2019

QoE Driven Multimedia Service Schemes in Wireless Networks Resource Allocation: Evolution from Optimization, Game Theory, to Economics

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by

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A Dissertation submitted to the Faculty of Claremont Graduate University and San Diego State University in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Computational Science

Claremont Graduate University and San Diego State University

2019

Approval of the Review Committee

This dissertation has been duly read, reviewed, and critiqued by the committee listed below, which hereby approves the manuscript of Shuan He as fulfilling the scope and quality requirements for meriting the degree of Doctor of Philosophy.

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Abstract

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In order to deal with the Quality of Experience (QoE) improvement issue in the wireless networks services. In this dissertation we first investigated the Device to Device (D2D) relaying approach in the conventional Base Station (BS) to User Equipment (UE) two entities multimedia service system. In this part, the Multiple Input Multiple Output (MIMO) technology will be implemented in the D2D communication. Furthermore, factors such as the multimedia content distribution (i.e., Quad-tree fractal image compression method), the power allocation strategy, and modulation size are jointly considered to improve the QoE performance and energy efficiency.

In addition, the emerging Non-Orthogonal Multiple Access (NOMA) transmission method is becoming very popular and being considered as one of the most potential technologies for the next generation of wireless networks. For the purpose of improving the QoE of UE in the wireless multimedia service, the power allocation method and the corresponding limitations are studied in detail in the

wireless system where the traditional Orthogonal Multiple Access (OMA) technology and the promising NOMA technology are compared.

At last, facing the real business model in the wireless network services, where the Content Provider (CP), Wireless Carrier (WC), and UE are included, we extend on work from the conventional BS-UE two entities research model to the CP-WC-UE three entities model. More specifically, a generalized best response Smart Media Pricing (SMP) method is studied in this dissertation. In our work, the CP and WC are treated as the service provider alliance. The SMP approach and the game theory are utilized to determine the data length of UE and the data price rate determined by the CP-WC union. It is worth pointing out that the concavity of utility function is no longer necessary for seeking the game equilibrium under the proposed best response game solution. Numerical simulation results also validate the system performance improvement of our proposed transmission schemes.

Acknowledgements

First of all, I would like to express my sincere gratitude to my advisor Prof. Wei Wang, for the continuous support of my Ph.D study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this dissertation. I could not have imagined having a better advisor and mentor for my Ph.D study.

I would also like to thank the rest of my committee: Prof. Tao Xie, Prof. Sunil Kumar, Prof. Ali Nadim, and Prof Allon Percus. Not only for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives. All the way from my qualifying exam which happened 2 years ago, to my proposal last year, until now, my dissertation defense, I really appreciate their tremendous amount of help.

I would also like to thank my fellow labmates: Krishna, Sebastian, Edwin, Patrick, Julia, Qin, Vamshi, Alan, Chase, etc., for their company in the last four years in the Lab.

I would also like to thank my family, to my parents, my wife, my 11-month son, for their supporting me spiritually throughout writing this thesis and my 4 years of America life in general.

Last but not the least, I would like to thank my dear friends in SD: Sperrys, Zellers, Lennick-Reynolds, Wen, Alvin, Freddy, Joe, Jenny, Vy, Oliver, Atsu, Ning, ICF group, Werewolf groups. Because of them, I went through and overcame all the loneness time.

This research was supported in part by National Science Foundation (NSF) grants CNS-1463768, CNS-1743427, and CNS-1744182, and San Diego State University College of Sciences faculty startup fund. I also want to thank their supports.

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Chapter 1

Introduction

1.1 Motivation

During the past couple of decades we have witnessed gradual, but steady evolution of mobile wireless communication from second, third generation towards the fourth and next generation of wireless networks (i.e., 5G). The incurred challenge with the developing technology is how to deal the everlasting increase of multimedia traffic in the wireless networks service. To address such challenge, more efficient and low cost transmission schemes and technologies are needed to the network operators, for the purpose of improving the Quality of Experience (QoE) of end users and increasing the economic profits of wireless service providers. For example: the promising Device-to-Device (D2D) transmission schemes need to be thoroughly investigated due to its high transmission speed and ultra-low latency. More research is needed to be conducted by using the Multiple Input Multiple Output (MIMO) technology since the high transmission efficiency and low Bit Error Rate (BER) of MIMO. In addition, comparing with the traditional Orthogonal Multiple Access (OMA) scheme, i.e., OFDMA, the new Non-Orthogonal Multiple Access (NOMA) transmission scheme has features such as better spectrum efficiency, energy efficiency, and user-fairness. Thus, taking the features of NOMA into consideration is necessary when we conduct the research in the new multimedia service strategy in wireless networks.

Furthermore, besides the conventional research on the wireless multimedia QoE improvement issue between the Base Station (BS) and User Equipment (UE), where the utility gain (i.e., economic profits) of BS and the QoE gain of UE were thoroughly investigated. It is essential to extend researcher's view to a wider picture as well. More specifically, 1) the exploration on the utility or QoE gain of the three entities in wireless multimedia service. i.e., the Content Provider (content provider), the Wireless Carrier (WC), and UE; 2) the investigation on the relationships and service schemes among these three entities, and 3) the research on the new resource allocation methods under the three entities framework. It is worth noting that one big challenge when considering the content provider-WC-UE three entities model is that the dramatically increasing of the complexity of the heterogeneous wireless networks. Lots of factors in the system would impact the utility/QoE gain, i.e., the power allocation, the multimedia content quality, the physical channel conditions during the transmissions, the amount of data consumed by UE, the data price the charge by CP or WC, etc. Thus, the research on new approaches, i.e., game theory from economic field and machine learning method from artificial intelligence, are need to address the resource allocation issue in the new complex wireless networks.

1.2 Contribution

This dissertation focuses on the UE's QoE improvement issue and CP or WC's profits maximization problems in the next generation of wireless multimedia service. The contribution of the research presented in this dissertation is four folds.

First, the D2D relaying approach is studied in the typical BS to UE two entities multimedia service system. The MIMO technology will be implemented in the D2D communication, through which the transmission efficiency and energy efficiency will be improved simultaneously. In addition, factors such as the multimedia content distribution (i.e., Quad-tree fractal image compression method), the power allocation strategy, and modulation size are jointly considered in the research presented in this dissertation. Under the help of new transmission schemes implemented on relay device, the multimedia service quality (i.e., QoE of UE) would be significantly improved.

Second, to improve the QoE of UE in the wireless multimedia service, the power allocation method and the corresponding limitations are studied in detail in the wireless system where the traditional OMA technology and the promising NOMA technology are compared. Furthermore, at the multimedia content level, the dynamic video Quantization Parameter (QP) adaptation method is utilized. The quantitative analysis of the impact of transmission power allocation strategy and QP size selection on UE's utility gain is conducted in this dissertation.

Third, to extend the conventional BS-UE two entities research model to the CP-WC-UE three entities model, a generalized best response Smart Media Pricing (SMP) method is studied in this dissertation. More specifically, the CP and WC are treated as the service provider alliance. The SMP approach and the game theory are utilized to determine the data length of UE and the data price rate determined by the CP-WC union. It is worth pointing out that the concavity of utility function is no longer necessary for seeking the game equilibrium under the proposed best response game solution.

Fourth, one incurred challenge after considering three entities (i.e., CP, WC, UE) in the wireless media service is the dramatically increasing complexity of the problem. More specifically, the multimedia quality and unit data price at the CP side, the transmission technologies (i.e., MIMO, NOMA) at WC side, and the data service requests at UE side. Thus, the machine learning based method will be shortly discussed in the conclusion part of this dissertation, as the future work that we plan to use the machine learning method to analyze the impacts of power allocation strategy on the system performance (i.e., the utility/QoE gain of each entity) in the NOMA wireless system. It is a good starting point to apply the high level artificial intelligence to the low level advanced NOMA technology.

1.3 Organization of the Dissertation

The organization of this dissertation is as follows. In Chapter 2, the user-centric QoE driven multimedia relaying and rebroadcasting methods is proposed to address the resource allocation issue, for the purpose of improving UE's QoE gain. In Chapter 3, we will present a QP and power control method in the wireless multimedia communication system, where the conventional OMA transmission and promising NOMA are considered. In Chapter 4, a best-response combing with the promising SMP method is studied to improve the QoE of UE and rewards gain of SP. The conclusion and future work of this dissertation is drawn in Chapter 5.

Chapter 2

Proposed User-Centric QoE Driven Multimedia Relaying and Rebroadcasting Methods in Wireless Systems

As stated in the introduction section, the multimedia broadcasting applications are getting more and more interests in the coming popular and increasing 5G networks. While on the other hand, the conventional BS to devices multimedia data broadcasting approaches are not east to meet the highly diversified QoE requirement from users' perspectives. In this chapter, by considering the strict energy constraints, we first propose a user-centric multimedia re-broadcast approach which leverages the D2D communication method with energy consumption. The provided approach works in two folds: 1) at the lower level, i.e., the physical layer, it would optimize the transmission energy of each rebroadcasting UE, simultaneously by taking modulation rate scaling with energy consumption constraint. 2) The proposed method is also intersect-layer optimal method to enhance multimedia quality of experience. Besides the multimedia rebroadcasting method, for the goal of making fully use of the new transmission technology, we propose an optimal multimedia relay scheme in this chapter as well.

Where the application multimedia content prioritization distribution and the selection of UEs' antenna (we assume the multiple antenna devices are used on our work) are jointly considered. Under the help of the Channel Information Feedback (CIF) and MIMO diversity gain in relay systems, the ways to device the trunk part and leaf part of multimedia content and multiple antennas selection method would be dynamically adjusted with the real-time ICF, which would potentially increase the wireless network service performance such as the energy efficiency and the UE's multimedia QoE gain. More specifically, two sides of work are done in this chapter, one is the Quad-tree fractal image compression approach, the other is the famous Alamouti space-time coding method is used and tested when we consider the application of different antenna chain for different multimedia data content.

2.1 Background and Related Work

The coming high transmission data rate for the next generation of wireless network system, i.e., 5G systems, are expected to offer the high quality Internet Protocol Television (IPTV) and Digital Video Broadcasting (DVB) services [1]. Features such as high resolution multimedia data content, faster transmission speed, fairness-consideration service modes are researched by the DVB and IPTV groups. By facing the challenges, i.e., SP tries to deliver high quality video service to a large amount of terminal clients under energy limitation, when the PS provides large portion of 4K Ultra High Definition (UHD) DVB-T services, it is necessary to come up with some new high performance method for the 5G multimedia video services.

In addition, the power control and modulation scheme are two vital factors in wireless communication. Since a major difference between wired network and wireless network is that many nodes have the energy constraint in wireless environment. Such as in wireless sensor network (WSN), the sensors are always limited by energy due to the size of carried battery. Same as the distributed nodes in WSN, mobile devices in 5G networks are also encounter the same situations: lack of energy, transmitting or receiving data through D2D and request of high multimedia quality. Mobile device requests and receives data from the BS is the traditional wireless technology. The traditional way has two shortages. First, user has to pay a lot to BS in order to get the higher data service if the whole data transmission is completed by the BS. Second, it is not easy to ensure the service quality due to the long distance.

Facing these problems, the device to device communication is becoming popular in the academic research. Comparing with the existed tradition device or relay broadcasting methods in the wireless network service, in this chapter we will study a new method of rebroadcasting cached multimedia contents to neighbors, try to use both transmission power allocation and data rate optimization approaches to increase the user-centric QoE. We not only implement D2D communication scheme, but also consider the different physical channel conditions. Eventually, we would maximize the multimedia QoE jointly thinking about the transmission power and constellation size. The two very important factors, one is transmission power control, the other is the sending modulation rate control, are adopted in our work for the purpose of achieving desirable energy efficiency multimedia data (re)broadcasting in 5G wireless communications. Fig. 2.1 illustrates the service scenario we consider in this chapter, where the concept of retransmitting the stored multimedia data with resource allocation controls in wireless networks is shown. UEs 1 to N are randomly placed around the base station, some UEs are closer to the BS while others are further. All UEs will get broadcasted or multicast multimedia data contents through a wireless channel, where it is possible to transmit data in a certain resource in the down layers of network protocols. Some UEs, i.e., the closer ones, are able to smoothly get and decode the multicast data from BS but some others (i.e., the UEs physically located further to the BS) may fail to catch the multimedia data contents during wireless broadcasting. In our work, we assume the UE who has the best channel condition, serves as a rebroadcasting device (i.e., plays the role of relaying data) to further transmit its cached information to his neighbors (who failed in catching these information data) in the next achievable time period. Under the help of re-broadcasting process, we would improve the system overall QoE gain and reduce missed packets. To be specific, at some given time moments, the equipment who be chosen as the rebroadcasting device will be given with some resource pieces to send multimedia data to other UEs (i.e., the N UEs shown in Fig. 2.1). Every receive equipment who has the same lost frames but still wants to obtain another copy of high quality of information content from the re-transmitting equipment.

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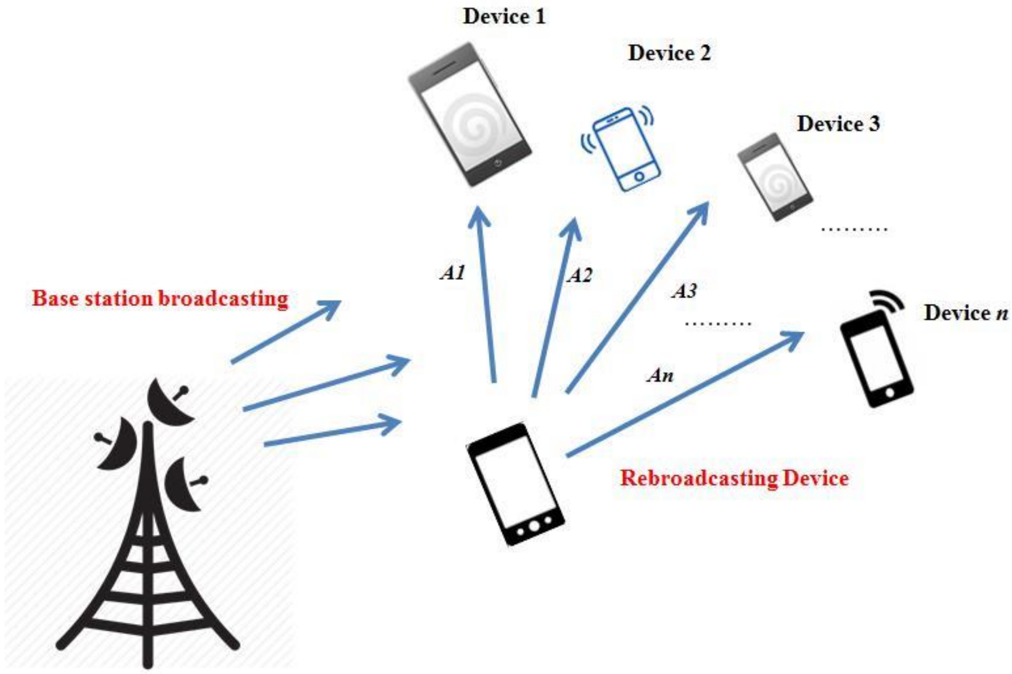

Figure 2.1: The illustration of the rebroadcasting service scenario. The relay device would re-broadcast the cached data through D2D channel. The various channel information of receivers are also considered in rebroadcasting process. Figure refers to [19].

