Efficient Coding Scheme for Broadcast Cognitive Pilot Channel in Cognitive Radio Networks

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Abstract—**With the trend of technology innovations in recent years, network heterogeneity and inefficient spectrum usage are the great challenges in Cognitive Radio Networks (CRNs). As one of the solutions for efficient heterogeneous network information delivery in CRNs, a common broadcast signaling channel named Cognitive Pilot Channel (CPC) is proposed with its large coverage and easy implementation characteristics in contrast to usually inefficient and time-consuming spectrum sensing techniques. In order to improve the accuracy of network information delivery, the geographical regions are divided into small meshes and the network information in each mesh is broadcast one by one. This paper proposes an efficient coding scheme for broadcast CPC, called Differential Mesh Information Coding (DMIC), to reduce the redundancy of similar network information among different meshes. The strategies of choosing the basic mesh with popular commonality and quantizing the differential information among meshes are also proposed and proved by numerous results.**

Keywords-cognitive pilot channel; cognitive radio; cognitive radio networks; diffential mesh information coding

I. INTRODUCTION

Recent years have witnessed a great many innovations in wireless communication networks, which include the 3rd generation (3G) technologies putting into commercial use and accelerating standardizations aiming at Long Term Evolution (LTE) and Long Term Evolution Advanced (LTE-A) [1]-[2] in the coming years. New technologies such as the Cognitive Radio (CR) [3] technology are brought forward with flexible spectrum assignment scheme to improve the spectrum utilization, trying to solve the conflicts between great demands from secondary users for available spectrum resources and spectrum underutilized by the primary users as indicated in Federal Communications Commission (FCC) reports [5]-[6]. Based on the Software-Defined Radio (SDR) [4] and CR [3] technologies, intelligent radio technologies with the capability of context-awareness to complete the reconfiguration autonomously by learning from the changing environment are available, leading to the irreversible trend towards the Cognitive Radio Networks (CRNs). However, the heterogeneous network information awareness is one of the bottlenecks for the efficient spectrum utilization, which need further explorations and innovations.

In the literature, traditional spectrum sensing mechanisms are used to observe the network information, such as the radio access technology (RAT) and unoccupied frequency, by user equipments (UEs) independently or cooperatively [7]-[8]. But these spectrum sensing mechanisms face the challenges of time-consuming and power inefficient spectrum sensing process, especially when the spectrum bands that need to be sensed are extraordinarily large. Recently, efficient alternatives are proposed by using the signaling channels to transmit the network information, such as the spectrum vacancy, RAT occupancy and available networks in a specific area. The concept of Cognitive Pilot Channel (CPC), which was proposed within the IST-E^{2}R project [9] and continued to be one of the highlights within the ICT-E^3 project [10], is one of the solutions to broadcast the network information to the UEs through a specific signaling channel, enabling a much more efficient context information awareness in CRNs.

In the former researches on CPC, both the out-band and in-band CPC implementation schemes are proposed by using a common worldwide frequency and a logical channel within the existing RAT respectively [11]-[12]. Both of these schemes are implemented in a wide area divided by a great number of meshes in [11]. Further research on the optimal mesh division scheme which considers the effects of the GPS localization shift error and information loss ratio in the multi-RATs overlapped scenario is proposed in [13], to improve the accuracy and efficiency of network information delivery. In terms of the delivery modes of CPC, the broadcast CPC mode is proposed in [11], which delivers the heterogeneous network information of all meshes one by one periodically and continuously in a large coverage area via the downlink channel. Although the broadcast CPC mode has the advantages of large coverage and easy implementation, it still faces the problems of long waiting time and time-consuming broadcast period, when a great number of meshes exists and the demand from UEs for heterogeneous network information is urgent. Recent research using the homogeneous mesh grouping scheme has been considered as a renovation to the original broadcast CPC mode with improved delivery efficiency in [14]. Besides, the on-demand CPC mode is also proposed in [15]-[16] by using both uplink and downlink channels, through which the UEs can send requests whenever needed. Though the on-demand CPC mode is much more efficient with uplink channel to send the requests by UEs only when needed, problems still exist when too many requests from UEs in a specific mesh are received by the CPC Server, which is responsible for the network information delivery control, in a short period. In this scenario, the CPC Server will face the risk of congestion and the duplicate network information delivery of one specific mesh will lead to low efficiency of the whole system under on-demand mode. Furthermore, considering the indispensable uplink channel for the on-demand CPC mode, splitting a bandwidth from the

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scarce candidate spectrum bands for CPC is still a big challenge, where the recent status of CPC standardization in IEEE SCC41 and ETSI RRS is summarized in [17]-[18].

