A Novel BWA System Based on Time and Frequency Domain United Processing

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***Abstract*—In order to satisfy the demand of future Broadband Wireless Access (BWA) with high mobility, high data rate and low cost, Tsinghua University proposes a novel BWA system named BRadio with independent intellectual property rights. This paper describes the BRadio system from the aspects of physical layer technologies, Medium Access Control (MAC), networking methods, and services. The physical layer technologies focus on Time domain and Frequency domain United Orthogonal Frequency Division Multiple Access (TFU-OFDMA), Time domain and Frequency domain United Single Carrier Modulation time division multiple Access (TFU-SCMA), Interleave Division Multiple Access (IDMA), and Multiple Input Multiple Output (MIMO). In MAC layer we describe several new functionalities in BRadio system. The networking methods of BRadio are divided into networking independently and networking with the existing networks. BRadio can support various services, among which, the Personal Media Service (PMS) is presented in detail. Relying on the technical superiority of its high data rate, high mobility and low cost, as well as its flexible networking and comprehensive service platform, BRadio has become a potential technical solution for BWA.**

Keywords- BWA; BRadio; TFU-OFDMA; TFU-SCMA; MIMO; IDMA; PMS

I. Introduction

With the rapid development of modern information technology, Broadband Wireless Access (BWA) is a promising technology, which can provide high-speed wireless Internet access and data network access over a wide area to meet the requirement of increasing data traffic. With the tendency of penetrating and merging interactively with Internet networks and broadcast networks, BWA will also bring new services in future. WiMAX[1] is a world-wide BWA system for local and metropolitan area networks but not applied in China due to the frequency conflict with TD-SCDMA. Several innovative BWA systems are designed and realized in China, such as SCDMA [2] and MiWAVE [3]. Tsinghua University proposes a BRadio (Broadband Radio) system with independent intellectual property rights, which can support high-rate data transmission and high mobility for users with low cost.

BRadio is a technical set with main features including Time domain and Frequency domain United Orthogonal Frequency Division Multiple Access (TFU-OFDMA) in the downlink, Time domain and Frequency domain United Single Carrier Modulation time division multiple Access (TFU-SCMA) in the uplink, Interleave Division Multiple Access (IDMA), Multiple Input Multiple Output (MIMO) and Personal Media Service (PMS). BRadio can support MIMO technology in the downlink transmission with 2 and 4 transmit antennas. Besides, it adopts a serial concatenations of BCH and LDPC, called BCH and LDPC cascade code, for channel coding. Furthermore, it introduces several special features in the MAC layer. Taking into account these factors, BRadio lays firm foundations for users to obtain low cost broadband services.

The key technologies of BRadio are applied in the relevant experimental systems and products. As the downlink transmission technology of BRadio, TFU-OFDMA combines the main technologies in the China digital television terrestrial broadcasting system, it has experienced a number of system tests in which networks are set up in more than 20 provinces and municipalities with tens of thousands of users. Products of broadband wireless multimedia transmission system based on Single Carrier Frequency Domain Equalization (SC-FDE) technology, which is the basis of TFU-SCMA technology adopted as the uplink transmission technology, have been widely used in the systems of public security, frontier defense, and professional field. Most key technologies of BRadio are in the protection of inventions application by Tsinghua University, in which TFU-OFDMA, TFU-SCMA and system related technologies have applied for more than 60 patents and hold more than 50 patents.

BRadio has already obtained good support from industry, with the relevant chip development and field test completed. It can support wide area coverage in high speed mobility scenario, with up to 250km/h speed and up to 20Mbps@8MHz transmission rate (can be extended to 75Mbps@8MHz with MIMO enhancement). Besides, it can support various kinds of services, such as voice calls, media stream broadcasting, voice and video conference, video monitoring, etc.. With these abilities, BRadio can be applied to various exclusive wireless network communication scenarios, such as public security, armed police, firefighting and so on.

The paper is organized as follows. Section II and III present the physical layer (PHY) technologies and the MAC functionalities respectively. Section IV discusses the networking aspect and Section V describes the services supported. Finally, conclusions are given in Section VI.

