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Cooperative content and radio resource allocation for visual information maximization in a digital signage scenario ☆

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ABSTRACT

In this paper, we present a cooperative content and resource allocation algorithm that selects networks and sub-carriers for digital signage scenarios based on visual information. In these scenarios, both 2D and 3D content are handled in open space for the advertisement of commercial products. To quantify visual information, we propose a quality of visual service (QoVS) metric based on human perception. We then construct the expected QoVS problem to guarantee the maximum QoVS for service users. The QoVS is determined based on the level of 2D visual sensitivity, and on the ability to perform 3D binocular fusion by users located at various viewing distances. By utilizing the QoVS, we predict wireless packet errors and loss of visual information caused by limited radio resources. After 3D content is selected to be multicasted to users by means of the large displays, sub-carriers are optimally allocated for the remaining smartphone users to facilitate point-to-point communication through lossy wireless channels. Simulation results of the proposed scheme demonstrate the advantages of automatic control of visual information and radio resources for multiple users without additional interactions. Moreover, the method developed herein can be flexibly applied with low complexity to several visual application services provided over heterogeneous displays and channels, such as advertisements, exhibitions, and forums.

1. Introduction

In accordance with the increasing size and resolution of viewing environments, next-generation video content has evolved into ultra high-definition (UHD) resolution. In parallel with the development of the UHD 2D display, 3D technology has also been developed to provide more visual presence to viewers by means of the projection of virtual depth in the 3D display. Moreover, as display sizes have become sufficiently large to cover the full visual angle for a given viewing distance, it has become possible to deliver visual information to viewers to allow them to perceive more realistic scenes with greater immersion [1,2]. Accordingly, service scenarios can be diversified with the provisioning of diverse programs, such as advertising with large screens or multiscreens, while displaying commercial content to multiple users. When applied in public and commercial places, this technique is referred to as digital signage service [3].

In practice, there is no solid standard specifying the viewing environment of digital signage service, including the type of display, the community, and the business model [30,31]. Thus, in this paper, we make an effort to generalize the multiuser environment in accordance with the desired scenario, which can be adaptively applied to similar types of visual service without modifying the environment specification. Fig. 1 depicts an example of the multiuser service scenario in which multiple users view advertisements displayed by a large 3D screen. The display is placed in a service area to show commercial content, such as advertisements, movie previews, and so on. A server transmits the content, including videos and images, to a set-top box by means of a wireline network. The content is then multicasted to viewers by means of the large screen. To select an appropriate program, user requests are transmitted to the server, and the server makes the final decision regarding program selection. To provide realistic visual services, it is assumed that 3D and 2D content is respectively displayed on the large screen and on smartphones.

In this space, it is assumed that the advertisement is periodically updated by displaying multiple programs in the consecutive order of majority of requests made by users; each user is assumed to select one program to view its desired information. To provide viewers with greater freedom in program selection, it is necessary

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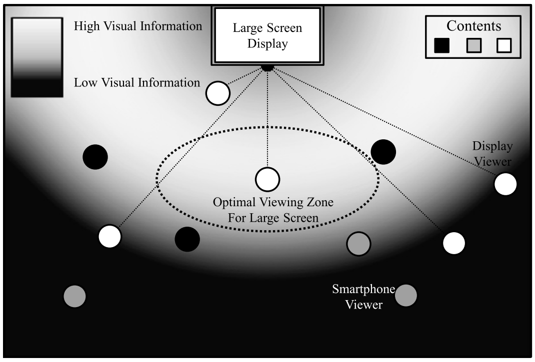

Fig. 1. Example of multiuser service scenarios in which three contents are advertised to users. The users are randomly distributed. A large screen display is utilized for multicasting one content to users. Users who want other content request it by using their smartphones. The volume of visual information delivered by the large display is represented by colors from white to black at various positions. The optimal position—where the visual information is maximized—is indicated in the center of the open space as the optimal viewing zone for the large screen.

to accommodate user demands in the realization of visual content services. To allow users to report which programs they want to be displayed, it is assumed that they employ a remote control application on their smartphones, which are connected with the display over a wireless network. By means of user commands using such an application, users can request their desired programs to appear on the display.