As future networks are full of heterogeneous RATs, different types of networks are usually overlapped for coverage and capacity enhancements, such as GSM/TD-SCDMA to guarantee the large coverage and WLAN/femtocells to enhance the network capacity for hotspots and indoor scenario. Therefore, the generally non-uniform distribution of different RATs networks across a large area is reasonable in practical environment. Then, how to deliver the network information efficiently is a challenging task. Under these analyses, this paper focuses on the efficient network information compression coding scheme in broadcast CPC mode. Inspired by the differential encoding scheme used in differential phase-shift keying (DPSK) which uses the previous symbol as a phase reference for the current symbol and only the differential phase between the current symbol and the previous symbol is encoded as the information [19]-[20], this paper proposed the Differential Mesh Information Coding (DMIC) scheme for broadcast CPC. Furthermore, the DMIC scheme is designed with two key procedures by choosing a basic mesh with popular commonality and quantizing the differential information of each mesh against the basic mesh using image processing techniques, which greatly reduce the redundancy of duplicate network information and improve the efficiency of broadcast CPC.

The rest of the paper is organized as follows. In Section II, the overview of original broadcast CPC mode is introduced briefly. Section III will focus on the assumptions and analyses of the proposed DMIC scheme. Optimal scheme of choosing the basic mesh with popular commonality is illustrated in Section IV. Further quantization strategy of DMIC is designed and analyzed in Section V. Numerous results are shown in Section VI. Finally, the last section concludes the paper.

II. OVERVIEW OF ORIGINAL BROADCAST CPC MODE

As one of the delivery modes of CPC, the original broadcast CPC mode is proposed in [11] as a narrow-band broadcast channel for limited network information delivery with a large coverage. Further design of the broadcast CPC mode is presented in [15] which will broadcast the network information of all meshes periodically and continuously. The flow of original broadcast CPC mode is shown in Figure 1, which depicts that the network information of all meshes is broadcast one by one periodically. Within each mesh, different fields are encoded with different numbers of bits to represent the network information, such as the Geographical field (Geo info for short), Operator field, RAT field and Frequency field (Freq for short).

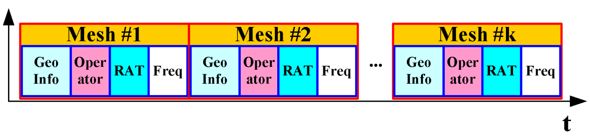

Figure 1. Flow of the Original Broadcast CPC Mode

The advantages of broadcast CPC mode include the large coverage, only downlink channel and easy implementation for UEs which would just switch on and listen to the broadcast information. However, potential problems still exist when the information corresponding to a specific mesh is missed by the UE, which has to wait for a whole broadcast period to catch the information again. The network information redundancy of adjacent meshes will consume a large portion of precious spectrum resources and will cost the unnecessary time delay in the broadcast CPC mode. These are the pros and cons of the original broadcast CPC mode. Therefore, the DMIC scheme is proposed in this paper in order to reduce the redundancy of duplicate network information in adjacent meshes, improve the efficiency of broadcast CPC mode.

III. ASSUMPTIONS AND ANALYSES OF DMIC SCHEME

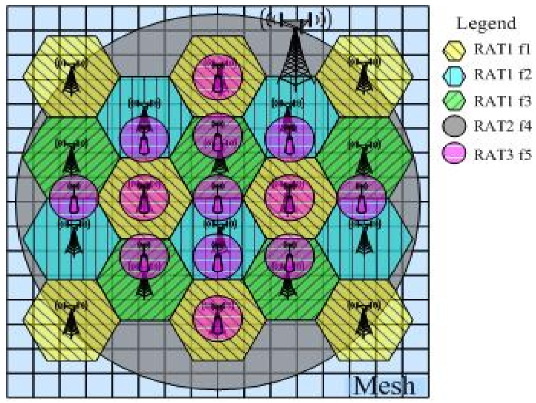

Figure 2. Multi-RATs Overlapped Network Scenario

A typical multi-RATs overlapped network scenario is shown in Figure 2 with different frequencies and different RATs. Some of these RATs have a cellular layout with different frequencies of the same RATs, such as the RAT1 with frequency f_1, f_2 and f_3. Others have a larger coverage, such as the RAT2 with frequency f_4. Also, in some hotspots the RATs with the centralized coverage range are shown in Figure 2, such as the RAT3 with frequency f_5. The heterogeneous network scenario with multi-RATs overlapped is divided into appropriate meshes based on the existing research in [13], which is out of the scope of this paper.