There is lots of research work has been conducted out on the energy consumption reduction issue with regards to the traditional wireless network service. Generally speaking, the transducers are always limited by the dimension of its carried battery, thus cost of energy is took into consideration at every round of information content transmitting [2]. Such fact confirms that statement that "saving power equals saving the energy". On the other hand, properly choosing the modulation size in the transmission is a new way to save energy [3] [4] [15]. In [5], the writers achieved the reduction of overall power source consumption through adjusting the dynamic modulation size and data speed, with understandable user service late. Furthermore, authors in [6] used the modulation scaling method to increase the system throughput, even under the situations such as fading channels. Except the power and constellation size dynamically adapting idea, the D2D becomes popular in both industry and academia [7] [8] as well, in terms of research work for next period of wireless networks. The rationale behind this is that the device to device method will dramatically enhance the framework throughput (i.e., the high transmission speed through mm-wave communication), especially in the 'UEs not close to the base station' scenario [9]. Authors in [13] provided an approach to realize the power source balancing of many hops while at the same time considering the quality of media information. In this chapter, both transmitting energy and constellation size would be taken into consideration when aim at improving the multimedia rebroadcasting quality (a.k.a QoE) while under energy constraint.

In addition, facing the fact that the trend of how to improve UE's QoE is a big problem, in other words the QoE-driven multimedia services are the main load in wireless network [16-19]. What's more, the web based life based picture content internet common using help a great deal to the versatile information transmitting. Profiting by the quickly developing of remote system foundation and offices, the issue of administration lack brought about by the drastically expanded utilization of cell phones, for example, cell phones prompts an exponential development in versatile media traffic can be tended to in some degree [20].Good results have been achieved such as supported by plenty of research advancements such as D2D communications schemes, and massive MIMO [8, 21-22]. Parallel to the advanced research came out at physical layer, the source image coding issue (i.e. image compression) is also widely addressed to improve the energy efficiency [23-25].

Thus, inspired by the research at the application layer and source image coding/compression, in this chapter we propose another methodology for vitality proficient remote picture hand-off, utilizing not only application layer picture data dividing in pressure but also lower level channel multiple input multiple output decent variety. The MIMO is a very new but with great potential technique that used for the multiplying the capacity of any data transmission link (i.e., BS-UE downlink and D2D link) by applying multiple transmission and receiving antennas on the sending and receiving devices to exploit multipath propagation. In [26], researcher Alamouti studied the transmitting scheme with two branches (i.e., two antennas) on one device, which would dramatically increase the BER performance in the wireless data links. A cross-layer strategy is provided by authors in [27], where the application and physical layer diversities that allow Adaptive Channel Selection (ACS) over MIMO are utilized. The ACS-MIMO strategy had demonstrated improved multimedia quality in wireless video transmissions. Furthermore, by make full use of MIMO technology, a QoE-ensured remote interactive media administration design was examined in a hand-off based two-bounce transmission situation [28]. Moreover, the asset allotment and energy effectiveness plans have likewise been generally considered in writing tending to the QoE issue utilizing MIMO system. Authors in [29] manufactured a energy productivity model in the MIMO-OFDM interactive media correspondence framework with factual administration quality imperative. With minimal additional asset utilization, a productivity input MIMO asset assignment plot was provided in psychological radio system [30].

Considering the high layer in the network protocols, normal cutting edge picture pressure frameworks utilize either Discrete Wavelet Transform (DWT) or Discrete Cosine Transform (DCT) systems in change space. For example, the outstanding

JPEG picture pressure measurement utilizes DCT pressure conspire. The DWT conspire is generally utilized in JPEG2000 and Set Partitioning in Hierarchical Trees (SPIHT) [31]. Previously mentioned strategies have demonstrated the capacity to accomplish very pressure proportions and transmission proficiency in remote correspondence frameworks, in spite of the fact that the computational intricacy is generally high. Fractal picture pressure innovation utilizing Quad-tree deterioration procedure can accomplish higher picture pressure proportion and rate-quality execution without complex changes [32]. It has the favorable circumstances, for example, simple to actualize and being appropriate for low power cell phones. The fractal pressure idea is utilized as the source coding approach in this paper. Isolating positions and qualities by distinguishing Quad-tree structures (speaking to expansive level territories) and tree leaves (speaking to fine subtleties), we use Quad-tree disintegration and Huffman entropy coding for picture bit-pressing before MIMO transmission. As appeared in Fig. 2.2, we propose a remote hand-off plan together considering picture pressure and reception apparatus choice to hit the media quality of experience problem in power source imperative remote correspondences. Transmitting (T_x), transfer and accepting (R_x) devices are altogether thought to be outfitted with various radio wires in this work. At the physical layer, the Alamouti's space time coding plan is studied by us for tending to the radio wires determination problem. The Quad-tree fractal pressure strategy is learned at application layer to organize the picture substance.

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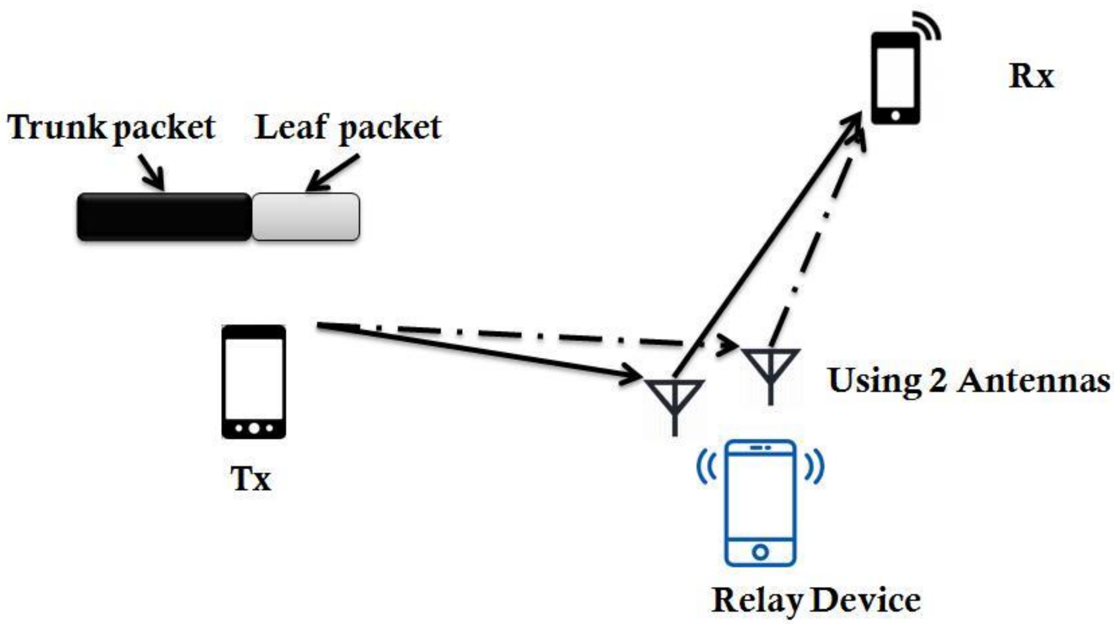

Figure 2.2: The system model of this chapter, single or multiple antennas are chose at T_x and R_x in the transmission. Figure refers to [37].

2.2 System Model

2.2.1 Multimedia Rebroadcasting

The goal of this sub-chapter is to improve the multimedia quality gain under energy constraints situation while considering the transmitting energy and modulation size simultaneously. The problem is mathematically formulated as Equation (2.1 ~ 2.4) [10]. It necessary to mention that in our work we select two, four, six, and eight as the modulation because higher modulation size (16 or higher) might be unrealistic in low-end wireless systems [11]:

$$\{b_i, Pt_i\} = argmax\{\sum_i E[D_i]\}, \forall i \in [1, N] \tag{2.1}$$

Subject to the energy limitation in rebroadcasting:

$$\left\{\sum_i E_{TX}(i) + \sum_j \sum_i E_{RX}(i,j)\right\} \leq E_{max}, \forall i \in [1, n] \tag{2.2}$$

$$b_{min} \leq b_i \leq b_{max} \ \& \ Pt_{min} \leq Pt_i \leq Pt_{max} \tag{2.3}$$

$$E_{TX} = P_t \frac{L_i}{R_S b_i} \ \& \ E_{RX} = P_r \frac{L_i}{R_S b_i} \tag{2.4}$$

where E_{TX} and E_{RX} are power cost of the rebroadcasting equipment and receive UEs separately. E_{max} denotes the total energy budget for the rebroadcasting system.

From above formulas we conclude that with the power source constraints, diminishing transmitting energy and expanding group of constellation size are great methodologies regarding sparing energy. However, less transmitting energy brings more packet error speed, and interactive media quality would diminish in the end. Their mathematical relation is shown in Equations (2.5) ~ (2.7) according to [20] [24].

$$e = \frac{2}{b}\left(1 - \frac{1}{2^{\frac{2}{b}}}\right) erfc\left(\sqrt{\frac{3}{2(2^b - 1)} \frac{P_t A}{R_S N_0}}\right) \tag{2.5}$$

$$P_i = 1 - (1 - e)^{L_i} \quad (2.6)$$

$$E[D] = D(1 - e)^L \quad (2.7)$$

$$E[D(i)] = D(i)(1 - P_i) \prod_{k \in R_i} (1 - P_k) \quad (2.8)$$

We use the term R_i indicate the reliance set of i-th frame. Equations (2.1) to (2.8) refer to [19]. More information about the I, B, P frame and their relation, please refer to [26], where frame and packet are interchangeable in the whole context. Equation (2.7) and (2.8) illustrate how to compute the frame distortion reduction for I frame and P packet separately. From Equation (2.2) ~ (2.8), we conclude it is the unavoidable tradeoff between energy utilization and media data quality increase by upgrading the transmitting energy and modulation size.

2.2.2 Multimedia Content Prioritization and MIMO

The target of our work is to enhance the quality of experience at beneficiary in the hand-off based remote systems. We propose the numerical model by mutually considering the picture content pressure and radio wire chain determination among cell phones. By considering the fractal picture pressure strategy, picture content is compacted into two sorts of bundles: the trunks portraying the positions and leafs depicting the qualities as appeared in figure 2.2. S_{trunk} and S_{leaf} imply the assets handing out policy sets for trunk and leaf bundles. Each set specifically shows the antenna selection situation in the transmission path, i.e., how many antennas keeps active for sending/receiving data. More specifically, $S_{trunk} = \{(L_{trunk}, M_{T_x - R_x})\}$ and $S_{leaf} = \{(L_{leaf}, M_{T_x - R_x})\}$. And our objective is addressed as an energy constrained QoE enhancement problem under good resource allocation method.

$$\{S_{trunk}, S_{leaf}) = argmax\{QoE\} \tag{2.9}$$

s.t.

$$E_{Tx} + E_{Relay} + E_{Rx} \leq E_{max} \tag{2.10}$$

The rationale that why the limitation of energy consumption is important in our model is based on: in the wireless communication, especially when we considering the D2D communication to help out re-transmitting data, the energy budget (i.e., energy capacity is limited by the size of battery carried by device) is the most important factor for UEs in wireless data transmission. Generally speaking, the leaf part has lesser reducer of Root-Mean-Square-Error (RMSE) than the trunk part, and it has longer frame length. That is to say, the truck packets are shorter compared with the leaf part, but it includes more important information of the whole packet and it takes vital part in image coding. One big benefit of the image (data content) divergence strategy is that the important part of content, i.e., trunk parts, who would unmistakably influence the nature of multimedia information transmitting, are supposed to be sent with greater need if the asset (i.e., transmission power and data transfer capacity asset) is carefully restricted.

After the MIMO technique is implemented at physical layer (we assume the mobile devices equipped up to two antennas in our work). The number of active antennas in the devices is determined by the importance of data content that would be sending out. The choice of either activates one antenna or two is dynamically changing along with the real environment conditions. Let M_{Tx-Rx} imply the antenna link choice policy among the T_x and R_x. Let S_{space} as

$$M_{Tx-Rx} \in S_{space} \tag{2.11}$$

$$S_{space} = \{0000, 0001, \dots, 1110, 1111\} \tag{2.12}$$

For simplicity, single relay is used in this work. But our proposed method can be easily extended to more complex scenario, i.e., multiple relays between the transmitting device and receiving device. When there is only one relay, there are totally 16 strategies. As shown in Equation 2.12, we use 4 numbers to manifest the antenna link policy description of all possibilities, because there are four points that antennas are needed. The point at the transmitter, the point at the receiver side of relay, the point at the sending side of relay, and the last one is the receiving side of the receiver. Let 4 continue ‘0000’ be the easy antenna link policy, which denotes there is only 1 antenna being used at all UEs (transmitter, relay, and receiver). The ‘0110’ means that one antenna is active on T_x/R_x and 2 antennas were active on relay, as shown in figure 2.2.

at the RHS of Equation (2.9), the quality of experience at receiving side is calculated as:

$$QoE = D_{trunk}\left(1 - p_{Tx-Relay}\right)\left(1 - p_{Relay-Rx}\right) +$$

$$D_{leaf}\left(1 - p_{Tx-Relay}\right)\left(1 - p_{Relay-Rx}\right) \qquad (2.13)$$

where D_{trunk} and D_{leaf} imply the trunk and leaf part's root mean square error reduction. It is worth pointing out that the decrease of RMSE gain of frame would be computed at getting side if and only if the transmission is successful. And from then from the relay to the receiver R_x. The attainable RMSE would be zero if the packet is lost or occurred any error during the transmission. This is one of the reasons to make the number of relay between two mobile devices limited to small. The PER p_{A-B} is determined by the channel BER. As the work we did before, the random error model is selected when we consider the PER or BER in the wireless channel. The BER or PER is calculated as shown in Equation (2.6). Based on the work shown in [26], the channel BER can be significantly decreased when the space time coding technology is adopted in the transmission.

One shortage of the application of multiple antennas method is the extra energy consumption, because when we keep more antennas activate, more energy consumption to maintain the system. Let the term T_i denote the amount of antenna that keep, the overall energy consumption is shown as:

$$E_{Tx} = P_t \frac{L_o + L_{trunk} + L_{leaf}}{R} + P_c \frac{L_o + L_{trunk} + L_{leaf}}{R} T_{Tx} \quad (2.14)$$

From the above equation we observe the energy consumption includes two parts, one is the power cost in transmitting data and the other one is the incurred circuit power cost in the whole receiving procedure. Then we have the energy cost at R_x and relay sides, as follows.

$$E_{Rx} = P_c \frac{L_o + L_{trunk} + L_{leaf}}{R} T_{Rx} \quad (2.15)$$

$$E_{Relay} = P_c \frac{L_o + L_{trunk} + L_{leaf}}{R} T_{Relay} +$$

$$P_t \frac{L_o + L_{trunk} + L_{leaf}}{R} T_{Relay} + P_c \frac{L_o + L_{trunk} + L_{leaf}}{R} T_{Relay} \quad (2.16)$$

Equations (2.9) to (2.16) refer to [37]. It is necessary to explicate one detail about the power allocation when there are two antennas being activated on one device. That is, the transmitting power P_t will be evenly used for every antenna if the two antennas are working. While the transmitting power P_t will be whole used in the antenna if only one is activated. Based on above Equations we know that there are 2 factors that would influence the energy consumption in data rate transmission. One is related to the resource allocation issue, for instance the transmission power allocation on each device and the antenna-chain selection for the multimedia content. The other is the proportion, i.e., how much the length of trunk/leaf parts of source image data respectively.

2.3 Resource Optimization Issues on the Rebroadcasting and Multimedia Content Prioritization, Physical Antenna Selection in Relaying

After analyze the rationale of the proposed resource optimization and MIMO application in the diversity multimedia content transmission issues. We will walk into the details of the implementation of our proposed method. As stated before, the resources (i.e., transmitting power, constellation size) allocation options would impact the UE's QoE gain, the content prioritization and antenna selection in the transmission would influence the utility gain of UE as well. These two aspects will be addressed in the section respectively.

