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Prospects and Challenges of Context-aware Multimedia Content Delivery in Cooperative Satellite and Terrestrial Networks

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***Abstract*—Cooperative satellite cells and terrestrial wireless communication networks (comprising macro-cells, pico-cells, and the Internet) are much anticipated access technologies to enable users to seamlessly access rich multimedia content (e.g., television (TV) broadcasting, video-on-demand (VoD) streaming, and other services) on their devices. Furthermore, context-awareness has become popular to accompany these services not only to enhance the users' perceived service quality but also to improve the overall utilization of such cooperative networks. However, delivering context-aware multimedia content through these cooperative networks is associated with a significant research challenge due to the inherently different satellites and terrestrial networks technologies. For example, to provide context-specific TV programs to a user, a satellite needs to adopt unicast-style delivery. This may be an expensive operation since satellites are intrinsically useful for broadcasting or multicasting services to a wide audience. In contrast, terrestrial communication networks can be better suited to perform unicast based context-aware content delivery. In this article, we address these challenges and propose a dynamic bandwidth allocation method to effectively utilize the satellite and terrestrial networks for providing context-aware contents to many users. Computer-based simulation results are presented to demonstrate the effectiveness of our proposed method.**

***Index Terms*—Context-aware information, satellite, terrestrial network.**

I. Introduction

In present, the telecommunications market is often characterized by rapidly evolving heterogeneity of both access technologies and user-devices [1]–[4]. On the access side, different terrestrial technologies, ranging from wired optical access networks to wireless and cellular technologies including long term evolution (LTE), 3G, 4G, and so forth have become widely popular to provide access to the Internet. Satellites service delivery integration with these wired and wireless terrestrial access networks is also gaining popularity. Cooperation amongst these technologies are likely to form the future heterogeneous network capable of delivering rich multimedia contents (e.g., television (TV) broadcasting, video-on-demand (VoD) streaming, and other services) to large-scale audience. Also, from the users' side, they can nowadays easily access multimedia contents on their devices, which have gained tremendous diversity in terms of both hardware and software capabilities. In addition, awareness of context (i.e., users' interests, places and locations, device specification (e.g., display resolution, capacity), subscribed data plan, and so forth) has recently become a popular feature to accompany these services to enhance the quality of service as well as the overall network utilization. Our paper focuses upon context-aware content delivery through cooperative satellite networks and terrestrial wireless communication networks [5] because of their potential to deliver multimedia content and services to users anywhere on the planet. However, due to the inherently different technologies used by satellite networks and terrestrial mobile networks, there may be a significant impact on the users perceived service quality and resources utilization. For example, in order to deliver context-aware TV programs to a user through a satellite, the delivery method is typically unicast, which is obviously an expensive operation because satellites are intrinsically useful for broadcasting or multicasting services to many users. On the other hand, usually terrestrial mobile networks are better capable of delivering unicast based context-aware content delivery. Furthermore, traditional cooperative satellite and terrestrial networks share a fixed bandwidth allocation method. However, due to non-uniform geographical distribution of users, dissimilarity of required contents depending on specific regions and/or users, and so forth, the fixed bandwidth allocation and the conventional way to usually utilize these networks (e.g., satellite networks are used during post-disaster recovery operation while terrestrial networks are used during normal time) are inefficient. In order to address these challenges, in this paper, we propose a novel method to dynamically assign bandwidth in the satellite/terrestrial frequency sharing system to deliver context-aware contents to many users.

The remainder of the article is organized as follows. Section II surveys some relevant research works. Key challenges pertaining to the context-aware information delivery are elucidated in Section III. Section IV describes our considered network model of satellite and terrestrial frequency sharing system. The section also illustrates the problem of the traditional fixed bandwidth allocation in the cooperative satellite and terrestrial networks. Then, our proposal is presented in Section V, followed by its performance evaluation in Section VI. Finally, the article is concluded in Section VII.

II. Related Research Works

A US vendor called GlobalStar is currently pursuing approval from the Federal Communications Commission (FCC) for the terrestrial use of its approximately 25 MHz of satellite spectrum [6]. Their approach, referred to as the Terrestrial Low Power Service (TLPS), is expected to offer new and clean WiFi spectrum for carriers and enterprise. According to their initial test results, TLPS is able to achieve five times the distance and four times the throughput capacity of public WiFi. Furthermore, it was indicated that the current smart phones, tablets, and other devices with radios have the potential ability in their hardware to use the GlobalStar spectrum on a terrestrial basis.