In contrast to the original broadcast CPC mode which broadcast the network information of each mesh totally, the proposed DMIC scheme will choose a basic mesh with popular commonality as a reference. Other meshes will make a reference to this basic mesh and only the differential information will be encoded and transmitted through the narrow-band broadcast CPC channel, greatly improving the efficiency of information delivery.

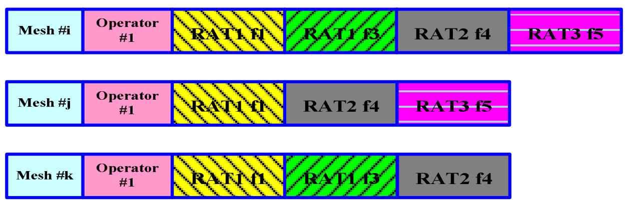

Figure 3. Original Broadcast CPC Mode Coding

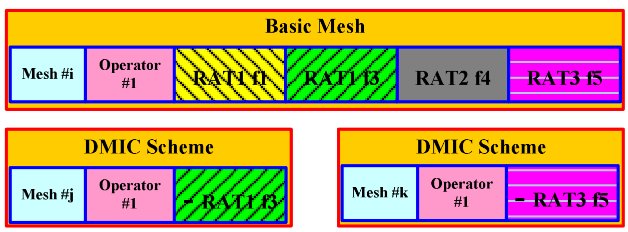

Figure 4. DMIC Scheme

The coding scheme of the original broadcast CPC mode is shown in Figure 3, which includes all the network information in each mesh. The network information in Mesh #*i*, #*j* and #*k* depicted as M_i, M_j and M_k, is shown as an example to interpret the difference between the original and DMIC schemes. The proposed DMIC scheme using differential coding strategy is shown in Figure 4, which only transmit the differential information in each mesh against the basic mesh, saving spectrum resources and improving the broadcast efficiency. To be specific, M_i is chosen as the basic mesh and M_j only transmits the differential information of deleting RAT1 with f_3 comparing to the original whole information list such as the RAT1 with f_1, RAT2 with f_4 and RAT3 with f_5. The same scheme applies to M_k which only transmits the differential information of deleting RAT3 with f_5. By using the DMIC scheme, the most commonly appeared network information is transmitted in the basic mesh and other meshes only transmit the differential information against the basic mesh, which greatly saving spectrum resources and improving the information coding efficiency in the broadcast CPC mode. However, challenges are still exist, such as how to choose the basic mesh with the popular commonality and how to design the DMIC scheme. The rest parts of this paper are devoted to solving these problems and making evaluations.

IV. Optimal Scheme Of Choosing The Basic Mesh With Popular Commonality

In order to greatly compress the redundancy of the network information in all meshes, the basic mesh with popular commonality should be chosen appropriately first. This section proposes an optimal scheme of choosing the basic mesh by using the frequency occupancy graph in virtue of the image processing techniques.

Based on the image processing techniques and analyses in [21]-[22], the frequency occupancy condition of multi-RATs overlapped network scenario in Figure 2 is first digitalized by binary values and then depicted by different colors to denote the frequency occupancy condition. It is also assumed that the receiving power levels of each RAT in each point are known in the first place. If the received power level of frequency f_i in point (x,y) is above the predefined threshold, the frequency occupancy graph for this point will be marked with binary 1 to denote the coverage existence of frequency f_i. The formula is shown in (1) based on the results in [21].

$$M(f_i, x, y) = \begin{cases} 1, & \text{if } P(f_i, x, y) \geq P_{th}(f_i) \\ 0, & \text{if } P(f_i, x, y) < P_{th}(f_i) \end{cases} \tag{1}$$

Where $M(f_i,x,y)$ is the binary value of frequency occupancy condition of frequency f_i in point (x,y). $P(f_i,x,y)$ is the receiving power level from frequency f_i in point (x,y). $P_{th}(f_i)$ is the threshold of received power level from frequency f_i.

