allow the creation of more powerful and accurate approaches.

Regarding human management approaches, new online, non-intrusive, and QoE video prediction/assessment solutions must be created to measure the quality level of real-time videos with different characteristics as close as possible to human viewers. Standardization bodies and research groups, such as ITU-T Study Group (SG) 12, have been proposing well-structured QoE assessment models. However, in practice, existing solutions have not been discussed and implemented in wireless multimedia systems with videos with different characteristics, humans with different preferences, and heterogeneous cooperative mobile devices. Thus, new in-service 2D/3D video quality assessment schemes must be implemented taking a set of human perceptual attributes into account, including the overall video quality, environmental characteristics, device features, and comfort, which, in turn, are the result of technical, social, and psychological factors. Understanding the behavior/experience of a single or groups of users is a critical issue for video quality assessment.

Quality of feeling and emotional-based metrics and experiments are expected to be defined in future HCN proposals and will be conducted to improve the accuracy of video quality monitoring approaches. Moreover, the use of crowdsourcing for subjective human studies will reduce the time needed and increase the performance of new solutions. In a future multimedia era, users can pay for video services based on a *pay as you experience* approach and not a flat rate (or QoS measurements) as currently happens. The human experience can be used to define service-level agreements and other video distribution contracts.

Recently, intensive effort has been made by MPEG and other video-related research groups to create new standards and content-aware schemes for streaming multimedia over Internet, such as MPEG Dynamic Adaptive Streaming over HTTP (MPEG-DASH). A problem to be solved is how to code/decode/transcode video content, taking the human experience into consideration and making it as adaptable as possible to different network conditions and mobile devices. Signal, image, and video processing schemes are time consuming and hard to implement in real-time. Therefore, the description of the video characteristics is a key issue for allowing real-time videos to be assessed, negotiated, and adapted with high accuracy. The creation (or adaptation) of novel 2D and 3D video codecs adaptable for human experience environments is still an open issue and must be addressed in future systems. Networking techniques can also use the video description to optimize the delivery process.

Internet and mobile cloud computing enriches transcoding with more powerful features and human-awareness. However, the video bitrate adaptation alone is not enough to [2, 6, 20] efficiently create new versions of the content for users in wireless heterogeneous networks. Human models, context-awareness, networking statistics, and sensing information must be used to optimize transcoding schemes for HCNs.

The previous approach can also be used and extended for caching schemes (popular in CCN/ICN). One of the benefits of CCN/ICN is the exploitation of in-network caching. However, a video source that streams multiple video formats to a single geographic location (e.g., home and VANET) will consume network resources for each different video quality and size. Caches can be placed at edge/mobile clouds and optimized according to different contexts, human models, and device resources. A key requirement for improving caching schemes is to integrate human centric experiences such that each user provides probing and feedback to the video cache service. This information can then be used to optimize and selectively cache/transcode videos as needed and deliver the content to mobile devices as human-adapted streams. Such approaches can allow the network to generalize multiple geographic regions containing multiple different devices and coalesce to a small number of high quality video streams, which can be cached in-network.

Additionally, as the amount of participatory data produced and consumed at the edge grows and dominates the available network bandwidth, we can consider techniques to transform and transcode data at the edge rather than incurring the latency of traversing to the data source located at the datacenter cloud. For example, social networks promote re-sharing and editing of content (such as Vine). An image may be originally shared, than filter effects added to enhance the image. Next, multiple of such images may be combined together to create a collage or short video. Additionally, these images are shared on various screen sizes. In these cases, rather than sharing the full image at the edge, new solutions can be proposed to exchange only the image differences, which are an order of magnitude smaller than the actual image. Therefore, if one image is the cropped version and image filter of the original, a user with the original image applies the crop transformation and then the filter transformation to the original rather than fetching the full image. Cooperative mobile cloud schemes aim to increase the processing and memory capacities of mobile devices increases (including multi-core equipment). A single high quality image is shared, transformation differences are exchanged, and end-nodes perform the necessary transcoding to fit their screen as well as apply the transformations. Human-centric multimedia storage, search and retrieval schemes are also important issues to be addressed in future systems.

Human and content management information must be used to improve networking approaches with human, application and environment-awareness. HTTP streaming has become a dominant approach in commercial deployments and must be extended for reporting human experiences and improving the video delivery process. New transport protocols will replace UDP with more advanced HCN capabilities, especially in multi-homing and cooperative environments. Resource reservation, routing, mobility, queuing, and access control schemes must be extended with human, content, and context-aware information. For instance, in wireless networks with high error rates, packet redundancy approaches, such as FEC, must add redundant video packets according to the user perspective, device characteristics, and information about the source of the network congestion process. Additionally, mobile devices must handoff to new access points according to QoE/human-related factors and not only based on RSSI or network layer metrics. Mobile cloud devices can cooperate with each other to share resources, content, experience, while reducing the system overhead and increasing the user satisfaction and the usage of scarce wireless resources.

The implementation of previous challenges and open issues are not simple tasks and require studies and experiments. The interaction between different areas, such as informatics, engineering, visual arts, medicine, and psychology, is crucial to understand the human visual system, behavior, feeling, and psychological factors. A common sense is that Internet clouds together with mobile clouds will make the implementation of human-centric mobile systems possible and will enrich them with more advanced, cooperative, and powerful features.

V. Conclusion

This paper discusses recent research activities and open issues for human-centric multimedia mobile cloud computing. Mobile cloud will offer new opportunities for users, content-generators, and administrators. Understanding and modeling user behaviors, experiences, feelings, and psychological factors when consuming and sharing multimedia content are key issues for HCNs. The seamless integration of Internet and mobile clouds with HCN will optimize the usage of network/device resources and enrich multimedia wireless environments with more advanced, cooperative, and powerful features, including high processing and memory, scalability, availability, and adaptability. Although still in its infancy, human-centric mobile cloud computing will become the dominant model for multimedia applications in the near future.

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