In contrast to previous commercial examples, in our service scenario, user interaction is not involved in program selection. Rather, it is assumed that each user autonomously informs the display of his or her desired program. The display receives the selection and delivers it to the content server. The content server then intelligently selects relevant programs to ensure user satisfaction by means of visual information maximization based on the characteristics of the 2D and 3D content and users' real-time locations. The volume of visual information is different for each content, because the contained 2D spatial and 3D depth characteristics vary. In addition, the perceived visual information can vary according to the user location, with respect to spatial frequency and perceptual depth.

For these reasons, it is important to define the required visual information more clearly, and also to measure the volume of visual information of each content. In this paper, a novel quantified visual information metric is defined, termed quality of visual service (QoVS); this metric is detailed in Section 3. Previously, there have been a few studies regarding the quantification of visual information in terms of bits for use in studying the reconstructed quality of video in practical applications. In [6], we quantified the visual information of 2D content over the wavelet domain; however, the application of this technique was limited to 2D image compression and did not consider error propagation. In [27], the concept of visual information fidelity was proposed; this metric was applied to the distortion of content compared to an original, and entailed full-reference quality assessment, but thus had the limitation that it could not be applied when no reference is available. Moreover, these early concepts of visual information are not appropriate for our digital scenario, because they do not consider differences in the visual information that arise from differences in user location. The proposed QoVS is advantageous because it considers human visual characteristics including 3D binocular vision in accordance with user location, and does not require the use of the originals in bits.

Additionally, if some users want to watch other programs, it may be necessary to switch to other content to maximize quality of service (QoS), basing such switching decisions on predictions of the volume of visual information. In this way, the optimization problem can be constructed to maximize the visual information provided to all users. Along with QoVS, another important issue is loss of visual quality due to lack of wireless resources when multiple users simultaneously request content in the public space [4,5]. In [12], we explored a device-aware video quality adaptation technology that responds to the screen size of heterogeneous devices to provide N-screen service while minimizing loss of video quality; the layerwise sub-carrier allocation method was used to optimize radio resources for 2D content. For the digital signage scenario dealt with in this work, it is necessary to account for several important factors to provide more appropriate networking service for multiple users.

Firstly, the multicast is conducted by using a large, public screen, and the content is provided over a wireline network. Contrastingly, personal communications are conducted in private by using smartphones, and content is provided over a wireless network. Therefore, in contrast to conventional homogeneous services, this scenario is conducted in an environment of heterogeneous networks and displays.

Secondly, because multiple users share wireless resources in a limited space, it is very important to determine which program is to be multicasted and how to manage radio resources to optimize the QoS provided to the users in real time. Therefore, an expected QoVS (EQoVS) metric, detailed in Section 4.1, must be defined to formulate the low-complexity optimization problem more consistently. To this end, visual information should be measured to allow assessments of compatibility of 3D video for multicast service and 2D video for individual service.

Thirdly, depending on user location, each user receives different visual information from the screen [6]. Generally, QoVS is the greatest at a certain viewing distance from the display at the central point, as depicted in Fig. 1. Moreover, because of the limited screen space, it would be inefficient to display all requested content. Therefore, if most users request a certain advertisement, displaying it on the screen would maximize the QoVS. This serves the multiuser request while maximizing visual satisfaction. Contrastingly, if content is requested by only one user who is located away from the sweet spot, it would be more effective to deliver it to that user's smartphone than to the screen. In this case, each user individually controls his or her service for improved QoVS. To maximize QoVS throughput, it is necessary to determine viewer location, the number of users viewing the same program, and the channel status of the local area network.

In this paper, we define QoVS and EQoVS to quantify visual information, and then use these metrics as optimization criteria. QoVS indicates the amount of visual information based on human perception and content, whereas EQoVS includes loss of visual information caused by channel errors. Unlike conventional QoS, which is primarily based on channel throughput, QoVS is defined as the number of decoded bits, weighted by perceptual importance. The proposed EQoVS has the following advantages:

- Reflects contrast sensitivity by means of weighting according to viewing distance.
- Measures information loss caused by channel degradation over a wireless network environment.
- Maintains compatibility of both 2D and 3D content applications, enabling trade-offs to be made between 3D and smartphone displays.

In the digital signage scenario, in which each user group desires different content, the EQoVS of the group for 3D visual content service depends on users' locations. Therefore, according to the selection of the content displayed on the 3D screen, the EQoVS of viewers is considerably affected. Contrastingly, for point-to-point