By marking the frequency occupancy condition of each point with the binary value, the sum of binary value of different frequencies is given by (2) as presented in [21].

$$I(x, y) = \sum_{i=1}^{N} M(f_i, x, y) 2^{i-1} \tag{2}$$

Where I(x,y) depicts the sum of frequency occupancy in point (x,y). N is the total number of frequencies. For example, when N=5 frequencies f_1, f_2, f_3, f_4, f_5, a point which is covered by 5 frequencies will be marked by $I=(11111)_2=(31)_{10}$.

The appropriate mesh division size is predefined by the existing research in [13]. Let us define the digitalized value for each mesh. Parameter I_{Mk} is used to depict the value of different frequencies in M_k. Parameter N_{Mk} depicts the total number of points in M_k. The value for each mesh is calculated by (3), which means that the average value of all points in each mesh is used to represent the digitalized value of M_k. And mathematic function $\lfloor x \rfloor$ is used to obtain the maximum integer that is not bigger than value x.

$$I_{M_k} = \left\lfloor 0.5 + \frac{1}{N_{M_k}} \sum_{(i,j) \in M_k} I(x_i, y_j) \right\rfloor \tag{3}$$

In virtue of the mesh based frequency occupancy graph in Figure 8, the mesh with the most commonly appeared color will be chosen as the basic mesh. Statistic results of the distribution of different mesh values are shown in Figure 9, which represent that the basic mesh should be chosen with the value $I_M=(12)_{10}=(01100)_2$, depicting the network information of RAT2 with f_4 and RAT1 with f_3.

V. Quantization Strategy Of DMIC

Due to the correlation of network information between adjacent meshes, the quantization strategy of DMIC scheme is proposed to reduce the redundancy of network information in all meshes by encoding only the differential information against the basic mesh. And the improvements of the DMIC scheme will be evaluated by the total bits that need to encode the network information of all meshes.

In terms of the coding scheme of all meshes in the broadcast CPC mode, existing research work in [15] has done preliminary research on both theoretical analyses and calculation formulas for network information encoding. As shown in Figure 5, the original broadcast frame format has four different fields that are encoded with different bits to represent the network information. For example, a total number of B_{GEO}=41bits is used to represent the Geo information field. 3 digits and 2-3 digits are used for the Mobile Country Code (MCC) and Mobile Network Code (MNC) [23], which form the Operator information field with 20 bits altogether as B_{OP}=20bits. B_{RAT}=4bits and B_{FREQ}=16bits are used for the RAT information field and the Frequency information field respectively.

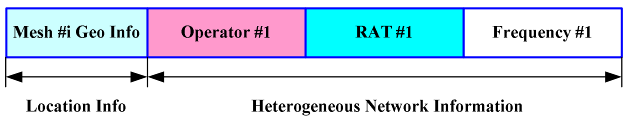

Figure 5. Original Broadcast Frame Format

However, the general assumptions and bit calculation formulas in [15] are inefficient to reduce the redundancy of network information among adjacent meshes. Therefore, this paper has proposed further improvements on the frame format design, which have been done with the basic mesh frame format and the differential mesh frame format in Figure 6 and Figure 7. The Basic Mesh Flag field is used to distinguish the basic mesh from others with B_{BMF}=1bit, where '1' depicts the basic mesh frame format as shown in Figure 6 and '0' depicts the differential meshes. The Add/Delete Info Flag field is designed to represent the differential network information against the basic mesh with B_{ADF}=1bit, where '1' for adding differential information and '0' for deleting differential information in contrast to the basic mesh as shown in Figure 7.

All the UEs in each mesh will first decode the basic mesh information and then add or delete the differential network information based on its location.