In a similar spirit to use the cooperative satellite and terrestrial networks, researchers at the National Institute of Information and Communications Technology (NICT) in Japan are currently working on technologies for frequency sharing use of satellite and terrestrial networks [7]. Their research primarily focuses on the need to reduce interference between the satellite and terrestrial networks. In this vein, they aim at determining the geographical placement of devices and frequency allocation to produce less interference between these networks.

Aman *et al.*, in their work in [8], highlighted the emergence of a small-size, low-powered and cellular phone like hand-held satellite-earth terminal, which is capable of communicating with both mobile satellite systems and terrestrial systems depending on the users locations, QoS, and resources availability. According to [8], this improves spectrum utilization efficiency, and also enlarge the bandwidth of the satellite system for high-capacity communications. Aman *et al.* also proposed a new traffic prediction scheme for the shared frequency of the integrated satellite and terrestrial communication system.

None of the afore-mentioned works on the cooperative satellite and terrestrial wireless networks, however, considered context-specific content delivery to the users. Since our work aims at addressing the challenges pertaining to the context-aware content delivery across such networks, and envisioning an adequate proposal to deal with the challenges, it is also important to have a brief overview on recently conducted researches on context-aware service delivery. The challenges pertaining to context-aware service delivery, personalized user interfaces, and multimedia content adaptation were discussed in the work in [9]. The features for personalized service adaptation covered by the work included users' preferences, interests, knowledge and expertise, intra-individual differences, environmental differences, locations, technology characteristics (i.e., variety of available devices with different hardware and software specifications, operating systems, and available media player), access time length, and so forth.

According to the work conducted by Baldaron *et al.* in [10], context-aware applications aim to provide end-users with personalized services. According to the work, increasingly larger amounts of personalized information (i.e., context information reflecting the behavior and demands of the end-users) are available in the Internet owing to the tremendous advances in mobility, convergence, and integration. However, the work

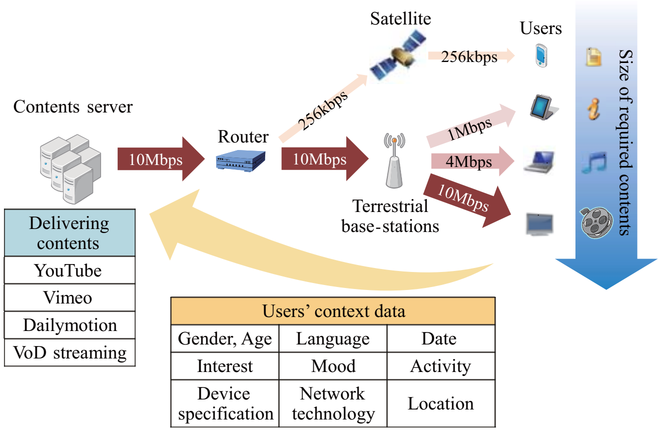

Fig. 1. Challenges of context-aware information delivery.

highlighted the fact that the context information is usually fragmented, and contemporary applications need to deal with the context management themselves. The work in [10] offered a solution for a converged context management framework and how it can be used in a future Internet to integrate information from all context sources and deliver the personalized services to the client application in a seamless as well as transparent fashion. While their framework utilizes the intelligent and convergent features of future networks, Baldaron *et al.* did not consider exploiting the next-generation satellites and terrestrial cooperative networks.

Park *et al.*, in their work conducted in [11], indicated that the tremendous growth of multimedia contents would become the main driving force for data explosion in the next decade. This might, according to Park *et al.*, lead to smart content delivery issues which the current Internet Protocol (IP)-based networks do not have the ability to deal with in an adequate manner. In order to ensure smart content delivery in future networks, they focused on smart content delivery by utilizing context information called context-based content delivery (CBCD). Their empirical studies demonstrated that a network provider could achieve more than 30 percent backbone traffic reduction by realizing the CBCD concept. Furthermore, the research conducted by Huang *et al.* in [12] exhibited the effectiveness of using integrated context-aware scalable multimedia content delivery for heterogeneous mobile systems. Their work also highlighted good context-aware use-cases with video streaming for best possible quality under different constraints such as client device capability, network conditions, and users' preferences. However, these researches also did not specify the use of cooperative satellites and terrestrial networks to deliver context-aware services to the end-users.