2.3.1 The impacts of the power and modulation size on media quality gain and energy consumption

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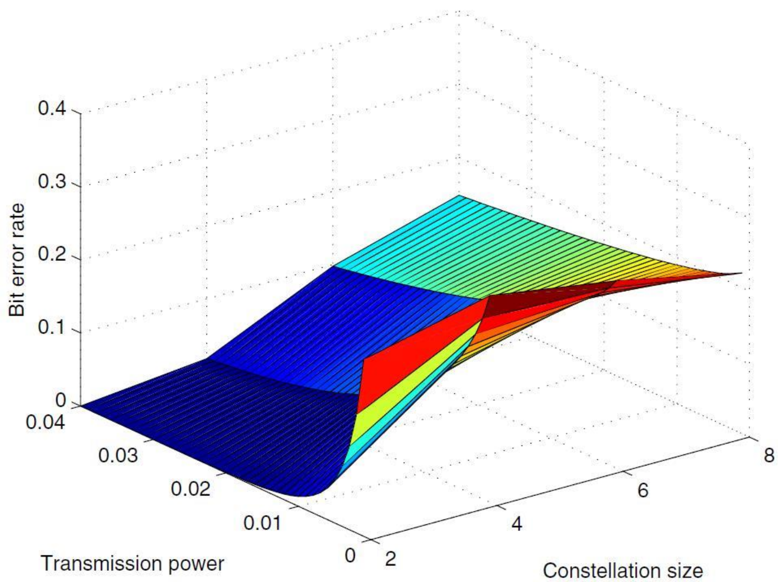

Figure 2.3: The illustration of BER under various power and modulation size set up. Figure refers to [19].

Generally speaking, the BER is controlled by a few factors, for example, transmission energy, channel data information, image speed, the density of noise power, and modulation size in the physical layer transmission asset assignment. In the dissertation we center on two factors – the energy consumption and constellation size. Because these two can be changed by us in the designation. As appeared in figure 2.3 and figure 2.4, the greater transmitting energy prompts less BER and the greater constellation size would lead greater piece blunder rate yet accomplishes higher transmission speed. In the application layer point of view, where the information precision or got information quality is considered as significant factor to UE, we see that the diminishing of BER at non-high layers is the best method to expand the interactive media quality of experience. So also, figure 2.4 demonstrates the power utilization with various transmitting power and modulation dimension selection. So when consider energy impediment, we will have sensible interactive media gain by together choosing the reasonable transmission energy set up and constellation size.

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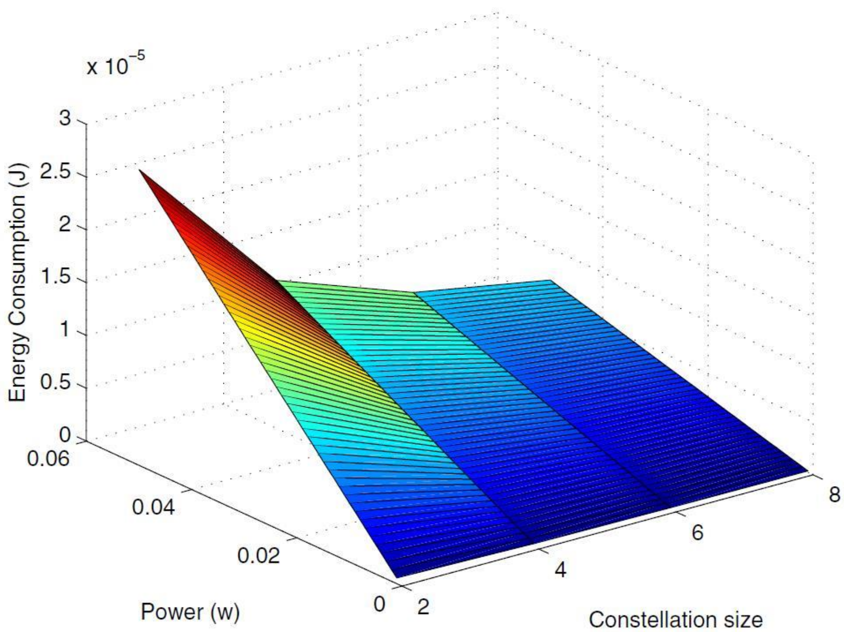

Figure 2.4: The energy cost with various power and modulation size. Figure refers to [19].

2.3.2 Different Channel Information Factors

Except the power control and constellation size issue illustrated above, the CIF factor, which is stable in certain sort period of time but keep changing, cannot be ignored when we analyze the received multimedia gain. The term A, is the symbol of channel information factor. It includes all misfortune parts in the transmission in general. Under requirement of energy spending plan for media rebroadcasting, Fig 2.5 shows how multimedia characters changes with variety of channel condition A. For the multimedia data quality performance evaluation, the metric called peak signal to noise ratio (PSNR) is selected in our work. The PSNR has been used a lot in multimedia quality system performance quantitatively analysis [12].

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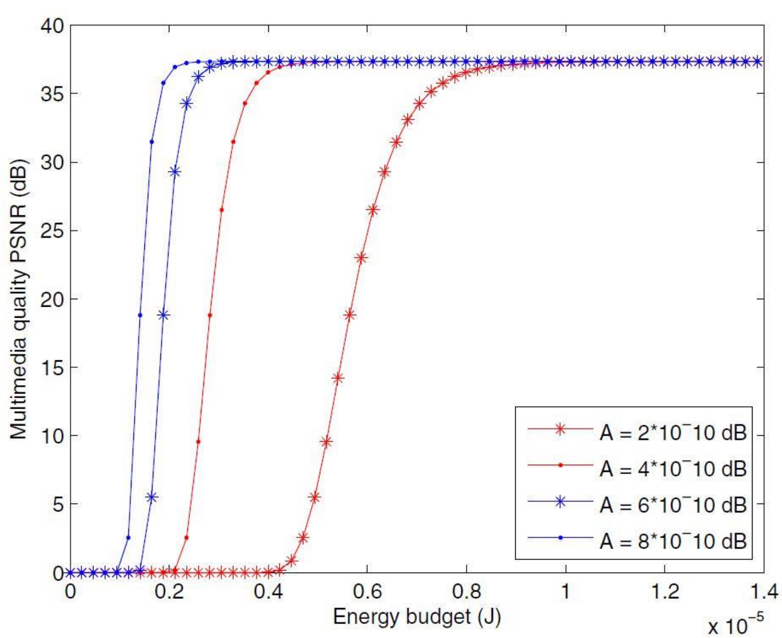

Figure 2.5: The illustration of multimedia rebroadcasting gain with various channel conditions among devices. Figure refers to [19].

Instead of going to details about each factor, such as different, rumble, channel fading and interference among different UEs, we take various A_i to indicate the cannel condition that including all factors. Before the rebroadcasting device starts transmitting data, there will be an adjusting phase. The adjusting phase is like the hand-shake procedure in the TCP protocol, through which the transmitter and receiver would obtain some basic information about each other. And the environment information (i.e., channel condition A) will be gained as well during the adjusting phase. The objective of this stage is to decide the ideal transmitting energy set up and constellation size which will be utilized in the data sending. The assurance procedure pursues Algorithm 1, the algorithm refers to [19]. The output of the proposed method is the optimal power and modulation size (a.k.a constellation size in the transmission), based on the current channel conditions. If we obtain these yields out of the calculation, we modify some parameters in the deep layer on data sending gadget and begin to transmit information to getting gadgets. Diverse link data confirms that we will have a novel blend of intensity and constellation speed necessity as far as expanding media QoE. One interesting point is that we would run the algorithm periodically, since the output of the algorithm may change with the time.

Algorithm 1: To find the optimal power, and constellation size in the modulation

1. Define the input and output of algorithm:

Inputs: (1) Channel information factor A. (2) Symbol rate R_s. (3) Energy constraint E_{max}.

Outputs: (1) Maximum of $E[D]$. (2) The P_t and b.

2. Initialize parameters: A, P_t = 0 and $E[D]_{max}$ = 0.
3. For b_i = 2:8
4. Compute the E_{con} according to P_t and b_i.
5. While $E_{con} < E_{max}$
6. Gradually increasing the P_t.
7. Compute the BER according on Equation (2.6).

if frame p is I packet type

Compute the frame's D_i

based on Equation (2.7);

if frame p is not I type

Compute the D_i of packets

based on Equation (2.8);

8. if $E[D]_p > E[D]_{max}$

$E[D]_{max} > E[D]_p$; Save the P_t and b_i;

9. End While

10.End For

2.3.3 The Rebroadcasting Procedure

The data sending approach in this part of dissertation is named as rebroadcast. The rationale behind the data content re-broadcast is that after certain devices (i.e., close to the BS and obtain better wireless data service) received the data and cached the data content, these devices would re-broadcast the cached data to their neighbor devices who didn't get the full data or lost come part of the origin data. The data copy from the relaying phase would significantly increase the received data quality of these devices that is with bad channel condition with the BS and failed to catch the data in the first time frame. In this part of our dissertation, we will center at the accumulative media data gain of users, where the data comes from the BS and the data comes from the relay device (through re-broadcasting). The proposed optimization approach would be evaluated to the situation as shown in Fig. 2.1.

2.3.4 The Image Content Diversity at Application Layer

Technically speaking, when we store the image data or any other multimedia data on electric equipment, the data frames have large number of redundancy and similarity. Such redundancy and similarity among huge amount of source data makes the data content compression very necessary and feasible. Through properly utilizing the fractal compression method, we are able to separate an image block into 4 pieces into different small blocks according to preset certain quality requirements. Fractal compression method will dramatically reduce the transmission resource consumption benefiting from its greater compression percentage. The outstanding work of our dissertation is we are aiming at hitting the problem of designing and allocating the media information for image data through the Quad-tree approach. So we can reach that some bits have high quality index and some others don't [37]. One image can be partitioned into two parts: the short part but with the crucial information about the image- trunk packets, and the long part that includes the non-important but necessary to provide the high data quality service-leaf packets [33].

2.3.5 Different Scenarios Discussions

As we can observe from Equations (2.6) and (2.13), quantitatively speaking, the QoE gain of the receiver in the wireless multimedia service is majorly decided by the root mean square error reduction of all received frames and the channel condition (i.e., in terms of BER) at the physical later. Besides, the vitality utilization likewise assumes an imperative job to influence the quality of experience, since the battery measure is carefully restricted in cell phone. In the accompanying, two distinctive transmission cases are talked about in subtleties.

CASE I: High BER in Bad Channel Condition. Considering the UEs are being placed in a situation with very bed channel conditions. In such case, devices need to depend on the hand-off and radio wire choice to make up the profoundly parcel misfortune rate so as to keep up certain dimension of got multimedia information quality. The condition of craftsmanship innovation space and time square coding mechanism would be contemplated in the exposition to display the numerous receiving wires situation. As appeared in Fig. 2.6, let N indicate the quantity of image sets will be sent. Term b denotes the modulation size in the chose adjustment. Term Tx and term Rx mean quantity of radio wires for sender and beneficiary, individually, at the route like images characterized in [34]. Contrasting and the customary transmitting plan, where all gadgets just utilize single radio wire to send and got, i.e., the '0000' in our work, which means single transmitting and getting reception apparatus, the BER would altogether diminish when using '1010' (two receiving wires transmit and single radio wire gets). The number '1111' (where 2 reception apparatuses transmit and 2 receiving wires get) mode. In figure 2.6, the sending power assignment Pt in multiple input multiple output and customary (one radio wire) strategies were supposed to be the equivalent. It merits calling attention to that the additional expense for applying the high productivity numerous reception apparatuses conspire on cell phones is to just to prepare an increasingly mind boggling radio wire circuit exhibit. Yet, it would be effectively payed out since the more awful channel formation is, the greater media administration quality execution the multi-receiving wire strategy would get.

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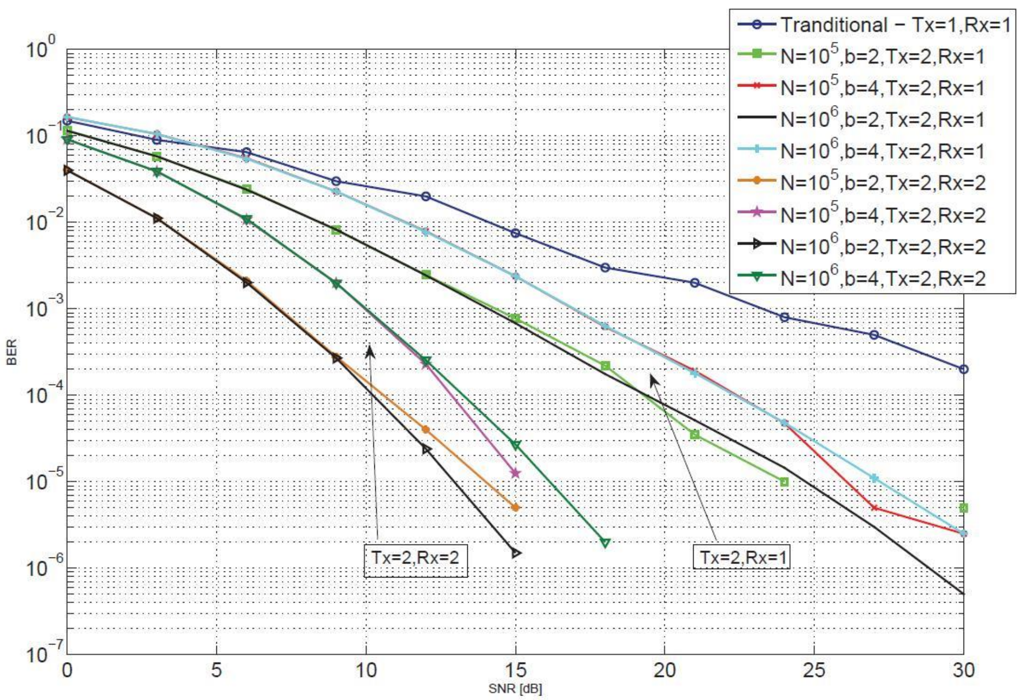

Figure 2.6: Illustration the various bit error rate performance: the conventional antenna link with T_x = 1, R_x = 1, the new antenna selection (T_x = 2, R_x= 1 and T_x = 2, R_x= 2). Figure refers to [19].

CASE II: Strict Energy Budget in Wireless Relays. As stated before, the energy consumption issue is a big challenge when we introducing the D2D communication in the wireless networks, because of the energy spending limit is carefully constrained by the battery's ability prepared on the cell phone. One uplifting news is that the Quad-tree fractal pressure technique is intended to satisfy the exchange off among power consumption limitation and media character. Amid the pressure procedure, each picture will be compacted into 2 gatherings with various amount, one would be the significant trunk bundle gathering and another one is immaterial leaf parcel gathering, while the all out amount of trunk and leaf parcels is keeping steady (the length of the origin image). The big advantage of our proposed method is that we can dynamically change the portion of trunk packets or leaf packets along with the energy budget no matter the power is enough or the power budget is strictly limited. As referenced previously, trunk bundle contains the most significant data of pictures (quantitatively, greater root mean square error decrease per bit), that ought to be considered to send early if the assets were short. Indeed, face the fact that trunk bundles just take a little bit of the entire picture, the last gathered decreased root mean square error would be fundamentally enhanced if the storage compartment parcels been effectively transmitted in the severe vitality spending circumstance.

The importance of trunk packets and the priority of trunk packets in transmission have been talked many times. To actualize this thought, in our proposed transmission strategy, the multi-radio wire technique would just be enacted for transmitting trunk parcels, to such an extent that the framework guarantees the excellent picture information is supposed to be sent in low bit error rate situations. Then, the leaf packets were transmitted by using the single antenna model (marked as “0000” in our work) among transmitter, relay, and receiver for the purpose of saving power. The system can obtain the best root mean square error reduction per unit power cost through selection the reasonable trunk part in the content division. More details about how the antenna selection on trunk packets and leaf packets would influence the RMSE reduction gain are shown in the numerical simulation discussion section.

The provided media image sending’s procedure is explained in Algorithm 2, refers to [37]. The image data compression strategy and antenna routing decisions in the wireless transmission are determined by the on-time channel factors feedbacks.