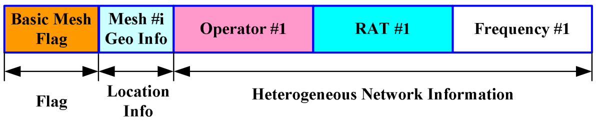

Figure 6. Basic Mesh Frame Format of DMIC Scheme

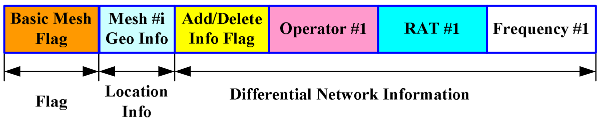

Figure 7. Differential Mesh Frame Format of DMIC Scheme

Moreover, in order to calculate the total number of bits to encode the network information with different operators, RATs and frequencies in M_j, improved formulas are represented by $B^{ORG}_{M_j}$ for the original broadcast mode in (4), $B^{BM}_{M_j}$ for the basic mesh in (5) and $B^{DM}_{M_j}$ for the differential meshes in (6). Suppose the number of operators in M_j is depicted by $N_{OP,j}$ with $N^{OP,k}_{RAT,j}$ RATs of the kth operator and $N^{RAT,t}_{FREQ,j}$ of the tth RAT. Furthermore, the total number of bits for all meshes are depicted by B^{ORG}_{Total} for the original broadcast mode in (7) and B^{DMIC}_{Total} for the DMIC scheme in (8), where N_{MESH} is the total number of meshes. And the comparison of the original scheme and the proposed DMIC scheme will use the formulas in (7)-(8).

$$B^{ORG}_{M_j} = B_{GEO} + \sum_{k=1}^{N_{OP,j}} (B_{OP} + \sum_{t=1}^{N^{OP,k}_{RAT,j}} (B_{RAT} + \sum_{s=1}^{N^{RAT,t}_{FREQ,j}} B_{FREQ})) \quad (4)$$

$$B^{BM}_{M_j} = B_{BMF} + B_{GEO} + \sum_{k=1}^{N_{OP,j}} (B_{OP} + \sum_{t=1}^{N^{OP,k}_{RAT,j}} (B_{RAT} + \sum_{s=1}^{N^{RAT,t}_{FREQ,j}} B_{FREQ})) \quad (5)$$

$$\begin{aligned} B^{DM}_{M_j} &= B_{BMF} + B_{GEO} + \\ &\sum_{k=1}^{N_{OP,j}} (B_{ADD} + B_{OP} + \sum_{t=1}^{N^{OP,k}_{RAT,j}} (B_{RAT} + \sum_{s=1}^{N^{RAT,t}_{FREQ,j}} B_{FREQ})) + \\ &\sum_{k=1}^{N_{OP,j}} (B_{DEL} + B_{OP} + \sum_{t=1}^{N^{OP,k}_{RAT,j}} (B_{RAT} + \sum_{s=1}^{N^{RAT,t}_{FREQ,j}} B_{FREQ})) \end{aligned} \quad (6)$$

$$B^{ORG}_{Total} = \sum_{j=1}^{N_{MESH}} B^{ORG}_{M_j} \quad (7)$$

$$B^{DMIC}_{Total} = \sum_{j=1}^{N_{MESH}} B^{BM}_{M_j} + \sum_{k=1}^{N_{MESH}} B^{DM}_{M_k} \quad (8)$$

VI. RESULTS AND DISCUSSION

In this section, the simulation scenario is proposed as shown in Figure 2 and numerous simulation results are shown in detail with illustrations thereafter. In order to prove the efficiency of the proposed DMIC scheme based broadcast CPC mode, the total number of bits used to encode the network information of all meshes is calculated and compared between the original broadcast CPC mode and the DMIC scheme based broadcast CPC mode. The simulation region is a square with 10km*10km, where 3 RATs belonging to 3 operators are assumed in this scenario with 5 frequencies. Each cellular-like base station has a coverage range of 1km with frequencies f_1, f_2, f_3. The radius of the hotspots coverage area is set to 600m with frequency f_5. The radius for the large coverage base station is 5km. And the mesh size is chosen appropriately based on the research results in [13] with 200m*200m for each mesh with the resolution of 10m, resulting totally N_{Mk}=400 points in mesh M_k.

First, the mesh based frequency occupancy graph is created as shown in Figure 8, which is based on the analyses in Section IV. Then, the detailed distribution of different numbers of meshes is calculated and shown in Figure 9. In view of the mesh based frequency occupancy graph and the distribution of different mesh values, the mesh with the most commonly appeared color is chosen as the basic mesh with the value $I_M=(12)_{10}=(01100)_2$, depicting the network information of RAT2 with f_4 and RAT1 with f_3.