III. Challenges of Context-aware Information Delivery

It should be noted that context-aware information collection and management are not within the scope of our article. Instead, our article aims at finding an effective context-aware service delivery technique to the end-users through satellites and terrestrial cooperative networks. Therefore, first, the challenges associated with the concept of context-aware service

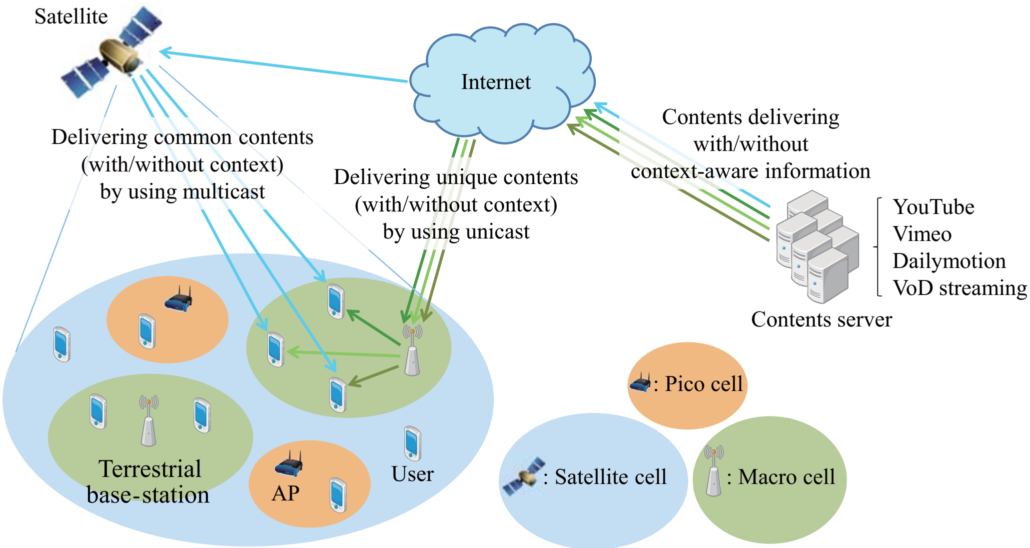

Fig. 2. Considered network architecture of cooperative satellite and terrestrial networks for facilitating content delivery (with/without context information of the users).

delivery need to be clearly understood. Context-awareness implies that the user's information need can be anticipated and responded to in an almost automated fashion. Given a particular user, his/her information and service needs vary depending on his immediate and/or individual situation, which dictates his context. As depicted in Fig. 1, the context-aware service aims at providing the user with contextually relevant information such as his/her preferences in terms of gender, age, language, used network technology, location, date/time of access, interest, activity, mood, device specifications, and so forth. Consider a simple example of a user, who frequently watches YouTube videos on his smart-phone and other portable devices such as laptops and tablet computers. Assume that the user subscribes to a pay-per-volume-use data plan (e.g., 3G/LTE data connection from an Internet/terrestrial provider). If he accesses high-resolution videos on one of his low-resolution devices, it may waste bandwidth for which the user has to pay. In this example, the user's context is the display resolution of the device he is currently using to access the YouTube video. Let us now consider a second example which involves a user having a data plan subscription, which is significantly expensive while roaming abroad. While in his home country, he might watch high-resolution videos on his smart devices. However, while in abroad, the user may prefer to using a low-resolution streaming to avoid hefty billing. This use case indicates the location context of the user. Let us consider a final example. As roughly shown in Fig. 1, assume that a user can access contents such as YouTube videos by using satellite and terrestrial technologies. The download speed at the user's device using the satellite, 3G, and WiFi technologies are assumed to be 256kbps, 1$\sim$4Mbps, and 10Mbps, respectively. Now, suppose that a user has subscription to a monthly flat-rate data plan which he uses to watch low-resolution videos on his smart-phone while driving to work, for instance. While he goes camping to a remote area where there is no terrestrial network signal, assume that his device has the capability to switch to a satellite provided data plan to access his desired content at a moderate data rate. On the other hand, while at home or at work, he can watch high-resolution videos by using the available WiFi connection to enjoy higher data rate. In this illustration, the user's context is, in fact, his preferred access technology. From these examples, one can clearly conclude that the choice of the video quality is subject to a number of factors, e.g., screen resolution of the device, available bandwidth, and cost. While there could be potentially many more factors such as language preference, time of access, available batter power of the device, and so forth, choosing the appropriate access technology (as demonstrated in the last example presented above) on behalf of the user in an automatic manner is a key research challenge, particularly in the combined satellites and terrestrial networks. In the following section, our considered network model of the satellite/terrestrial frequency sharing system for context-aware content delivery is presented.