Algorithm 2: The optimal antenna choice method through considering the media data division and channel information at physical layer.

1. Define the inputs and outputs of algorithm:

Inputs: (1) The system energy budget for UE E_{max}, and the total number of image N_{image}. (2) The data transmission Symbol Rate R and The SNR in the physical channel. (3) The transmitting power P_t and the circuit power P_c. (4) The amount of (quantitatively speaking) root mean square error reductions of trunk bundles and leaf frames.

2. Outputs: The better antenna choice policy for each image.

3. Initialization: E_{con} = 0

4. Initialization: $RMSE_{max}$ = 0.

5. T_x sends the entire image in a trunk bundle to R_x.

6. T_x receives the channel information response of R_x.

7. Improve the trunk portion of data L_{trunk}^{i}.

8. Choose the antenna pair M_{A-B}^{j} from '0000' ~ '1111'.

9. For $k = 1: N_{image}$

10. if $E_{con} < E_{max}$

11. Compute the accumulated energy cost E_{con} for each (L_{trunk}^{i}, M_{A-B}^{j}).

12. Compute the accumulated RMSE gain at receiver. If the new RMSE is greater than $RMSE_{max}$, keep the greater RMSE and current relay scheme

13. End else

14. For end

15.Output the most new re-transmitting method and that biggest $RMSE_{max}$

2.4 Numerical Simulation Discussion

In the first part of the simulation section, we carry out our simulations study to evaluate the system performance through our studied mechanism. In this experiments, the density of noise N_0 equals $4 * 10^{-22}$ J/Hz. The symbol speed R_s in the transmission is $2 * 10^7$ Hz. The P_c is fifteen mw on each equipment. Regards to the multimedia information content, the MPEG-4 H.264 standard video clip "*Foreman*" with the given sequence type IPIPIP is used at the simulation. The constellation sizes used in the modulation are 2, 4, 6 and 8.

To evaluate the algorithm 1, only one sending equipment to single/multiple receiving equipment modes are used in our work. We suppose the system power budget is gradually enhancing. Figure 2.7 illustrates the media obtained character gain by properly adopting the factor modulation size and factor transmitting power simultaneously. The results show that the choice of smaller constellation size in the modulation is better for the new wireless transmission service scenarios. Especially in the poor channel condition situations or UEs choose to be conservative when the channel is changing rapidly (fluctuation).

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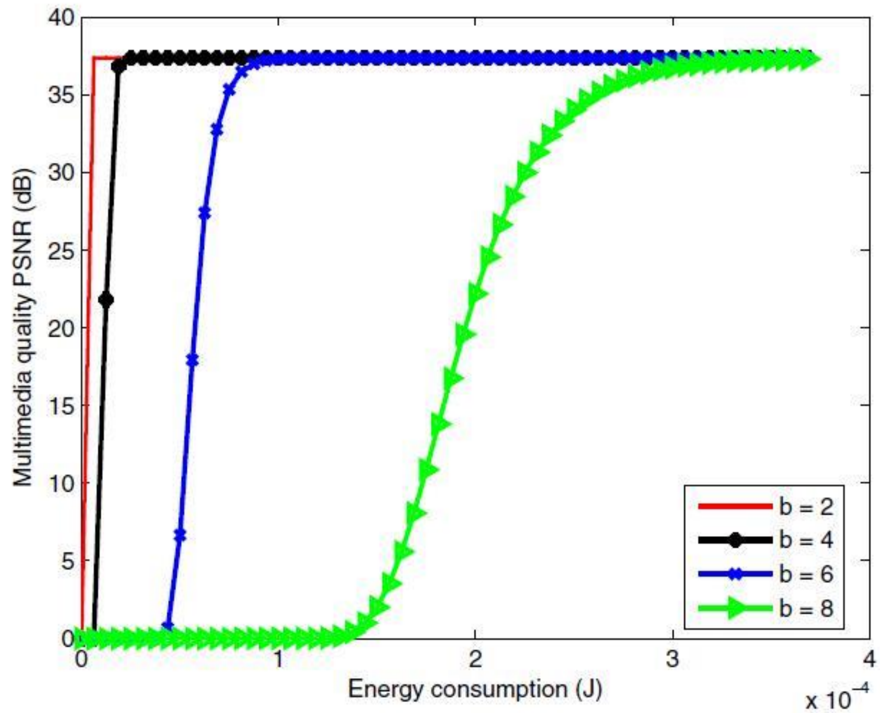

Figure 2.7: The multimedia quality gain in the relay device rebroadcasting under different constellation size in modulation. Figure refers to [19].

After obtain the optimal rebroadcasting sending energy policy and modulation size in the modulation, we carry out the simulation with one transmitting device and multiple (i.e., 4) obtaining equipment, figure 2.8 illustrates this conclusion. To better understand the advantages of the proposed method, there are 3 cases are set up in the experiments to conduct the comparison. In the 1st case, we suppose the sending energy and constellation size were selected randomly by the relaying equipment. But at the same time the relaying device has to satisfy the energy or power constraints and we mark this case as ‘C1’. Fort the channel information, we assume the channel A_i keep constant in this situation. In the second case, correlation (denoted “C2” in the figure) uses the calculation we provided to upgrade the re-broadcasting force plus adjustment measure. Equivalent to the previous situation, we appoint equivalent channel data information to every connection among the transmitting equipment and accepting equipment. In the end situation, the ideal sending power and constellation size is taken in the simulation and make them versatile to channel condition factor in 4 data sending links, to investigate the media re-multicasting character gain by facing power consumption constraint requirements, we mark this case as “C3”.

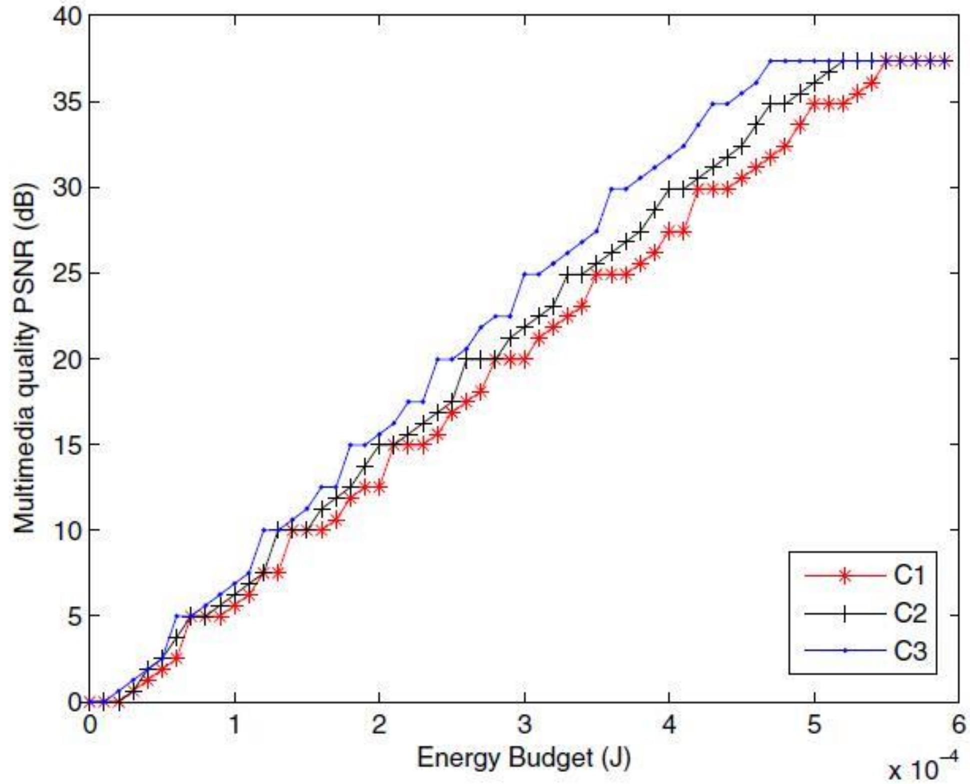

Figure 2.8: Illustration of the multimedia quality performance under three different cases. Figure refers to [19].

In the figure 2.8, the media gain versus the power consumption graphic is plotted. It’s sensible that we show signs of improvement media quality when together thinking about energy source, constellation method and channel factors in the re-multicasting procedure, for example case 3 over case 2 and case 1. Moreover, the UE would experience the QoE improvement alongside the higher energy spending in the rebroadcasting procedure.

After evaluate the system performance of rebroadcasting method, we also perform numerical experiments to test the capability of image content division method and space time coding technology. For the experiment parameters set up, assume the symbol speed R is 2*10^7 Hz. The sending power P_t and circuit working P_c are fifty mw and thirty mw separately. The grayscale images "*Cameraman*" and "*Lena*" were selected to be the media content in our experiments. The number of images is 20 in the transmission. The length of each image in the simulation is around 27250 bits. The resolutions of tested images could be scaled in 128 x 128, 256 x 256, and 512 x 512 pixels.

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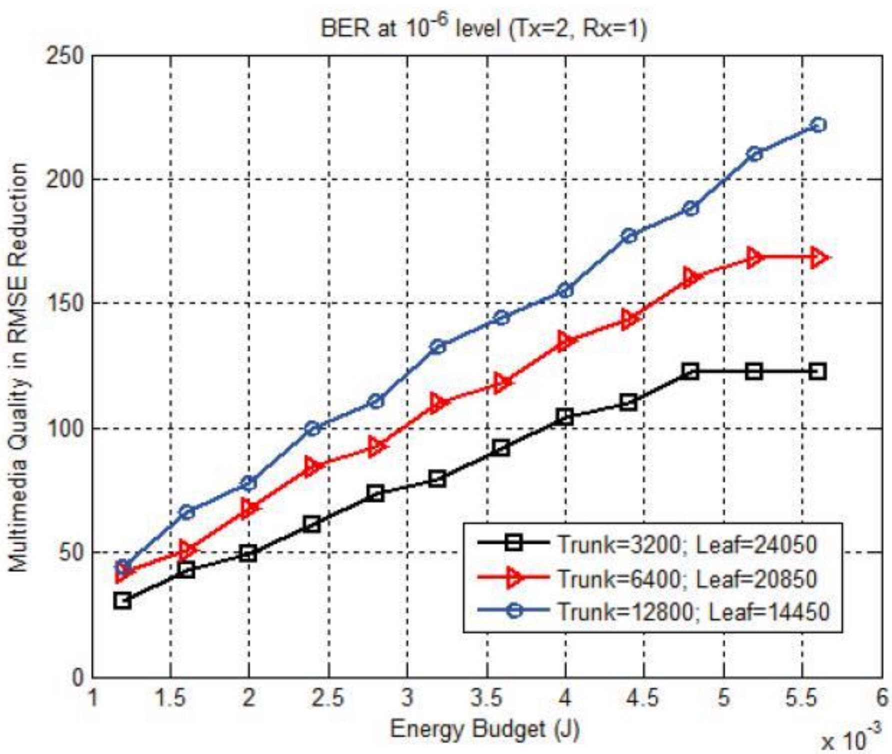

Figure 2.9: The illustration of the RMSE reduction performance when the channel is relative good, we observe that greater trunk packet case would get better quality performance. Figure refers to [37].

In Fig. 2.9, we tested the QoE performance under different energy budget set up with the 2:1:2:1 antenna(s) selection (a.k.a the '1010' mode). In this simulation, the physical channel condition is relative good, i.e., the BER for the single antenna mode is $1 * 10^{-4}$ when we test the RMSE reduction performance of receiving UE. As we can see from the result shown in Fig 2.9 that when the physical channel is good, the system would get the best RMSE performance when the trunk packets is greater than the leaf packets (the trunk packets can take up to 50% of the image content), illustrated in the blue line. In the best case, the root mean square error reduction gain is almost the twice times of the black line if the power supplies are efficient to support send the entire image content. In good channel set up, the less trunk part scenario will get the worst RMSE reduction capability with regards to multimedia quality, as shown in the black line. All in all, the gain of root mean square error reducing maintain the tendency of decreasing, when the trunk portion of is decreasing in the image compression.

Theoretically speaking, the physical channel with BER at 10^{-6} level is very good in terms transmitting data in the wireless service. The BER would be much worse due to various factors, i.e., the mutual interference among signals, channel noise, and multipath fading in the real wireless communication. In Fig. 2.10, we evaluate the RMSE performance of system by considering the physical channel at the BER of 10^{-5} level. It can be observed from the simulation results that the system root mean square error reducing metric will go down when the channel factors are getting worse. But it would surprisingly get smaller than the 50% of it is where we discussed before good scenario (i.e. the best case when the BER is at 10^{-6} level). In addition, the greater trunk bundle method is not going to hold the high RMSE reduction capability if the physical factor is bed (i.e., the BER is getting higher). In this case, the less part choice of trunk frames starts to have better performance in multimedia quality capability when the channel is worse. To confirm such phenomenon, in Fig. 2.11, we test the system RMSE reduction capability in the very bad channel situations, where the BER is at 10^{-4} level. The simulation results illustrate that the smallest trunk, i.e., when the trunk packet takes 10% of the data content, has the best RMSE reduction gain performance in such a bad channel scenarios. Thus we reach the conclusion that short trunk packet and MIMO (means multiple antennas in the transmission) would be the optimal data sending policy when the channel condition is very bad, such as facing the high BER.

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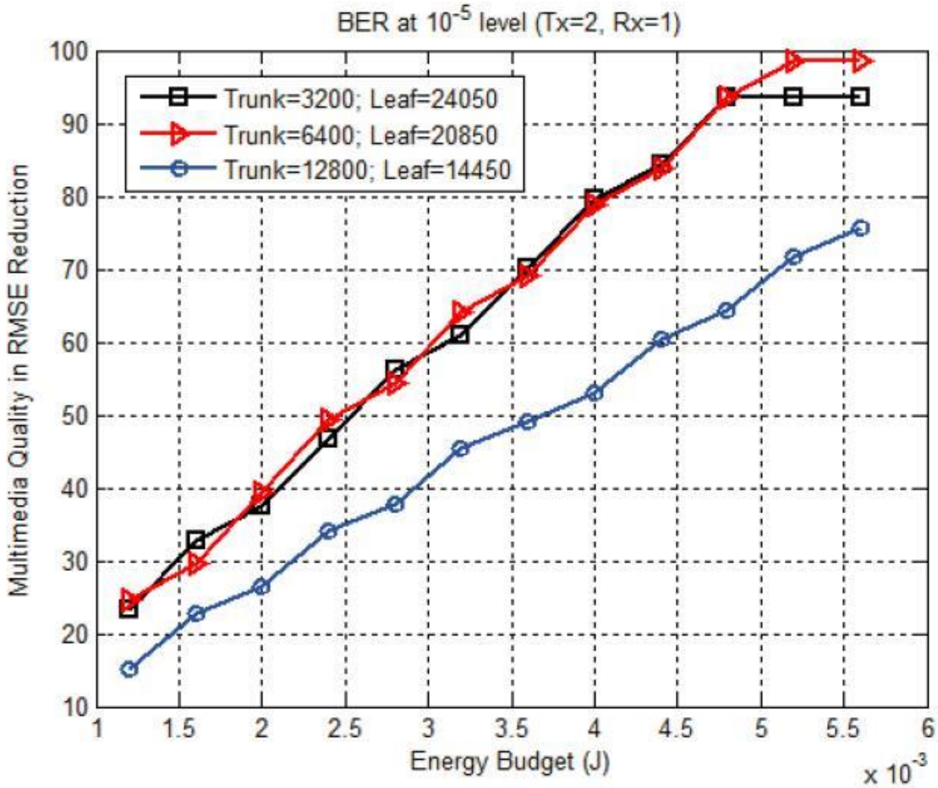

Figure 2.10: The illustration of root mean square error reduction gain, we test the performance at the BER in 10^{-5} level. Figure refers to [37].