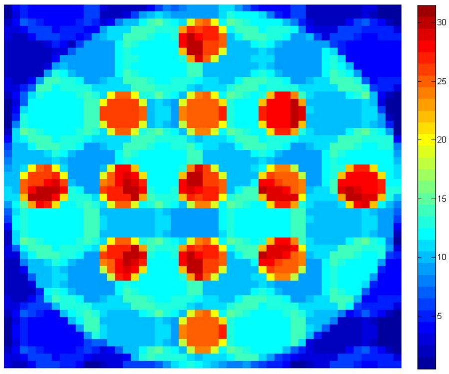

Figure 8. Mesh Based Frequency Occupancy Graph

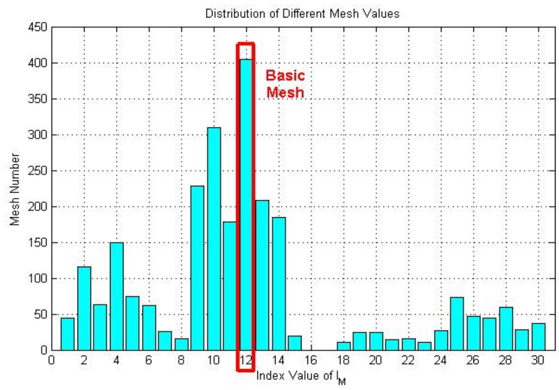

Figure 9. Distribution of Different Mesh Values

Furthermore, the total bits need for encoding the network information of all meshes are compared between the original broadcast mode and the DMIC scheme based broadcast mode as shown in Figure 10. Although, the DMIC scheme is a little bit inefficient especially when the network information in specific mesh is greatly different from the basic mesh such as $I_M=(2)_{10}=(00010)_2$, which need much more codes to represent its differential information against the basic mesh as shown by the red and green lines. Generally, most of the improvements of DMIC scheme come from the large amount of meshes which need only a few encoding bits to represent the little differential information against the basic mesh such as $I_M=(13)_{10}=(01101)_2$ and $I_M=(14)_{10}=(01110)_2$ as shown by the pink and blue bars. The total coding bits improvements of DMIC scheme are shown in Figure 11 by the pie graph. A slice of 10 percents decrease of total bits for encoding the network information of all meshes is highlighted in pink against the original broadcast CPC mode as the whole pie. The simulation results in both Figure 10 and Figure 11 depict that the DMIC scheme can greatly improve the efficiency of network information encoding among different meshes.

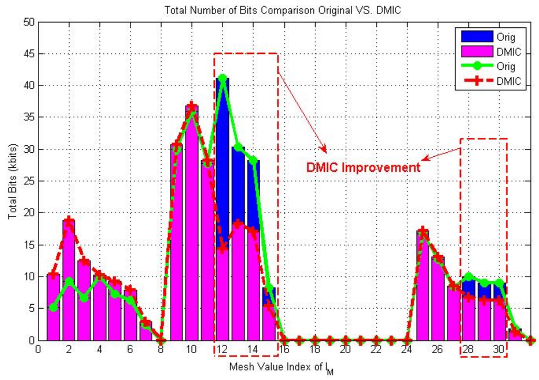

Figure 10. Total Bits Comparison (Orignal Broadcast VS. DMIC Scheme)

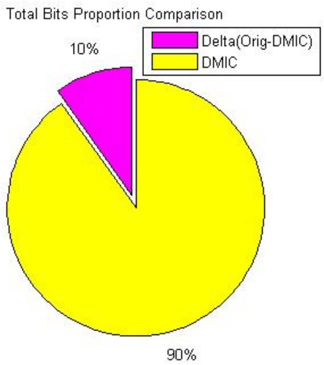

Figure 11. Total Bits Proportion Comparison

VII. CONCLUSION

Based on the candidate narrow-band broadcast CPC implementation, this paper has presented an efficient DMIC scheme based broadcast CPC in CRNs to improve the efficiency of network information encoding by reducing the redundancy of duplicate information in adjacent meshes. Two key procedures of DMIC scheme are designed and described thoroughly, including choosing a basic mesh with popular commonality and quantizing the differential information of each mesh against the basic mesh. Moreover, the frame formats for the DMIC scheme are also proposed and illustrated in this paper. In virtue of the image processing techniques and mesh division concept, numerous simulation results prove the efficiency of the proposed DMIC scheme based broadcast CPC mode.

It should also be noticed that the proposed DMIC scheme is efficient under non-uniform distribution of different RATs networks across large area, which is generally reasonable in practical environment, considering whole network planning requirements on effective coverage for large area and capacity enhancement in hotspots. And our future research directions will focus on terminal trajectory prediction based CPC-assisted efficient terminal handover strategy and dynamic square mesh division scheme in CPC. And the performance of efficient CPC information delivery will be evaluated by using SDR based hardware platform.

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