IV. Network Model of Satellite/Terrestrial Frequency Sharing System

Fig. 2 presents a broad overview of our considered cooperative satellite and terrestrial networks model for facilitating context-aware content delivery. As illustrated in the figure, notice that the multimedia content located at the content server can be made available to the users over the Internet by two ways. First, the users can access the content through the satellites. While a satellite can transmit common contents to many users by using broadcast/multicast delivery, it may be inefficient in delivering context-specific contents to individual users. Second, the users can use terrestrial networks such as macro/pico cells to access the content. Although this may be good for unicast transmission of context-specific content to the users, there may be bandwidth availability issue, inaccessible location of the users, and so forth.

In order to model the cooperative satellite and terrestrial networks, we suppose that the network is constructed by two different sizes of cells, namely the satellite cells and terrestrial cells as shown in Fig. 3. Since the satellite has a much wider coverage than that of any of the terrestrial base-stations, many terrestrial cells are deployed under a satellite cell. Generally speaking, the satellite coverage diameter is several hundred kilometers whereas the coverage area of a terrestrial base-station usually has only several kilometers of diameter. Thus, in our considered model, more than thousands or even tens of thousands of terrestrial base-stations can be deployed under a satellite cell. In the satellite cells, in order to avoid frequency interference, the frequency is utilized as a repetitive way between some cells, which are not next to each other. Here, we set the number of the repetitive frequency as N. In addition, in this network model, we focus on the area constructed by some satellite cells that use different frequency bands. It means that there are N satellite cells in the supposed area. Moreover, we refer to the area, which is covered by each satellite cell, as A_n where n indicates the identification number of the area. On the other hand, it is assumed that the terrestrial cells use the same frequency bandwidth like the cellular networks. In this network model, we assume that the number of terrestrial cells on each satellite cell remains the same. Therefore, the number of cells on the area of A_n is defined as c.

In the supposed network, the satellite and terrestrial base-stations share the same bandwidth. Here, we define the bandwidth that this network can utilize as $\mathrm{B}_{\mathrm{total}}$. It means that the bandwidth equals to $\mathrm{B}_{\mathrm{total}}$ is utilized in each area referred to as A_n. In addition, the satellite uses bandwidth in a repetitive way within the range of the bandwidth, which equals to $\mathrm{B}_{\mathrm{total}}$. Thus, the total bandwidth used by N satellite cells equals to $\mathrm{B}_{\mathrm{total}}$. Moreover, the bandwidth which is utilized by the satellite and that by the terrestrial base-stations in each area expressed as A_n are denoted by $B_{\mathrm{sat}}(n)$ and $B_{\mathrm{ter}}(n)$, respectively. Hence, the sum of $B_{\mathrm{sat}}(n)$ and $B_{\mathrm{ter}}(n)$ is expressed as $\mathrm{B}_{\mathrm{total}}$.

In the existing satellite/terrestrial frequency sharing system, the same bandwidth is allocated in each of the satellite cells. So, the values of $B_{\mathrm{sat}}(n)$ and $B_{\mathrm{ter}}(n)$ are always constant. However, the distribution of the network users is geographically non-homogeneous. Additionally, the required contents are different from region to region, and also from user to user. Moreover, in the traditional model, the satellite network and the terrestrial network are considered to be utilized separately while the bandwidth is shared by these networks. For example, the satellite network is mainly used for emergency situations such as post-disaster communication. On the other hand, the terrestrial network is used during normal time. Thus, the existing bandwidth allocation and the way to utilize these networks are inefficient. Therefore, we propose a novel method, in the following section, in order to dynamically allocate bandwidth in the satellite/terrestrial frequency sharing system. Furthermore, an efficient way to use both the satellite and terrestrial networks to provide context aware contents will be introduced.