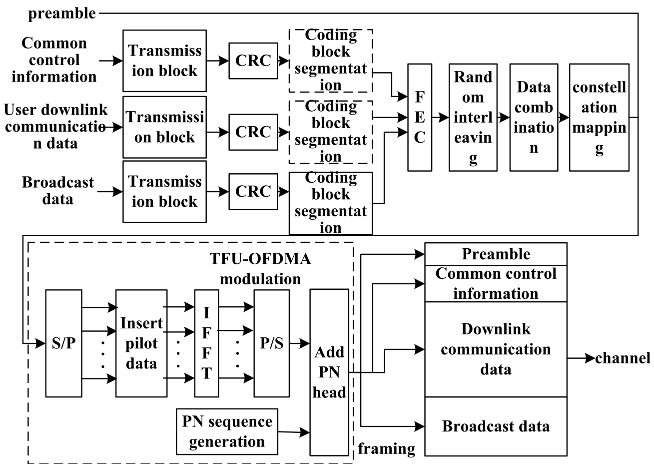

Figure 1. Downlink signal transmission process.

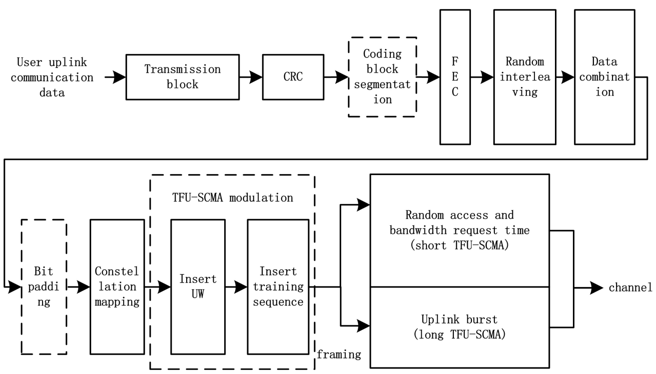

Figure 2. Uplink signal transmission process.

II. Physical Layer Technologies

The downlink and uplink signal transmission procedures in PHY are shown in Fig. 1 and Fig. 2. The Forward Error Correction (FEC) techniques including Convolutional Code (CC), Turbo code, Reed-Muller (RM) code and Bose-Chaudhuri-Hocquenghem (BCH) and Low Density Parity Check (LDPC) cascade code are supported. And the constellation mappings of QPSK, 16QAM, 64QAM are supported.

A. Overview

In the BRadio system, both the Frequency Division Duplexing (FDD) mode and the Time Division Duplexing (TDD) mode are supported. The FDD and TDD frame structures are depicted in Fig. 3 and resource allocation parameters for the uplink and downlink subframe are shown in Tab. I.

B. TFU-OFDMA

TFU-OFDMA [4] combines the advantages of the Orthogonal Frequency Division Multiplexing technology using CP techniques (CP-OFDM) and the Time Domain Synchronous OFDM (TDS-OFDM) technology (the key transmission technology adopted in the national standard of China digital television terrestrial broadcasting), and realizes efficient channel estimation. It fills the Pseudo-Noise (PN) sequence in the Guard Intervals (GI) and insert the specific pilots generated from Zadoff sequence into the IFFT block. Pilots are transmitted in pilot subcarriers, and user data in data subcarriers. Then at the receiver, synchronization and channel estimation are completed by the joint of the PN sequences and specific pilots inserted in time and frequency domain.

TFU-OFDMA uses PN sequences as the guard intervals instead of CP, which can be used by the receiver for synchronization operations. Therefore, compared to CP-OFDM, TFU-OFDMA needs no additional symbols, like preambles, for time and frequency synchronization, and thus occupies less overhead. Besides, pilots are inserted among data subcarriers in the frequency domain for channel estimation. Though TFU-OFDMA loses the cyclic structure, the demodulation can be achieved through an iterative processing, and the number of iterations is not large, thus making the signal processing complexity acceptable. The iterative processing algorithm for TFU-OFDMA is proposed and validated in [5], showing that TFU-OFDM can provide almost the same channel estimation and equalization performance in terms of Bit Error Rates (BER) and Normalized Mean Square Errors (NMSE) as CP-OFDM at a lower processing complexity

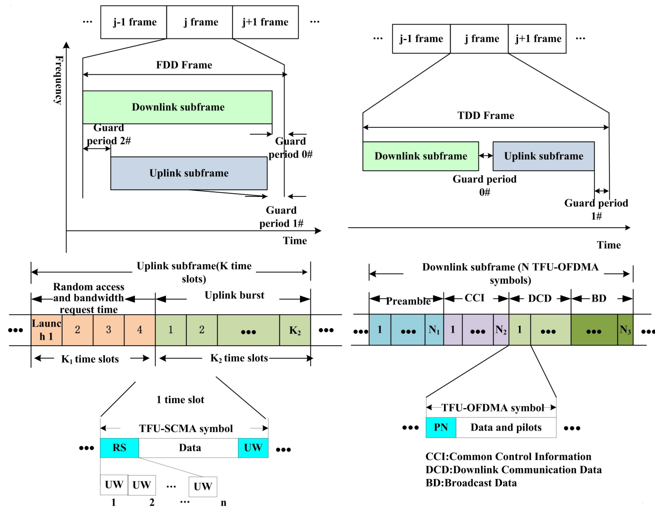

Figure 3. BRadio PHY frame structures.