Dig deep into the results shown in Fig. 2.11, we find that there is another reason for the RMSE performance when facing the high PER. Corresponding to Equation (2.6), PER p would be significantly increased alongside with the enhancing of frame length. Quantitatively speaking, when the BER is the same, the longer packet, the greater PER as a consequence, which will indirectly cause lower RMSE reduction gain at last. In next numerical experiments, we prove that we have a threshold that determines whether choose greater trunk or smaller trunk strategy in the real transmission. This is to say, there is a one special length of trunk bundle for a special channel condition, that's less trunk frames does not always lead the better RMSE capability. The rationale behind the point of trunk portion threshold is that: the vital information of each image has to be carried by the trunk portion, otherwise the RMSE reduction gain could not be able to summary to reach a huge amount during the data sending procedure.

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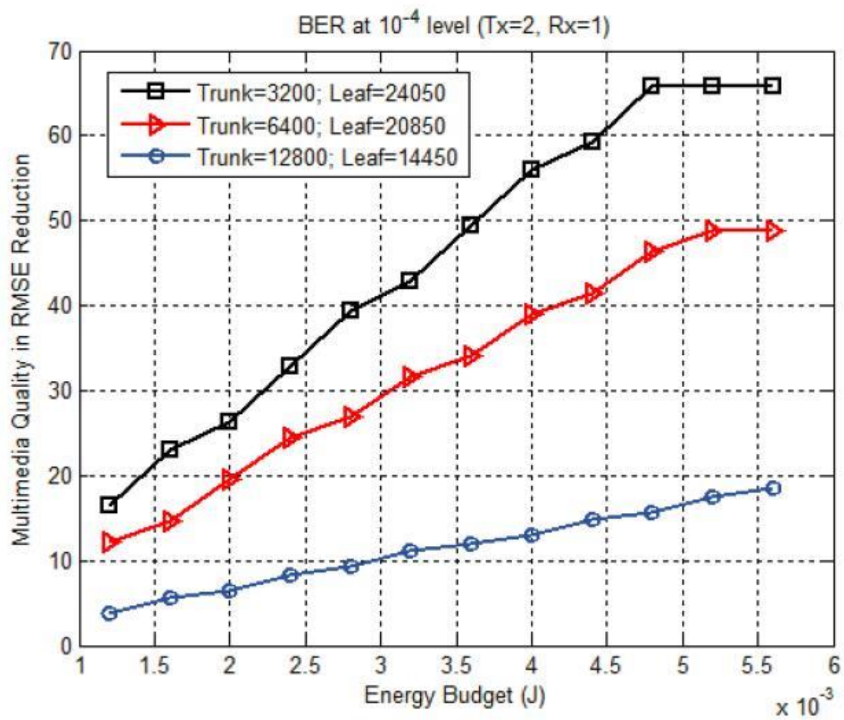

Figure 2.11: The root mean square error gain in a very bad channel condition. In this case, the smallest trunk compression strategy gets the best RMSE reduction performance. Figure refers to [37].

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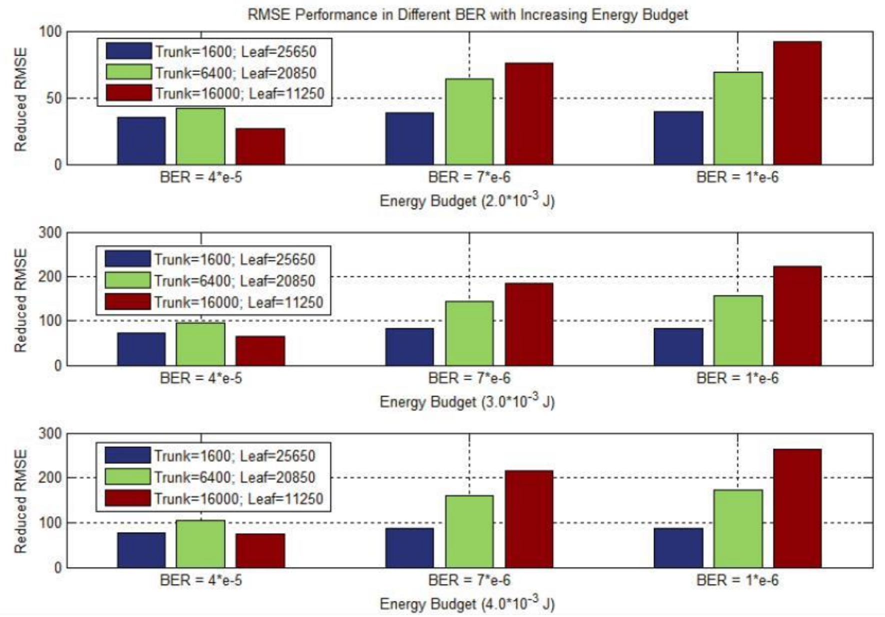

Figure 2.12: The system RMSE performance in increasing trunk portions cases, under different BER and energy budget scenarios. Figure refers to [37].

In this simulation, we take different percentages of trunk portion into consideration as well. For example, 6%, 23%, and 59% choices of the trunk part percentages are tested in the simulations respectively. The bit error rate implies condition of the MIMO technology. The experiments results of this situation are illustrated in Fig. 2.12. From the figure we can observe that the extremely small trunk (6%) case obtains the worse performance comparing with the case that trunk parts take the 23% of the image content, even in very severe physical channel condition. The reason behind this situation is that: like the previous simulation example, when the trunk packet is too small, it may already lost some vital information of the whole image content during the image compression, which causes the huge loss of RMSE reduction performance. On the other hand, the RMSE reduction would obtain 270 when the trunk part takes 59% of the image content in the nice bit error rate, this results is almost near to the root mean square error reducing upper-bound. The upper-bound here is measured as: we let the entire image in the trunk part and then send the big trunk packet in the best physical environment, i.e., the channel BER is 0.

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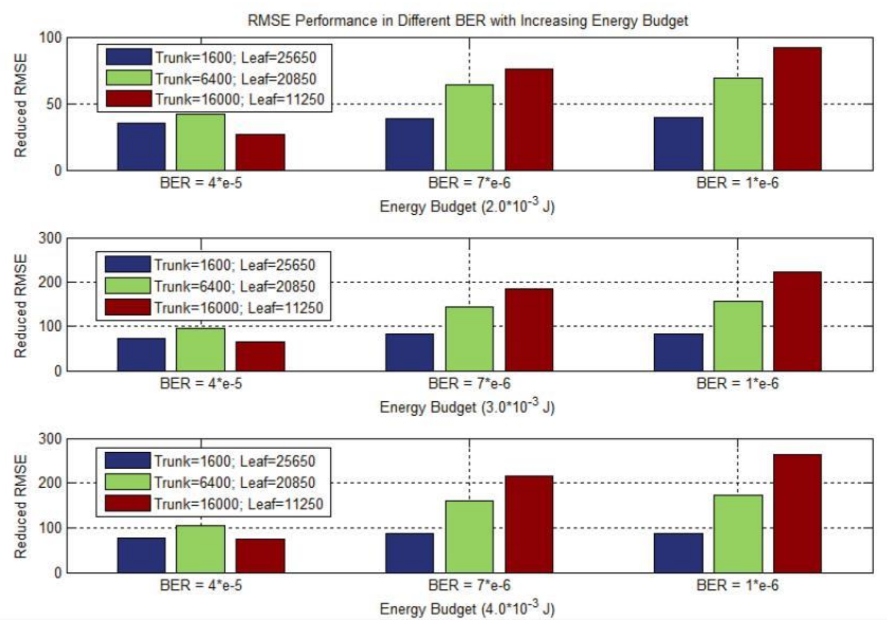

Figure 2.13: The RMSE reduction performance with regards to energy efficiency in ‘1111’, ‘1010’, ‘0000’ antenna selection modes. The physical channel condition is very bad in this simulation, i.e., BER at 10^{-3} level. Figure refers to [37].

At last, we test the energy consumption efficiency in the wireless image relay task in both conventional transmission scheme and the promising Alamouti scheme. In this simulation, we compress each image with extremely small trunk part and huge part of leaf part. i.e., 1% of the image content belongs to the trunk part. The numerical experiments results of this situation are illustrated in Fig. 2.13. The only shortage of this mode is the other power cost of '1111' mode, the reason is that we have to activate one more antenna on every side on every device in the transmission path when transmitting data. While through the results we can see, benefitting from the enhanced quality of experience, the QoE per Joule power cost outperforms all other schemes if we select the '1111' in the transmission.

2.5 Summary

There are a few basic difficulties to give high goals interactive media communicate and multicast benefits in 5G systems, for example, nature of administration and experience (i.e., QoE), exacting energy requirement and diverse physical environment perceived by different telecom collectors. In this part, we initially propose an ideal rebroadcasting asset portion way to deal with improve the interactive media QoE for various communicate and multicast UEs in energy obliged 5G systems, utilizing D2D correspondence capacity and rate control plots in asset allotment. Recreation results demonstrate that the proposed methodology has an upgraded exhibition to enhance the interactive multimedia relaying quality by mutually thinking about the power requirement and physical environment circumstance.

Then a novel remote transfer plot which together considering picture pressure and space time coding mechanism was studied to hit the media quality of experience challenge in the power imperative hand-off correspondence situations. All the more explicitly, the Quad-tree fractal mechanism is used to pack picture in organized trunk packets plus leaf packets dependent on the system pre-determined service paradigm. Contrasts and leaf packets, trunk packets have progressively significant data of picture with littler length, but enable it with big need in power limitation circumstances. At that point the STC technique is used to enhance the quality of experience by distributing more receiving wires to significant truck frames in hand-off. Keep going, in view of the input channel data, the proposed calculation receives dynamic picture pressure and reception apparatus determination plot. Numerical simulation results showed that the proposed remote transfer plot essentially enhance the quality of experience addition and power consumption proficiency with serious physical environment mistakes or severe power imperatives.

Chapter 3

Proposed QP Power Control in OMA/NOMA Downlinks

How to enhance the quality of experience of UE in wireless service is an everlasting vital challenge. In this chapter we will discuss the plan of two aspects: the adjusting video quantization parameter allocation at high level and the QoE-riven downlink wireless service focusing on the power allocation (in the form of NOMA/OMA) in the low level. Besides, we will study the system QoE performance with new the band new NOMA schemes in the typical BS to UEs downlinks, and talk about the system performance with both traditional OMA and NOMA schemes. In order to quantitatively analyze the results, the math model of UE's quality of experience gain is built in our study by jointly considering user equipment's obtained multimedia quality and the corresponding cost for catching these data. Then we will demonstrate that there exists an optimal amount of data that if UE consumed this length of data, it would achieve the utility maximization goal according to various cost coefficients. What's more, the transmission power allocation schemes and their corresponding limitation is deeply studied in both NOMA and OMA transmission approaches [67]. At last, we mathematically analyze how the power allocation and QP control method would influence the UE's QoE (or utility) gain and the framework performance through numerical simulations.

3.1 Background and Related Work

It is not easy to smartly deal the increasing desires on the QoE of UEs in the wireless service, especially by facing the big challenge where the never-stop growing of mobile multimedia service traffic between the BS and massive UEs. Not need to mention, the fast expanding requirements on the QoE of UE has also caused huge traffic low level wireless communication method [35-37]. To address this challenge, lots of research work has been conducted from both industry and academia to handle the energy consumption problem in the wireless multimedia service [38-39]. To examine and address these problems, at this part, we think about the general issue in two angles including the abnormal state media QP adjust at media data information and the small dimension energy control portion technique at the sight and sound remote downlink. Assessment metric, for example, framework throughput, user equipment's apparent quality of experience from the remote information administrations, and energy productivity is tended to.

As one of the most promising technologies in the next generation of 5G wireless networks, the NOMA has obtained great attention from both industrial and academia based on its better spectrum using, energy using, and user-fairness when we place it with the traditional OMA [40-44]. An overview of the state of art NOMA research innovation and the NOMA's applications is given by authors in [40]. The details about the NOMA's rationale and implementations, how the NOMA technology could ensure the system low latency and so on were also studied in these authors' research. There are also lots of work has been conducted on how to combine the new NOMA technology with the UE's QoE improving issue in the literature. Such as, authors in [41] proposed a context-aware plus game theoretical solution on the optimal power requisition scheme, where the NOMA scheme is considered in the wireless link under the aim of enhancing users' quality of experience in the their proposed wireless media serving scenario. According to the above work and mentioned good aspects, both the conventional OMA and NOMA are investigated in the wireless downlink system to solve the quality of experience improvement issue by pondering the QP control and energy using problem.

The framework of this task is drawn in figure 3.1. We center our work on the remote multimedia benefits among the base station and user equipment. We expect the base station stacks the first information from cloud server dependent on the user equipment's requirements. Our examination on the user equipment's quality of experience improvement contains the accompanying favorable circumstances: 1) we appropriately build the utility or QoE model of UE in our work; 2) the upper level layer quantization parameter control choice in the interactive media pressure at base station’s side is considered; 3) the base station’s power capacity assignment procedure is talked about as far as guaranteeing user equipment’s quality of experience gain; and 4) the non-orthogonal multiple access and orthogonal multiple access downlinks are assessed and looked at.

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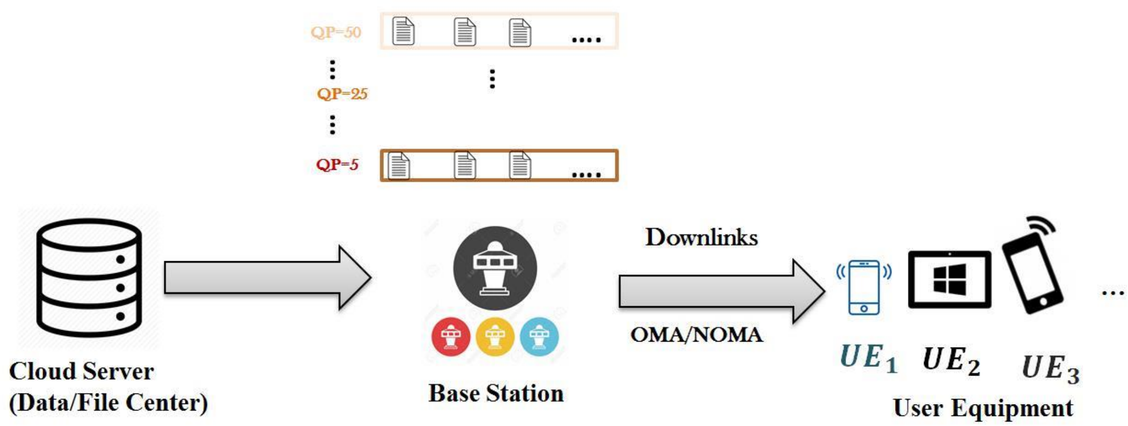

Figure 3.1: The figure to show our system model. We only focus on the downlinks between the base station and user equipment in this work. Figure refers to [67].