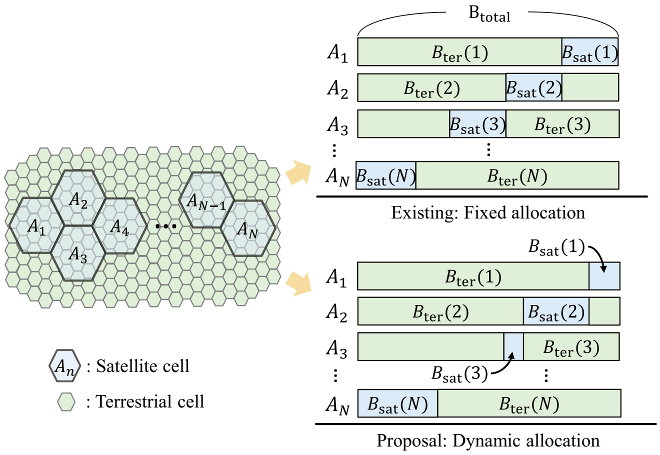

Fig. 3. A simple example demonstrating the frequency/bandwidth sharing problem in the existing fixed allocation method. Note how a dynamic allocation can improve the frequency sharing.

V. Proposed Context-aware Bandwidth Allocation

In this section, we propose a dynamic bandwidth allocation method to provide context-aware contents to many network users by using the cooperative satellite and terrestrial networks. In our proposal, we aim at increasing the efficiency to provide context-aware contents in the satellite/terrestrial frequency sharing networks. In order to achieve high capacity of the network, the superiority of the satellite multicasting and broadcasting due to its wide coverage is exploited. The proposal consists of two steps, namely the bandwidth allocation step and the optimization step to maximize the number of users that can enjoy the context-aware contents as follows.

Step1: At first, the bandwidth, which is allocated to each satellite cell is determined. Although each satellite cell has the same bandwidth as that in the existing system, it is inefficient because the distribution of the network users and their requirements are geographically non-homogeneous. Thus, it is necessary to allocate the bandwidth flexibly to each satellite cell, and this depends on the users' requirements. In our proposal, to make efficient use of the satellite's multicast and broadcast capability, the satellite allocates its bandwidth to each cell according to the amount of requirements for multicast or broadcast contents. As the guidepost to allocate the bandwidth, the summation of the number of users which require each content in each area of A_n is employed. We refer to the guidepost as G_n. Additionally, the number of users that require each multicast or broadcast content is defined as M_i where i indicates the variation of the contents. The total number of the contents is denoted as I. Moreover, we define that M_{i+1} is always the same or smaller than the value of M_i. Thus, G_n is expressed as $\Sigma_{i=1}^{I} M_i$. In our proposal, the satellite allcoates its bandwidth according to the largeness of G_n to each cell. Therefore, the bandwidth, which is allocated to each cell, $B_{\mathrm{sat}}(n)$, is expressed as follows.

$$B_{\mathrm{sat}}(n) = \frac{G_n}{\sum_{n=1}^{N} G_n} \cdot B_{\mathrm{total}}. \quad (1)$$

Step2: Secondly, we optimize the way to use the allocated bandwidth to provide context-aware contents to the network users as much as possible. In order to utilize the bandwidth of the satellite efficiently, basically, it may be better that the satellite provides multicast or broadcast contents, which usually are common contents among many users, and the terrestrial networks deliver context-aware contents that are often transmitted to individual users. However, context-aware contents sometimes also should be provided by the satellite because there are some context-aware contents that their target is more than one user. For example, information to all the users in a specific area should be provided by multicast or broadcast to utilize the bandwidth efficiently. Thus, our proposal determines which satellite or terrestrial networks should provide their contents to maximize the number of the users enjoying the context-aware contents.

Here, we define the number of users that require each context-aware content as C_j, where j denotes the variation of the content. In addition, we define that C_{j+1} is always the same or smaller than C_j. Moreover, the required bandwidth to transmit a multicast content or context-aware content by the satellite or terrestrial networks is denoted by S_{M}, S_{C}, T_{M}, and T_{C}, respectively. In this paper, we assume that there is no difference of the required bandwidth among individual contents. If the number of the multicast contents provided by the satellite in a satellite cell (which has the identification number, n) is set to $i'(n)$, the number of the context-aware contents provided by the satellite and terrestrial networks, namely $x(i'(n))$ and $y(i'(n))$, respectively, are expressed as follows:

$$x(i'(n)) = \frac{B_{\mathrm{sat}}(n) - S_{\mathrm{M}} \cdot i'(n)}{S_{\mathrm{C}}},$$
$$y(i'(n)) = \frac{B_{\mathrm{ter}}(n) - T_{\mathrm{M}} \cdot (I - i'(n))}{T_{\mathrm{C}}}. \quad (2)$$