Table I
Subframe Resource Allocation Parameter

Duplex mode	N	N_1	N_2	N_3	K	K_1	K_2
TDD	28	1	3	24	13	2	11
FDD	55	1	6	48	26	4	22

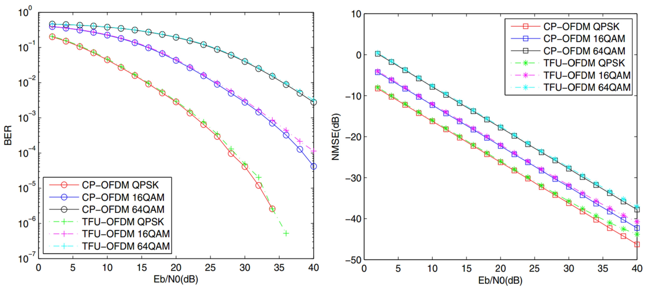

Figure 4. The BER and MMSE of channel estimation and equalization.

than TDS-OFDM, as shown in Fig. 4.

C. TFU-SCMA

TFU-SCMA is an improved version of SC-FDE using the cyclic prefix in the guard interval. TFU-SCMA has a Reference Sequence (RS) consisting of several Unique Word (UW) blocks at the beginning of the symbol, and one UW in the end. RS is mainly used for channel estimation and synchronization at the receiver, while the one UW is used to ensure the cyclic structure and to prevent inter-symbol interferences.

To avoid the Inter Symbols Interference (ISI) caused by time deviation, and the Inter Carriers Interference (ICI) caused by the Doppler effect and synchronization error caused by the different precision of Crystal Oscillators, [6] studied the timing and frequency synchronization methods to achieve good performance. In the timing synchronization, a simple correlation method can be adopted to achieve good synchronization performance. And for the Frequency synchronization, a joint UW and convolution algorithm is proposed [7]. It takes advantage of the constant envelope zero autocorrelation characteristic of UW, and combines this characteristic with the convolution to realize the carrier recovery quickly at low SNR. Compared to the traditional algorithm for frequency offset estimation, such as Fitz, L&R and L&W, this algorithm has a similar estimation range but lower complexity and higher accuracy than the traditional algorithms.

D. BCH and LDPC Cascade Code

BRadio system supports an advanced channel coding technique: BCH and LDPC cascade code. The LDPC code is utilized as the inner-code, and (762, 752) BCH code is utilized as the outer-code. This channel coding technique adopted in the downlink could improve link performance significantly.

The outer-code is (762, 752) BCH code with the following advantages:

- Not only detecting random errors, but also correcting burst errors.
- Rigorous algebraic structure and the performance of the short and medium code length can approach the theoretical value.
- Strong capacity of correcting errors and easy to construct, simple to encode and decode.
- Conjunct with LDPC code as outer-code can effectively resist to the bit error platform for LDPC at low BER.

The inner-code is LDPC code with the following advantages:

- Close to the Shannon limits with enough long code length.
- Lower error code platform compared with turbo codes.
- High degree of parallelism when decoding and suitable for high data rate systems.

And we use the method of matrix decomposition to construct the cyclic permutation matrix and get the LDPC generation matrix. The generation matrix G_{qc} of LDPC is:

$$G_{qc} = \begin{bmatrix} G_{0,0} & G_{0,1} & \cdots & G_{0,c-1} & I & O & \cdots & O \\ G_{1,0} & G_{1,1} & \cdots & G_{1,c-1} & O & I & \cdots & O \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ G_{k-1,0} & G_{k-1,1} & \cdots & G_{k-1,c-1} & O & O & \cdots & I \end{bmatrix} \quad (1)$$

where $\mathbf{I}$ is a unit matrix with $b \times b$, $\mathbf{O}$ is a zero matrix with $b \times b$, $G_{i,j}$ is a cycle matrix with $b \times b$, the definition of $G_{i,j}$ and its check matrix $H_{i,j}$ is according the Annex A and Annex B in [8]. The BCH code generation polynomial is:

$$G_{BCH}(x) = 1 + x^3 + x^{10} \quad (2)$$

The generating procedure of (762, 752) BCH code: build a 1013 bits stream by adding 261 bits ’0’ in front of 752 bits datas, after coding, it will be a system code with 1023 bits, then, delete the 261 bits ’0’in front, generate a 762 bits BCH code.