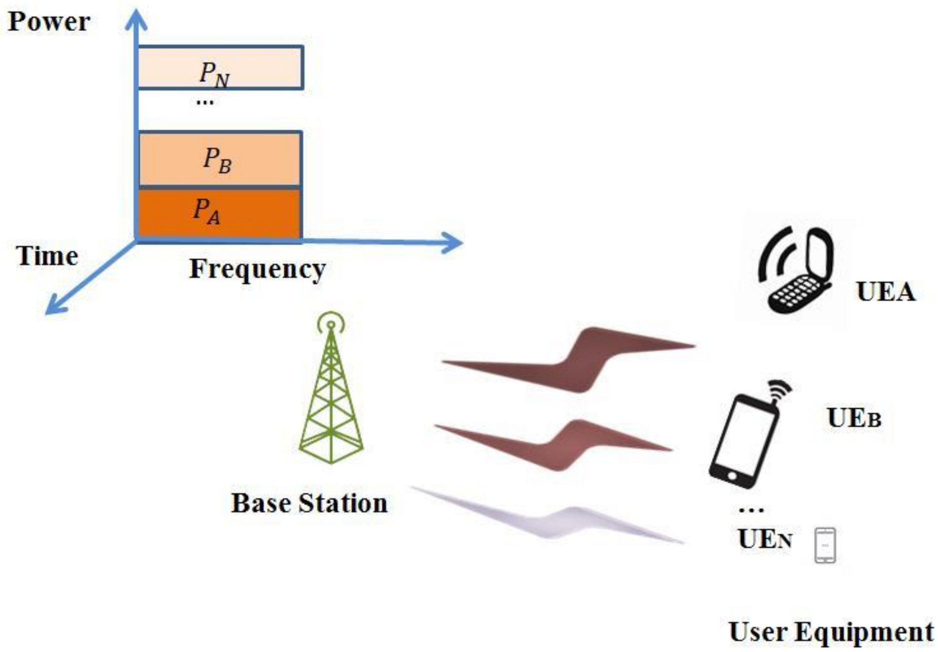

Figure 3.2: The illustration of details in the NOMA downlink. The BS will serve multiple UEs with different power level.

3.2 System Model

In this chapter, as illustrated in figure 3.1, where show the multimedia service scenario we considered in our work. Without loss of generality, we assume there are N UEs being served by the base station in the non-orthogonal multiple access or orthogonal multiple access downlink system. Contrast to the traditional OMA scheme, the NOMA allows the BS serves multiple UEs in the same time and frequency resource with different power level, as shown in Fig. 3.2.

3.2.1 The Utility Model of user equipment

In order to measure the user equipment's satisfaction on the base station provided multimedia services delivered through the BS-UE downlink, we provide the term utility in our work. Thus, we model the UE's utility gain as its experienced multimedia quality of experience from the wireless data services. Generally speaking, we assume utility of user equipment is non-negative and follows the logarithmic rule based on the previous work shown in [19, 43, 48]. Therefore, we adopted the UE's utility model similar to their work, we use model the utility to be a logarithmic function. So, the utility would be computed as money spending on multimedia, removed from the perceived media data quality. It is mathematically represented as

$$U_i = log_2\left(1 + \sum_{j=1}^{M} D_{i,j}(L_{i,j})\right) - c\left(\sum_{j=1}^{M} L_{i,j}\right). \quad (3.1)$$

Here the term U_i denotes the obtained utility of UE_i. Let the term M imply the number of frames that requested by UE_i from the BS through the downlink dataflow. The tern $D_{i,j}$ represents the distortion reduction (which is an objective metrics to evaluate the received data quality of packets) of the $j - th$ frame. Like our work in the previous chapter, the widely used PSNR metrics is utilized here to measure the media packets' distortion reduction. We can see that the packets' distortion reduction is associated to the length of each packet, therefore the term

$D_{i,j}(L_{i,j})$ is used in the utility function to indicate that the distortion reduction is a function of data length. As last, the data cost of UE_i is calculated as the unit length price (marked with c), times the overall length of data that the user equipment consumed in the downlink.

From above definition we observe that the user equipment’s utility, the sum of packets’ distortion reduction, would be decided by how much data the UE requested and consumed in the wireless service. At the same time, the distortion reduction (D_j) of each packet and frame length (L_j) of each packet are related to the multimedia data QP size q_j, which is generated during the frame quantization process before it been transmitted [44]. That is to say, the QP size q_j generate during the quantization procedure would have big influence on the length of packet and eventually have great impacts on the UE’s utility gain. More specifically, may be with wavelet or cosine change space for vitality extent or in the first spatial area for pixel helping power, the high QP size q_j will choose big bars while focusing a specific factor,. Such connection will cause less quantized examples being put into the packed video streams finally. Such outcome suggests that the edges would have low twisting decrease. What's more, the casing with more noteworthy length for higher qj is commonly shorter and the other way around.

3.2.2 The Transmitting Data Rate Analysis

Besides the multimedia content quantization method, another approach in this chapter to achieve our goal- improve the QoE gain of UEs, is to study both non-orthogonal multiple access and orthogonal multiple access transmission schemes in the downlinks. Without loss of generality, we assume these N UEs in the wireless system are listed with the order follows increasing channel. i.e., $|h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_N|^2$ and $|h_i|^2 \sim CN(0, \sigma^2)$. Also, all the downlinks will feel Additive Gaussian Noise (AWGN), and the independent and identically distributed (i.i.d) block Rayleigh fading and. In NOMA, the user equipment with better channels would have privilege to conduct sufficient Successive Interference Cancellation (SIC) to remove the user equipment's mutual interference from the weaker user equipments (weaker user equipment means this user equipment has lower channel gain) [40-41]. The achievable transmitting data rate of UE_i by using the SIC in the NOMA downlink system is calculated as

$$R_i^{NOMA} = Blog_2\left(1 + \frac{P_i|h_i|^2}{\sum_{k=i+1}^{N} P_k|h_k|^2 + \sigma^2}\right), \forall i < N. \tag{3.2}$$

Where the tern B denotes the shared channel bandwidth. All UEs will have the same system bandwidth and serving time in the NOMA downlinks. According to the name of the achievable transmitting rate of user equipment, it is easily to calculate the transmitting rate for of the strongest UE_N (who has the greatest channel gain $|h_N|^2$) as: $R_N^{NOMA} = Blog_2(1 + P_N|h_N|^2/\sigma^2)$. It is worth emphasizing that in the NOMA downlinks, the BS is capable to simultaneously serve multiple UEs with high data speed and high user-fairness.

As the traditional transmission scheme for the wireless downlink, the achievable transmission data rate of UE in the OMA scheme is calculated in different way. For simplicity, the Orthogonal Frequency Division Multiple Access (OFDMA) mechanism is used in our work. While our proposed method would be easily exted to any other traditional transmission schemes. In the OFDMA, the system bandwidth (a.k.a frequency) is evenly shared by all UEs in the downlink [46]. According to the Shannon Hartley theorem, then the achievable transmitting speed of every user equipment in orthogonal multiple access downlink is calculated as

$$R_i^{OMA} = \frac{B}{N} log_2(1 + P_i|h_i|^2), \forall i \in [1, N]. \tag{3.3}$$

Based on the Equation (3.2) and (3.3), we reach to the conclusion the power use strategy for each user equipment would have big impacts on the UE's achievable transmission data rate in different transmitting mechanisms, i.e., non-orthogonal multiple access and OFDMA respectively.

3.2.3 System Objective

Recall that the goal of our work was to enhance the QoE of UE no matter in the non-orthogonal multiple access or orthogonal multiple access downlink system.

According to the Equation (3.1) and the explanation of the correlation between frames' distortion reduction and multimedia content QP size, the goal of whole framework in this chapter is expressed as

$$\{(q_{i,j}, P_j) | \forall i \in [1, N], j \in [1, M]\} = argmax\{U_i\}\,. \tag{3.4}$$

s.t.

$$R_i \geq \frac{\sum_{j=1}^{M} L_{i,j}}{t_e}, R_i \in \{R_i^{NOMA}, R_i^{OMA}\} \tag{3.5}$$

$$\sum_{i=1}^{N} P_i \leq P_{budget}. \tag{3.6}$$

Here the t_e in Equation (3.5) is defined as the user equipment's expected service buffering time for a single data flow, i.e., the buffering time when we watch video online. The reasons we proposed the framework model (i.e., Equation 3.4) and the system constraints followed it (such as Equation 3.5 & 3.6) are addressed as follows:

1. The system object is clearly stated in the Equation 3.4. We are focus on the UE's utility maximization problem through reasonably adopting the multimedia QP size q_j for every packet and the BS's transmitting power allocation P_i of UE_i.
2. Generally speaking, we assume the user equipment's expecting data rate (i.e., $\sum_{j=1}^{M} L_{i,j} / t_e$) is smaller than real transmitting rate of user equipment in

the downlink. Otherwise the UE would never be satisfied by the wireless service. So we have the limitation shown in Equation 3.5. While the situation where the UE is not being satisfied will also be discussed in our work. Such as when the channel condition or shortage of system bandwidth due to massive UEs requesting service simultaneously.

3. At last, the total allocated transmitting power of user equipment could not over the power budget at the base station side, as illustrated Equation 3.6.

Recall that the multimedia data content QP size q_j of each frame would determine the frame's length L_j. Thus, in our work we would address q_j adjustment issue through choosing the optimal frame length (i.e., L_j) indirectly. What's more, to decide the good transmitting power allocation strategy for each user equipment in the multimedia downlinks, the promising non-orthogonal multiple access and conventional orthogonal multiple access transmitting schemes will be investigated separately in the following work. Al last, the optimal (q_j, P_i) adoption issue would be studied deeply in chapter 3.3.

3.3 Solution for the Utility Maximization Problem

3.3.1 The Correlations Discussion

In our work, Let L_j denote the total consumed data by UE_i in the BS-UE downlink service, where the L_j is calculated as $L_i = \sum_{j=1}^{M} L_{i,j}$, term M represents the number of frames. Recall the explanation of Equation (3.1), we can notice that the packet's distortion reduction D_i would be an increasing function with respect to the "variable" L_i, the consumed data by UE_i. For the purpose of looking into the relation between the utility gain of user equipment and it's used data length. In other words, to investigate the relation between U_i and L_i, the explicit form of function of the D_i to L_i in needed in our work when performing the mathematically analyzing.

According to the H.264/AVC standard ***Foreman*** video [44], which would also be utilized in numerical simulation section later, we draw the figure with the "distortion reduction as the vertical axis and the data length as the horizontal axis, as illustrated in Fig. 3.3 (a). As we can see, the X axis indicates the length of packet, in the unit of Kbits. The Y axis is the PSNR gain, in the unit of dB. In addition, the correlation between D_i and L_i (based on the ***Foreman*** sequence data) is also explained. Furthermore, we draw the relationship between multimedia frame's QP size and the data amount according to the source video data as well, as illustrated in Fig. 3.3 (b). All the work to draw the graphics is aiming at getting the explicit function $D_i\ (L_i)$. For doing this, the log regression method is utilized in Matlab in this dissertation according to the ***Foreman*** video data [47]. Like it is illustrated in Fig. 3.3 top panel, with p-value less than $1 * 10^{-4}$, we can get the function factors (13.372, 8.343). Then, we now could obtain the explicit relation between D_i and L_i as:

$$D_i = 13.372 + 8.343 * \ln(L_i). \tag{3.7}$$

Thus, the UE's utility function shown in Equation (3.1) could be rewritten as:

$$U_i = log_2(14.372 + 8.343 * \ln(L_i)) - c * L_i. \tag{3.8}$$

So far, we have obtained the approximately explicit function $D_i(L_i)$ and the correlation between multimedia content QP size of frame and the consumed data length L_i. In the following section 3.3.2, we will hit the utility enhancement problem in details by means of requiring the better QP size requesting.

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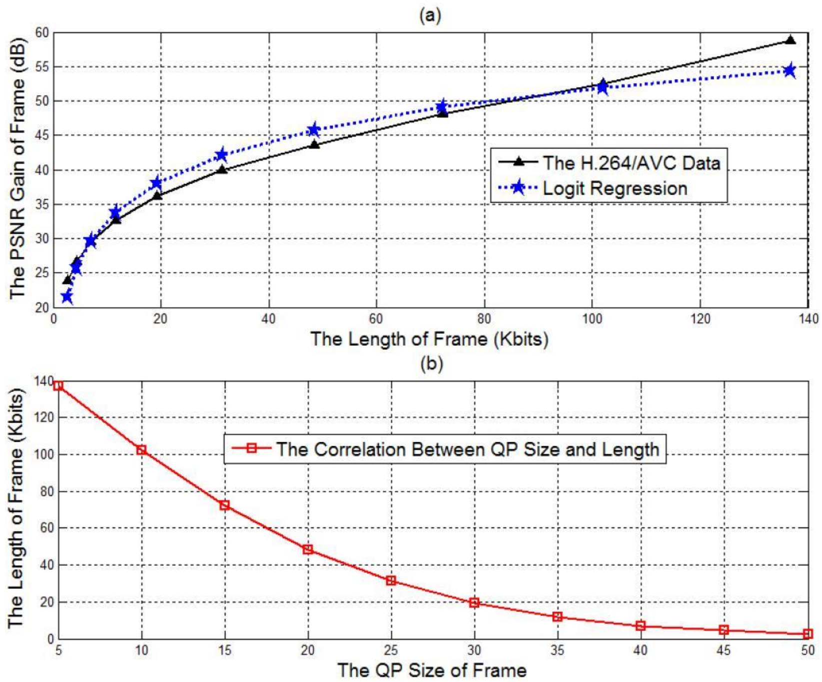

Figure 3.3: Graphics to show the relationships among factors such as packet's distortion reduction, the packet length, and the QP size of frame. Panel (a) illustrates the relationships among the packet and PSNR quantity. Panel (b) talks about the relationships among fame quantization parameter and the length of frame.

3.3.2 How the QP Size Adaption for Utility Maximization

Fig. 3.3 (b) tells the relationship among frame's quantization parameter and the length. Recall the property that the frame length L_i is decided by the frame QP size q, based on there one to one relationship, it is easy to get the optimal frame QP size q through seeking the corresponding better consumed data amount.

Proposition 3.1: There is one and only one optimal length L_i for UE_i such that the UE_i would reach its maximization utility.

Proof of proposition 3.1: In order to prove the uniqueness of the data length L_i which maximizes the utility of UE_i, we only need to prove the concavity of the utility function and then prove there only one solution when we set the first derivative equals zero. Thus, we request the first order derivative of Equation (3.8) by aiming at L_i. And we have

$$\frac{dU_i}{dL_i} = \frac{8.343}{ln2 * L_i * (14.372 + 8.343 * \ln(L_i))} - c. \tag{3.9}$$

Furthermore, we continue performing the second derivative of the utility function based on the above Equation (3.9) with respect to the data length L_i, then we have

$$\frac{d^2U_i}{dL_i^2} = -\frac{8.343 * (27.715 + 8.343 * \ln(L_i))}{ln2 * L_i^2 * (14.372 + 8.343 * \ln(L_i))^2}. \tag{3.10}$$

Based on the fact that the second derivative $\frac{d^2U_i}{dL_i^2} < 0$ in all cases, we conclude that the utility function U_i is concave. Then we reach the conclusion that each user equipment would obtain the optimal consumed data when we set $\frac{dU_i}{dL_i} = 0$. Also, we can't ignore the truth which is the used data should have a reasonable range, i.e., $0 \leq L_i \leq L_i^{max}$, then we claim following lemmas:

Lemma 3.1: A real function which is differentiable must be a continuous function [47].

Lemma 3.2: A continuous real function on a closed interval must have a maximum and a minimum value [47].

Conclude from above proof, interpretations, and lemmas, we claim that there has one and only one optimal data length, we mark it as L_i^*, which should guarantee the UE_i achieves the maximum utility gain. Recall the 1 to 1 relationship between quantization parameter and data length, now we could get the better quantization parameter. We denote the better or optimal quantization parameter and optimal data length as q_i^* and L_i^* respectively.

3.3.3 The Power Problems in Downlinks

As we can see from the two limitations that illustrated in Equation 3.5 and 3.6 respectively, the UE's transmitting power will be influence by two factors. One factor is the consumed data length, the other is the BS's total power budget for the data transmission. In the following, we will discuss the power allocation constraints in two cases.

Case I: The BS's total power budget P_{budget} is enough to support the wireless data transmission in OMA/NOMA downlinks. We already proved that we could obtain the optimal consumed data length L_i^* of UE_i in previous discussion. Then we can reach the goal shown in Equation 3.4 by determining the QP size with respect to the optimal length L_i^*.