Hence, the number of the users enjoying the context-aware contents in a satellite cell, namely $z_n(i'(n))$, is expressed as follows.

$$z(i'(n)) = \sum_{j=1}^{x(i'(n))} C_j + y(i'(n)) \cdot BS, \quad (3)$$

where BS denotes the number of the ground-based station in each satellite cell. Thus, the total number of the users enjoying the context-aware contents in N satellite cells, namely Z, is expressed as $\sum_{n=1}^{N} z(i'(n))$. Therefore, the optimal set of the value of $i'(n)$, which is represented as $\{i'(1), i'(2), \cdots, i'(N)\}$, to maximize the value of Z is adopted in our proposal.

VI. Numerical results

Here, we confirm the effectiveness of our proposal to provide context-aware multimedia contents in cooperative satellite and terrestrial networks by using numerical calculation. In this performance evaluation, we show the results of the number of users who can enjoy the context-aware contents by using our proposal. In the following, the parameter settings are first described, followed by the numerical results.

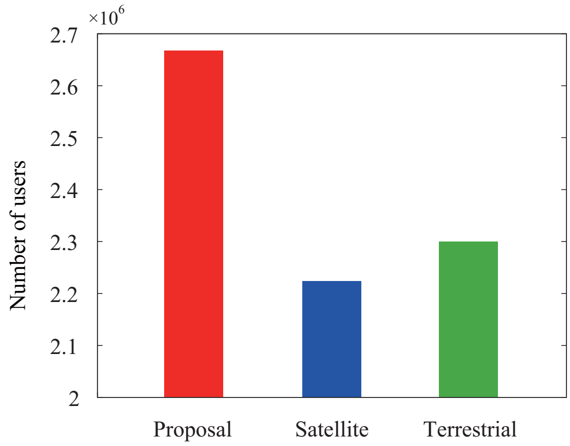

Fig. 4. Number of users who can enjoy the context-aware contents in case of our proposal, satellite-only, and terrestrial network-only scenarios.

A. Parameter settings

In this performance evaluation, we suppose that there are 3 areas, which are covered by 3 satellite cells. 2,000, 3,000, 6,000 terrestrial cells are deployed in each of the areas, respectively. Additionally, the numbers of users in the three areas are set to 200,000, 300,000, and 600,000, respectively. Moreover, the capacity of transmission (i.e., the available bandwidth) is assumed as 1000Mbps. Thus, the satellite and terrestrial networks share the transmission capacity to provide multicast contents and context-aware contents. In each area, 10, 15, and 30 multicast contents which are delivered to 20,000 users are provided, respectively. Furthermore, we suppose that a multicast content and a context-aware content consume 15Mbps and 2Mbps in the transmission capacity, respectively. By using these parameters, we evaluate the effectiveness of the proposal in the remainder of this section.

B. Performance evaluation

Here, we evaluate the number of the users who can enjoy the context-aware contents by using our proposal. As the comparative approach, the two cases where all multicast contents are transmitted by the satellite-only and terrestrial networks-only scenarios with the fixed bandwidth allocation, respectively, are also evaluated in this calculation. Fig.4 demonstrates the result in each of the considered cases. From the result, it is clearly evident that our proposed method achieves the highest number of users, who can enjoy the context-aware contents while the same number of multicast contents are provided in each case. The reason behind the result is that our proposal achieves efficient bandwidth allocation in the satellite/terrestrial frequency sharing system. In addition, our proposed method utilizes the bandwidth efficiently according to the feature of the contents, and as a consequence is able to service a large number of users in contrast with the satellite-only and terrestrial network-only scenarios.

VII. Conclusion

In this article, we addressed the challenges of context-aware rich multimedia content delivery through cooperative satellite and terrestrial wireless communication networks. To effectively address the challenges, we proposed a novel method to dynamically assign bandwidth in the satellite/terrestrial frequency sharing system to deliver context-aware contents to many users. Numerical results demonstrate the effectiveness of our proposal.

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