The code rates of 0.4, 0.6 and 0.8 are supported in the current BRadio standard [4]. Some simulation results under a vehicle environment of 60km/h are shown in Fig. 5 [9], from which we can see that the BCH and LDPC cascade code of 0.4 code rate can reach a BER of 10^{-5} with SNR no more than 15dB. Under the higher requirement for BER, the cascade code can achieve a better performance. Besides, with the inherent quasi-cyclic structure, it can achieve low encoding complexity, and decrease the cost of hardware largely. Hence, the BCH and LDPC cascade code in BRadio is of realizable practical significance.

E. MIMO Transmission

In the BRadio system, MIMO technology is employed in the downlink to enhance system performance. The current version supports two and four antenna transmission with open-loop transmission mode by the Space-Time Coding (STC) technique. Both spatial diversity and multiplexing are supported, following the increased link reliability and the transmission rate enhancement.

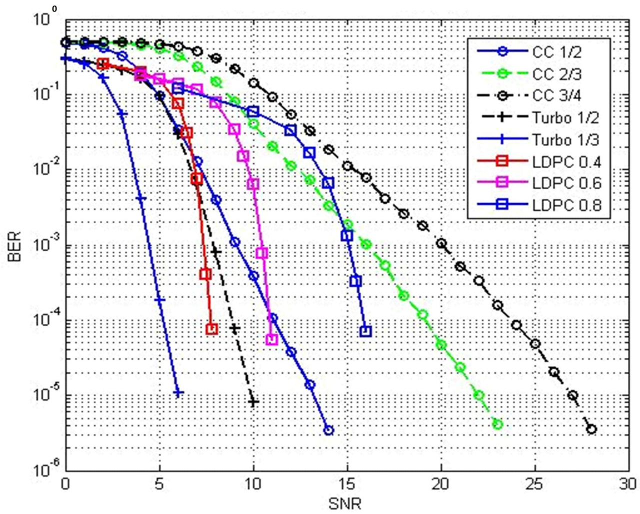

Figure 5. The link-level BER performance under different coding schemes and rates with 16QAM in vehicle environment.(60km/h)

Signal processing in MIMO transmission scheme is as follows: (multiple/single) original data bit streams are scrambled, modulated, layer mapped, pre-processing, space-time coding, the waveform shaped, and are sent by multiple antennas.

F. IDMA Technology

Since the base station has high computational capacity, IDMA technology can be introduced in the uplink of BRadio system to suppress interferences among neighbor cells. The main idea of IDMA is performing channel interleaving for channel encoded signals from different cells using different interleaving patterns, in order to obtain the effect of interference whitening.

In the BRadio system, the users in different cells are allocated with different interleavers, and each interleaver has a different interleaving pattern, interferences from other cells' users can be regarded as noises after interleaving. The Turbo iterative receiver structure is adopted at the receiver of IDMA, then the iterative soft decoding is carried out to suppress inter cell interferences [10].

III. Medium Access Control

A. Overview

The MAC layer is comprised of two parts: Convergence Sublayer (CS) and Function Sublayer (FS). The MAC CS provides any transformation or mapping between external network data and MAC Service Data Units (SDUs). And the MAC FS provides the core MAC functionality of system access, bandwidth allocation, connection establishment, and connection maintenance. In BRadio system, we add some new functional entities in the MAC layer, such as security submodule, sleep mode, and broadcast service. The function entities in MAC layer are listed in Fig. 6.

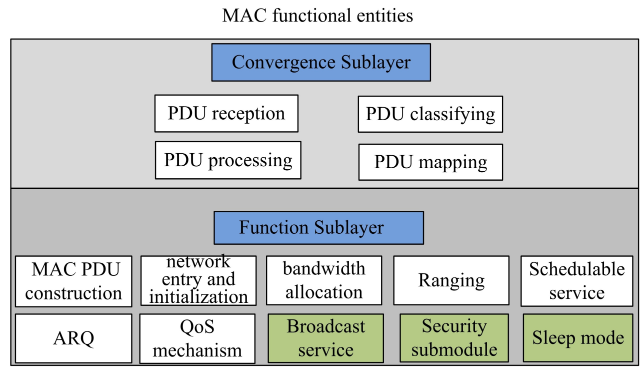

Figure 6. The function entities in MAC layer.