We consider the orthogonal multiple access downlink first, the transmitting data rate's constraints shown in Equation (3.5) can be readdressed as

$$\frac{B}{N} log_2(1 + P_i|h_i|^2) \geq \frac{L_i^*}{t_e}. \tag{3.11}$$

After some basic mathematical transformations, we could obtain the constraints of transmission power based on the transmission data rate constraints, it is

$$P_i \geq \frac{2^{\frac{N*L_i^*}{B*t_e}}}{|h_i|^2} - 1. \tag{3.12}$$

Then we conclude that the UE_i would obtain its maximum utility point, when the allocated transmission power in the OMA downlink satisfies the constraint shown in Equation (3.12).

Similar to the work in the OMA downlink, the limitation of transmitting data rate in the non-orthogonal multiple access downlink scenario could be rewritten as:

$$Blog_2\left(1 + \frac{P_i|h_i|^2}{\sum_{k=i+1}^{N} P_k|h_k|^2 + \sigma^2}\right) \geq \frac{L_i^*}{t_e}. \tag{3.13}$$

Here, we have the condition that $i \in [1, N-1]$, since the transmission data rate calculation of UE_N is different and we will talk about it later. In the similar way, we adjust the transmitting power of UE_i , and we can obtain:

$$P_i \geq \frac{\left(2^{\frac{L_i^*}{B*t_e}}-1\right)*\left(\sum_{k=i+1}^{N} P_k |h_k|^2+\sigma^2\right)}{|h_i|^2}. \quad (3.14)$$

Due to UE_N has the highest channel gain, the allocated transmission power constraint of UE_N is addressed as

$$P_i \geq \frac{\sigma^2*\left(2^{\frac{L_N^*}{B*t_e}}-1\right)}{|h_N|^2}. \quad (3.15)$$

It can be concluded from above two Equations (3.14) and (3.15) that: For the strongest UE, the transmission power of UE_N would not be influenced by other UEs' power allocation strategies. It is decided by the real channel situations and its own better consumed data amount. But for any UE_i $(i < N)$, who has weaker channel condition compare with UE_N, their allocated transmission powers are not only impacted by their consumed data length L_i and channel conditions $|h_i|^2$, but also determined by the power allocation of the stronger UE, i.e., the UE_j $(i < j \leq N)$. Thus, different with the power distribution strategies in orthogonal multiple access downlink, where all the UEs would obtain the power allocation simultaneously, the transmitting power allocation strategies in non-orthogonal multiple access downlink requires the allocation sequence from high channel condition to low channel conditions, i.e., the descending order $UE_N, UE_{N-1}, \dots, UE_1$.

Case II: The BS's power budget is not enough to satisfy the constraints in Equation (3.5) and (3.6). When the base station's power budget is not enough, the perceived service utility of UE_i is actually determined by the real received power through the downlink. Then, the optimal QP size value obtained from the idea case would not be the optimal option for UE_i. In fact, by facing the reality that power is not enough, the greater QP size value would like to be adopted in the downlink. The rationale behind this is that high QP size value frame comes with short frame length, this advantage makes it's possible that more frames being successfully transmitted in the downlink with limited energy budget. Moreover, in order to hand the Case II where the power budget is insufficient to support the downlink data service, a user-fairness-aware approach is proposed in our work. More specifically, assume term P_i^* is the optimal power of UE_i that meets the equal conditions in Equations (3.12), (3.14), and (3.15). Then the allocated transmission power of UE_i with respect to the user-fairness-aware approach is mathematically denoted as:

$$P_i \geq \frac{P_i^*}{\sum_{j=1}^{N} P_j^*} \times P_{budget} \tag{3.16}$$

where

$$P_i^* = \frac{2^{\frac{N*L_i^*}{B*t_e}}-1}{|h_i|^2} \; or \; P_i^* = \frac{\left(2^{\frac{L_i^*}{B*t_e}}-1\right)*\left(\sum_{k=i+1}^{N} P_k|h_k|^2+\sigma^2\right)}{|h_i|^2} \quad (3.17)$$

in orthogonal multiple access and non-orthogonal multiple access downlink respectively. Equation (3.1) to (3.17) refer to [67]. Under the provided user fairness power method, all UEs in the orthogonal multiple access and non-orthogonal multiple access downlink would be reached out by the base station with some amount of power. Besides the optimal power allocation strategy that we could obtain through the proof section, and the user-fairness transmission power allocation strategy when the base station's power budget is not enough, we also investigate some other power allocation policy for the purpose of exploring energy efficiency under different of BS and the UE's QoE performance under OMA and NOMA downlink data services. Such as the evenly power allocation strategy for the power, i.e., $P_i = P_{budget}/N$, the QP , randomly choose the QP size value for the QP. More studies and discussions about these will be given in the numerical simulation section of this chapter.

3.4 Numerical Simulation Discussion

In this section, we performed several numerical simulations to fulfill the purpose of discussing and investigating the relationships among various factors, such as the transmission power allocation of UE, the choice of frame's QP size, the data length. We also demonstrate the improvement of QoE and system throughput performance under the proposed method. As mentioned in chapter 3.3.1, the H.264 video sample ***Foreman*** is used on our experiments. More system parameters used in the simulations is listed in Table 3.1

Table 3.1: Parameters and the values used in the simulations. The data in table refers to [67].

Parameters	Value (range)
N	$2\sim5$
M	15
$\|h_i\|^2$	$1dB\sim40dB$
c	$0\sim20$ per 100Kbits
B	$800MHz$
σ^2	$0dBm$
q_j	$5\sim50$
t_e	1ms
P_{budget}	$0\sim36dBm$

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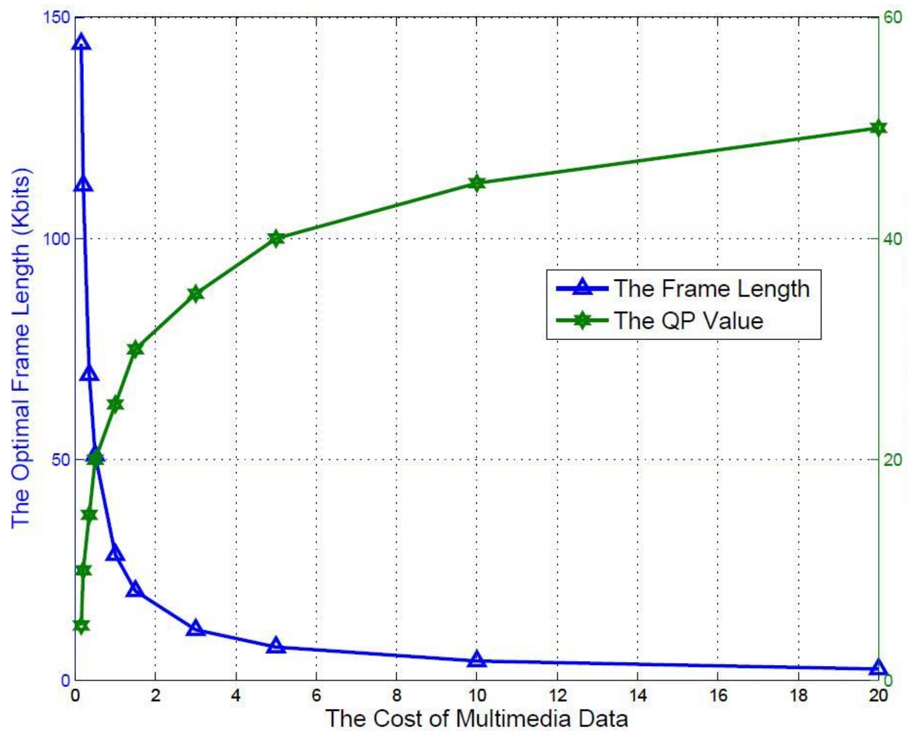

Figure 3.4: The illustration of the optimal frame length with regards to various data cost coefficients. The optimal frame QP size and corresponding frame length is also listed in the figure due to their one-to-one relationship. Figure refers to [67].

As we proved before, there is unique better QP size and packet length that would cause the user equipment reaches its maximum utility. The optimal packet length is decided by the cost of information which collected by base station. To investigate why and how the data spending would influence the user equipment's optimal consumed data length, we carry out experiments and the simulation results are shown in Fig. 3.4. From the figure we can observe that with the enhancing of the unit data cost, UE's optimal frame length would keep increase. The reason behind this phenomenon is that when the unit data price is large, i.e., with a greater cost coefficient c, to require less data would be the optimal policy for UE since the current data is very expensive. With less data consumed, the maximum utility that UE can achieve will also go down. While at the same time, recall the one to one relationship between the optimal QP size value and optimal consumed data amount, we could obtain the related better QP size of UE when with L_i^*, as illustrated in Fig. 3.4.

In Fig. 3.5, we consider the system power budget of BS is insufficient to support the OMA/NOMA downlink service. We evaluate the impacts of insufficient power on the q and UE's consumed data l. More specifically, the framework throughput is evaluated with different QP sizes set up in a two UEs OMA/NOMA wireless system. Since the power budget is insufficient in this case, the proposed user fairness power giving mechanism is used at base station side when it determines how to allocate power to UEs in the system. In the simulation, the average data rate of UE is tested along with the increasing power consumption. As we can observe from the figure, the achievable average transmission data rate in the non-orthogonal multiple access method outperforms the OMA method in all scenarios. This result confirms the advantages of the promising NOAM transmission schemes in the aspects such as high transmission power consumption policy and user fairness. In addition, our system throughput under the small QP size value outperforms the greater QP size value in the NOMA scheme when their power allocation policies are identical. According to the data rate definition in Equation (3.2), we would obtain the reason that with the NOMA technology, the power will achieve better allocated by the BS when we have the QP = 20 and QP = 25. The reason that the two red lines overlapped in this simulation is that there is no mutual interference among UEs in the OMA scheme (where all UEs evenly share the bandwidth). Thus under the user fairness transmitting power giving mechanism, the achievable data rates of all UEs are the same in the OMA downlinks.

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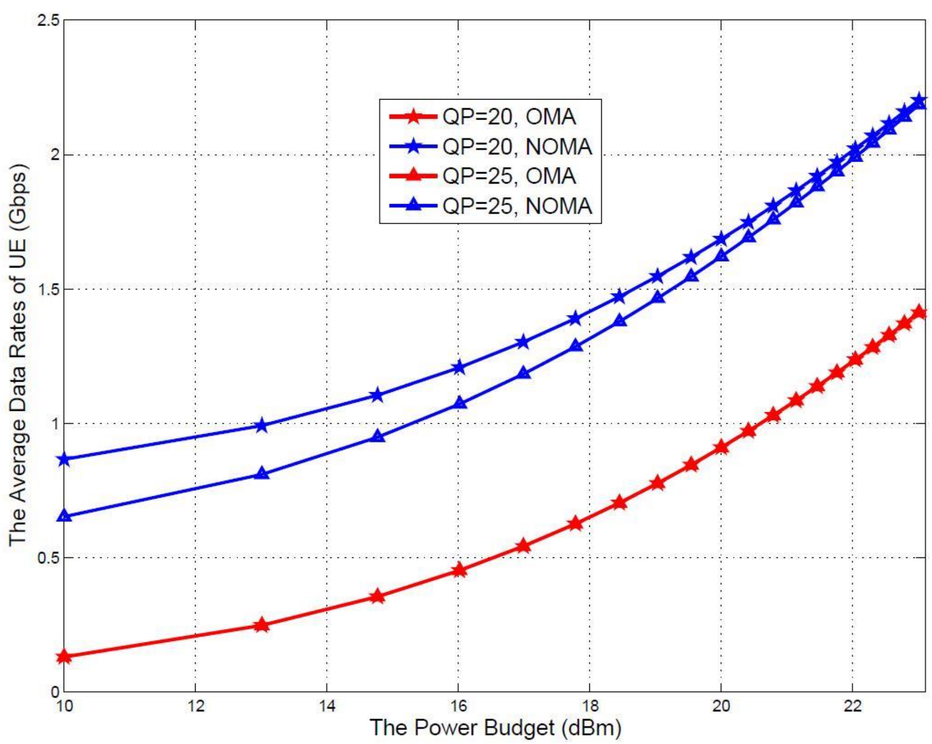

Figure 3.5: The performance of system throughput in the OMA and NOMA downlinks with regards to the increasing power budget. Two UEs are considered in the simulation (the channel are 20dB and 40 dB separately) and the QP size equals twenty and twenty-five at the non-orthogonal multiple access and orthogonal multiple access schemes. Figure refers to [67].

Parallel to the user-fairness power giving approach and the provided optimal power giving method, in Fig. 3.6, we broad the exploration to other power giving schemes, such as all user equipment evenly use the power of base station, when base station serves all user equipments through orthogonal multiple access and non-orthogonal multiple access downlinks. The QP size is 20 in this simulation and the channel condition keeps the same with the previous simulation (in Fig. 3.5). In the previous simulation we already proved that the non-orthogonal multiple access scheme would outperform the orthogonal multiple access scheme in terms of system throughput performance. So go through these simulations, we comprehend that the major reason to make non-orthogonal multiple access obtain a superior throughput exhibition is: our information speed of user equipment in good physical environment (i.e., the user equipment 2) will be altogether improved in the non-orthogonal multiple access conspire. Also, because of the impedance from the more grounded physical environments, the information speed of weaker channel user equipment (i.e., user equipment 1 at our experiment) in non-orthogonal multiple access is somewhat littler than orthogonal multiple access. The speed difference between two user-equipment with the provided user-fairness strategy shows littler than evenly energy distribution technique. Besides, respects to the evenly and user fairness control designation techniques, the information speed of user equipment 2 shows nicer performance with the equally distribution in non-orthogonal multiple access and orthogonal multiple access schemes. While the user equipment 1 is on the inverse, the information data rates (non-orthogonal multiple access and orthogonal multiple access) at user fairness technique is greater than the equal power designation performance. Such outcomes uncover the ideal framework control assignment is influenced by variables, for example, the transmission plans, and the information data rate necessities of user equipments.

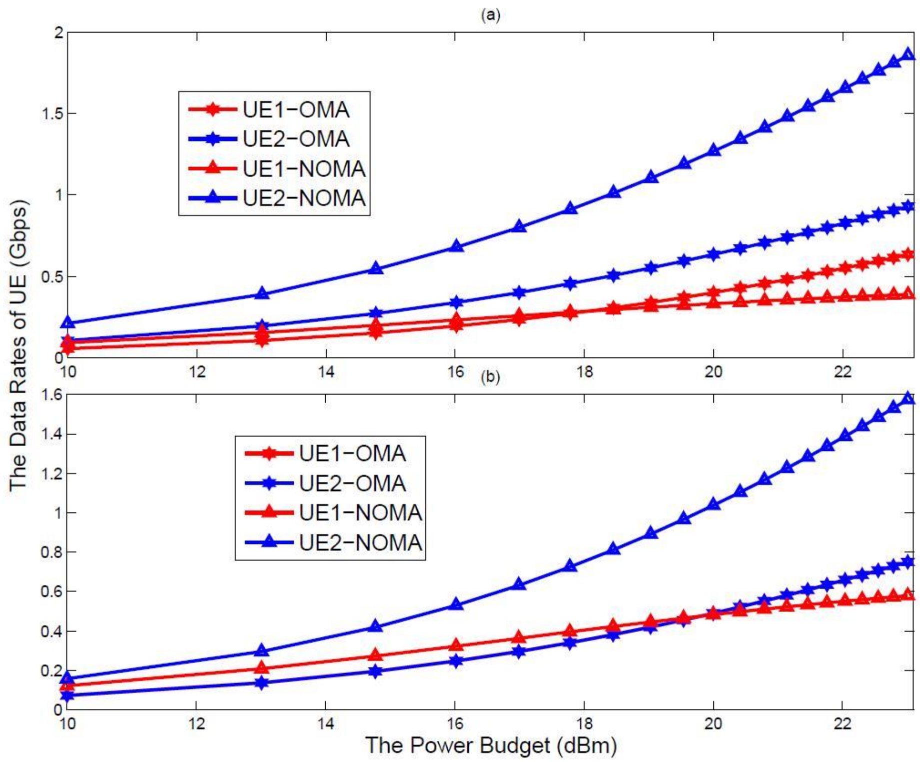

Figure 3.6: The illustration of the achievable transmitting rate of each user equipment. Panel (a) illustrates the even power giving out mechanism and panel (b) illustrates the provided user fairness power giving mechanism, there are 2 UEs in this simulation. Figure refers to [67].