B. Sleep Mode

Sleep mode can be activated or deactivated repeatedly. We define two types of sleep mode, which are defined, activated and deactivated by the Sleep-Request message/bandwidth request and uplink sleep control frame header, or Sleep-Reply message/downlink Sleep control extended sub-frame header.

Sleep mode is activated in the start frame of the first sleep window, and each subsequent sleep window is twice the size of the previous one, but cannot exceed the specified final value, otherwise, the specified final value will be used as the size of the sleep window. The sleep windows are alternated with the listening windows of fixed intervals. In the listening window, the UE can receive all the downlink transmission. When this sleep mode is activated, the UE can not send or receive any MAC SDU or send the bandwidth request.

Sleep mode becomes active at the start frame of the first sleep window. All sleep windows are of the same size as the initial window, and are alternated with the listening windows of fixed intervals. When this sleep mode is activated, the UE can send or receive any MAC SDUs in the listening window, but cannot send or receive the MAC SDU in the sleep window.

C. Security Submodule

The security submodule can provide several functions, such as encryption, authentication and privacy protection for users by encrypting the connection between BS and UE. BS encrypts a service stream to prevent the transmission data on it from being unauthorized accessed, and executes the Privacy Key Management (PKM) with the ability of authentication, distributes the Authorization Key (AK) to UEs.

The security submodule includes data encryption and PKM protocol. Data encryption is for MAC PDU payload, and the encryption algorithm adopts 3-DES (Triple Data Encryption Algorithm) with 128 bits in CBC(Cipher Block Chaining) mode. The PKM protocol complys with Chapter 7 in RFC 2437 [11], adopts the RSA public key encryption algorithm and digital certificates X.509 which complys with Appendix A in YD/T 1614-2007 [12]. When a UE sends the authentication requirement to the BS, it also sends its digital certificates X.509 information like its identification and RSA public key. When BS receives the authentication requirement, it activates an AK for UE and encrypts this AK with the public key to get user's final AK. The authorized UE can decrypt the TEK information form BS and get the TEK. The whole procedure supports for periodic re-authentication / authorization and key updating.

D. Broadcast service

A broadcast module in MAC layer is designed to support the broadcast service, accomplishing transmitting broadcasting information and user communication data at the same time. This module combines the advantages of communication system and broadcast system in the transmission aspects.

When registering in BS to receive the broadcast service, a UE starts the Dynamic Service Addition (DSA) process for broadcast connection to inform the corresponding BS that it belongs to this broadcast service.

A broadcast connection associates with a service stream through the Connection IDentifier (CID) of this broadcast service, which is shared by all involved users. The RAE on the physical layer used by the transmission data broadcast service CID is given by the DL-MAP (DownLink MAPping). Every UE involved in the connection is required to receive all transmitted data in a broadcast service CID.

IV. NETWORKING

BRadio can support wide area coverage in high mobility scenario, with the mobile speed of terminal more than 250km/h and the maximum information transmission rate up to 20Mbps, or extended to 75Mbps with MIMO technique. In network deployment, BRadio puts an emphasis not only on the complementary issue with the existing networks, but also on independent networking.

A. Networking Independently

The BRadio system is comprised of terminal devices, access network equipments, core network equipments and service network equipments. The terminal devices can be fixed, portable or mobile. The access network consists of the BRadio base stations and their controllers, supporting the functionality of radio resource management, etc. The core network is responsible for the authentication and the roam of the users while supporting the interfaces with other networks. The service network provides the users with various broadband data services. Fig. 8 depicts the BRadio system that networks independently, which can constitute a

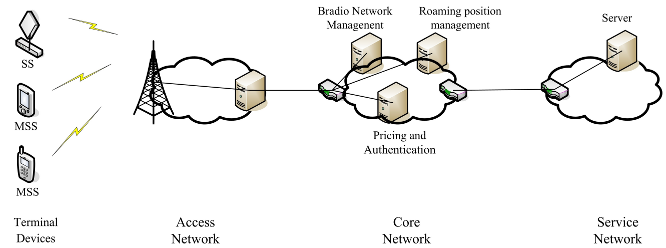

Figure 7. BRadio Networks Independently.

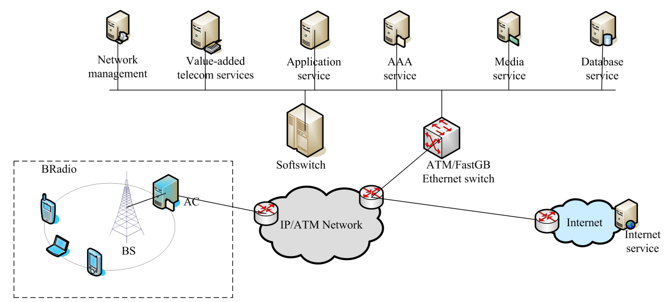

Figure 8. Network Model, functional entities and reference point.

complete mobile communication network from the perspective of technology and service.

B. Networking with Existing Networks

BRadio can implement the overlay networking with the existing networks. It can provide the functions and devices required by radio access. BRadio can access IP data network directly and interact with the service networks on it, to provide its users with IP data services on the existing service networks. This method of networking fully relies on the resources of the existing core network and services network, as shown in Fig. 8.

V. SERVICES

BRadio can be one of the basic urban information facilities with multiple services, including voice, data, image, and multimedia. When networking independently, BRadio mainly supports the service scenarios as following: wireless multimedia, emergency communication, complex environmental communication. When networking with the existing networks, BRadio mainly provides service in the following ways: softswitch, traditional intelligent services, multimedia value-added service, opening services to the third-party via Parlay/OSA application interface, converged services, and so on. Among those services, PMS service model as a special service is supported by BRadio system.

The PMS [13] includes three functional entity: User equipment, Authentication, Authorization and Accounting (AAA) server and Information Dissemination Management

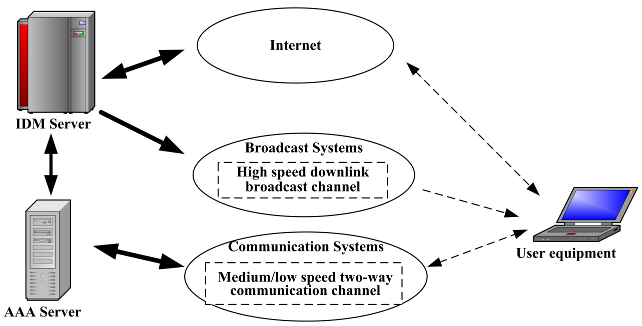

Figure 9. Intelligent PMS system Structure.

(IDM) server. The User equipment has the function of man-machine interface, authentication, authentication, billing, information search, information receiving and management, and information display; the AAA server has the function of authentication, billing, user-demand information transmission; the IDM server has the function of information acquisition, information storage, and the resource scheduling work about sending channel and transmitting time slot, providing network management services to system server at the same time.

The intelligent PMS system structure is shown in Fig. 9. After the user gets certificated by sending a request for authentication to the AAA server though medium/low-speed two-way communication channel, it updates its list of local media database through the Internet or other networks, and sends the demand information to the AAA server, then AAA server sends user needs information to the IDM server, IDM server performs scheduling of all information and informs the user through the downlink common broadcast channel, while the AAA server starts the billing control.

Resource scheduling scheme performed by the IDM server contains a joint scheduling of the potential factors, including the number of users, the average waiting time, the average user level and the accumulated costs of those resources.

The PMS service model combines the advantages of communication system and broadcast system in the transmission aspects, and achieves the innovation of the billing and service scheduling mechanism based on the features of new intelligent terminals. It arranges priority levels for users, determines the transmission time and the corresponding price based on the time limit of information acquisition. The PMS transmits information to the users who order the same video on demand (VOD) and achieves both information sharing and wireless physical link sharing. Overall, the PMS, which is a media service system with the ability of priority dividing, is suitable to provide cheap information acquisition for users.

VI. Conclusion

In this paper, we present BRadio system from the aspects of physical layer technologies, MAC layer, networking methods, and services. TFU-OFDMA and TFU-SCMA adopted as the downlink and uplink transmission technologies can not only improve the performance of synchronization and channel estimation, but also reduce the complexity of signal processing at the receiver. BRadio also employs air interface technologies such as IDMA, MIMO and LDPC to enhance the spectrum efficiency. Several functional entities are added in the MAC layer of BRadio, such as security submodule, sleep mode, broadcast service. Besides, with its flexible networking methods, BRadio can support rich kinds of services, among them, a novel service model PMS is proposed. Relying on the technical superiority of its high data rate, high mobility, and low cost, as well as its flexible networking and comprehensive service platform, BRadio has become a potential technical solution for future broadband wireless access networks, especially making it widely applied to various specialized wireless communication systems.

VII. Acknowledgment

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