Finally, we investigate the utility gain of user equipments for various qualities (N=2, 3, 4, and 5) in Fig. 3.7. All the more explicitly, we assess the normal utility gain of every user equipment in the orthogonal multiple access / non-orthogonal multiple access the proposed user fairness (set apart as “UF”) and the scheme under evenly (set apart as “E”) and control allotment techniques. Because of the expanded number of user equipments, we have diverse power spending plan for each orthogonal multiple access or non-orthogonal multiple access downlink framework (as appeared at the X axis). Besides, from Equation (3.8) we observe that the utility addition of user equipment is possibly dictated related to amount of expended information if the energy budget is adequate (i.e., fulfills requirements 3.5 and 3.6). So the most extreme utility increase ought to show the equivalent in entire framework sizes (we signify it as 100 percent utility gain). As portrayed in figure 3.7, where non-orthogonal multiple access transmission performance beats the orthogonal multiple access plot again regarding obtained utility. By using a bigger amount of user equipment joining the data links, evenly energy distribution designation system will have preferred capability over the provided user fairness strategy even before user equipments achieve their best possible utility gain. It merits calling attention to that the user equipments in non-orthogonal multiple access plan will dependably achieve their greatest utility quicker than the orthogonal multiple access, as appeared in the last two panels in Figure 3.7.

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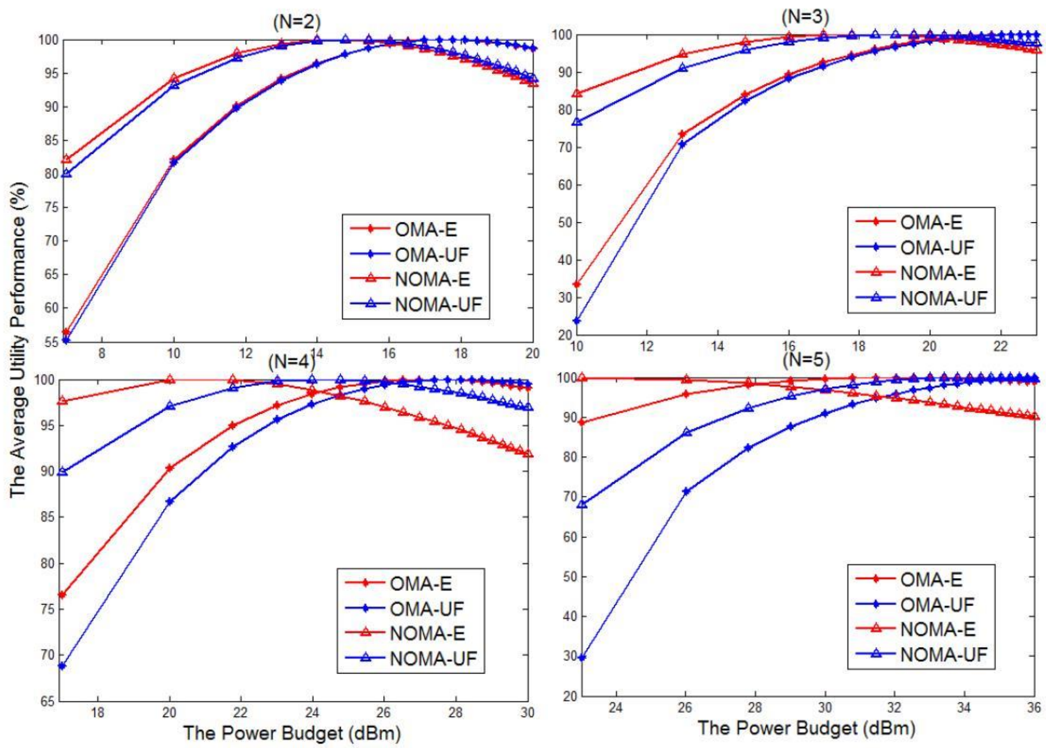

Figure 3.7: The user equipments' obtained utility (average) in various size of orthogonal multiple access and non-orthogonal multiple access system. In these four simulations, the channel gains are set as: 1dB, 20dB, 30dB, 40dB in the 5 UEs case, 10dB, 20dB, 30dB, 40dB in the 4-user equipment case, 20dB, 30dB, 40dB in the 3-user equipment case, and $|h_1|^2 = 30dB$ and $|h_2|^2 = 40dB$ in the 2- user equipment case. Figure refers to [67].

3.5 Summary

Confronting the test of consistently expanding of QoE prerequisite for media benefits in wireless data service systems, we try to solve the quality of experience enhancement problem by mutually thinking about the energy distribution and quantization parameter estimate choice in the run of the famous base station to user equipment service framework. In this Chapter, we first build the utility for user equipment as far as user equipment's apparent sight and sound quality and its monetary expense. At that point, in view of the one to one relationship between the consumed data amount and optimal quantization parameter size value, we research the ideal quantization parameter size choice for user equipment under various data cost factors. Moreover, the throughput and energy allotment procedures of the conventional orthogonal multiple access and promising non-orthogonal multiple access transmission innovations are talked about in detail. Moreover, so as to examine the energy shortage supplying case, we test the equally appropriated power designation strategy and the provided user fairness energy distribution assignment technique in the orthogonal multiple access and non-orthogonal multiple access downlink. At long last, through theoretically investigation and numerical reenactments we figure out that: 1) the ideal devoured information range of user equipment is dictated by unit information consumption determined by the base station, and 2) There is definitely no ideal power distribution system that will profit the whole user equipment all the while. While a superior power allocation policy can be acquired as for certain framework execution assessment measurements (i.e., in general framework capability, some gadgets requires fast speed, yet some other just should be presented with slow speed, and so forth.), and,

3) The little quantization parameter size is reachable in lots of cases.

Chapter 4

Proposed the Best-Response SMP Economic Method

The most effective method to jointly considering the improvement of user equipment's quality of experience gain and at the same time address the benefit boost issue of CP-WC is another financial test in wireless interactive multimedia correspondences. In this chapter, we think about utilizing the SMP idea and build up a summed up best-response diversion hypothetical mechanism to decide the consumed information content load from clients and the fees of media determined by content provider – wireless carrier alliance. In light of the smart media pricing mechanism of client and content provider – wireless carrier collusion, a summed up amusement hypothetical best-response diversion mechanism is studied in our work to illuminate the non-helpful narrow minded challenge between the two players. In addition, both mixed strategy and pure strategy are studied for accomplishing the Nash Equilibrium solution of the content provider – wireless carrier's information data cost and client's amount of information data utilization with our provided Best Response Nash Equilibrium (BRNE) algorithm. Numerical simulations also demonstrate the nice performance of the provided BRNE algorithm where both client and content provider – wireless carrier alliance [68].

4.1 Background and Related Work

In the fast growing multimedia Internet of Things (IoTs) and next generation of wireless network service, i.e., 5G, two profound problems would be needed to handle well are the avenue enhancement of CP-WC, and the enhancement of UE's QoE. The promising Smart Data Pricing (SDP) concept is one of the possible solutions for the generic data [49-51], and wireless smart media pricing for data services [52]. In smart media pricing mechanism, the "smart" allows the service provided dynamically change the multimedia price but taking buyer's reaction and measuring the wireless quality of experience requirement simultaneously [65]. Further than the SDP, the SMP sets up a new multimedia service mode that allows the content provider – wireless carrier union charge the buyer not only based on the consumed data, but also the quality of experience gain obtained by the user.

In Figure 4.1 we show the proposed SMP concept that "how to charge UE based on the quality of experience, not the data". In the SMP model, different interactive media bundles conveying distinctive quality of experience loads are doled out with various costs. The clients spend money on the content provider to obtain the interactive media data, and then content provider rents physical data links from the wireless carrier. In the long run the wireless carrier assigns wireless assets to give the interactive media administration at some level of quality of experience.

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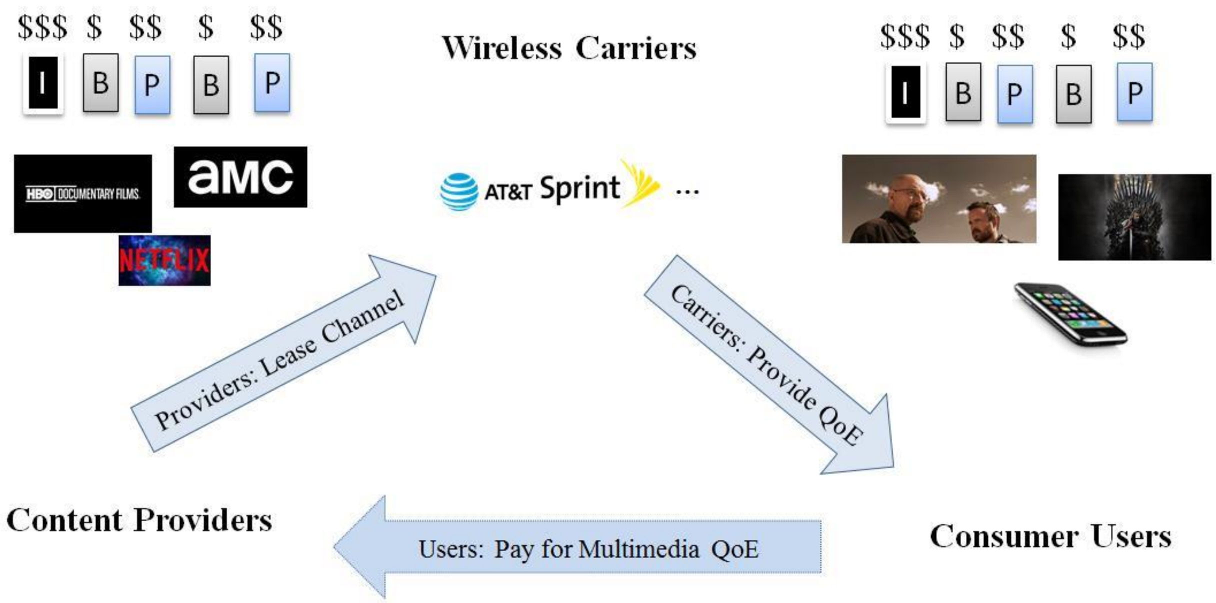

Figure 4.1: Smart media pricing service system. In this SMP model, the users pays content provider price based on the Qoe, the provider leases channel from wireless carriers, and the wireless carriers would provide the data service. Figure refers to [68].

Lots of research work has been carried out on the idea of allowing the service buyer, i.e., the consumers in the wireless terminal side, join the service price decision making procedure. The static price rate mechanism and consumer's usage based data pricing rate method is optimally put together by the authors in [53] based on the user's data rate requirements. While one disadvantage of their work is that the price scheme still needs to wireless internet service providers to provide over-provision for the data service at rush hours (i.e., the peak servicing period). The Time Dependent Pricing (TDP) conspire was given in [54], where the dynamic valuing profited the two administrators and clients by adjusting lower cost at off-peak time and the expense of congestion at peak period. Authors in [55] proposed a context aware quality of experience-driven evaluating administration worldview between end client and base station, with the end goal that both client and base station (went about as the wireless carrier) could get desirable utilities.

Previously mentioned examinations for the most part considered the normal two-party diversion with inward utility capacities, where procedures, for example, in reverse acceptance would be effectively connected for looking for the balance SDP/SMP arrangements [56]. Authors in [57] gave a value sell off amusement to tackle the energy productivity issue in the commonplace source-transfer helpful remote systems. In [7], the base station's cost and devices' capacity are treated as 2 elements worked by these 2 competitive participants individually. The framework could get the correct cost and power by getting the Stackelberg game equilibrium. In [58], a polymatroidal theoretic structure is given by authors to boost the benefit through legitimate transfer speed assignment.

4.2 SMP Network Economics Model

4.2.1 Explanation of User's Utility

As shown in Fig. 4.1, the three-party game in our work would be transformed to a 2 players game, through putting the CP and WC as an alliance. The reason is that we assume the content provider and wireless carrier would make a compromise before the show and they form a team to join the smart media pricing mechanism. In terms of UE, as the multimedia service quality of experience-driven participant in the game, we have to make sure the utility of UE is positive all the time, i.e., $U_{usr} > 0$. Then two players would join the game. Furthermore, the widely used objective quality measurement in the multimedia service, PSNR is adopted in our work to evaluate the UE's multimedia quality gain [38] [63-64]. The utility function of UE is explained equals the obtained overall quality of experience, removed by its data fees payed to the content provider-wireless carrier alliance:

$$U_{usr} = QoE\left(\sum_{i=1}^{N}\sum_{j=1}^{M_i} q_{i,j} * l_{i,j} * \prod_{k\in\pi_{i,j}}(1-p_k)\right) - C_{usr}\left(\sum_i\sum_j y_{i,j} * l_{i,j}\right) \tag{4.1}$$

where the U_{usr} is a non-decreasing and monotonically cost function which aligns the data cost to UE's quality of experience contentment, i.e., if $x \leq y$ then $U_{usr}(x) \leq U_{usr}(y)$. The term PER, also denotes as P_k , is connected to the physical link's BER and the corresponding packet length [66], it is calculated as shown in Equation (2.6). For user, we specify its cost function as follows, where we a constant factor α to align the data cost to quality of experience gain:

$$C_{usr} = \alpha \times \sum_i \sum_j y_{i,j} * l_{i,j} \quad (4.2)$$

In the Equation, the per-bit price y_i of each packet is decided by the service provider side and thus the content provider – wireless carrier would achieve their profit maximization goal by properly adjusting y_i. For simplicity, let y_0 imply the normalized base price. Let π'_j denote the dependency set of packet j [19]. After that, the relationship between the per-bit price y_i and base price y_0 can be presented as

$$y_j = y_0 * \sum_{k \in \pi'_j} q_k \quad (4.3)$$

After we introduced the Equation (4.3), we focus on finding the Nash Equilibrium base price y_0 instead of seeking the per-bit price y_i, that would lead to the highest utility gain at content provider – wireless carrier.

The big bright side of the provided smart media pricing method it very basic but isolate to any quality of experience approach. Some other existence quality of experience model such as frame video quality of experience mechanism which focusing on PER [59], would be perfectly merged into our proposed smart media pricing system. In our work, the quality of experience gain of user equipment is addressed as:

$$QoE = 1 + \left(a_1 - \frac{a_1}{1+\left(\frac{B_r}{a_2}\right)^{a_3}}\right) * e^{\frac{\sum_{i=1}^{N}\sum_{j=1}^{M_i} q_{i,j} * l_{i,j} * \prod_{k\in\pi_{i,j}}(1-p_k)}{a_4}} \quad (4.4)$$

where $a_1 \sim a_4$ are pre-set framework parameters to adjust the user equipment's quality of experience model. The term B_r denotes the rate of coding from multimedia content compressing procedure. The pre-set parameters were chosen as $a_1 = 3.8$, $a_2 = 4.9$, $a_3 = 3.6$ and $a_4 = 3.5$ similar to [59].

4.2.2 Utility Function of CP-WC alliance

The profit-driven player, the content provider-wireless carrier alliance, is another player in the game. In our work, we assume the utility gain of content provider-wireless carrier is approximated as the payment it obtained from the user equipment, subtracted by the transmission costs during the content moving and wireless service in the downlink:

$$U_{CP-WC} = \alpha * \sum_i \sum_j y_{i,j} * l_{i,j} - C_{CP}\left(\sum_i \sum_j q_{i,j}\right) - C_{WC}\left(\sum_i \sum_j \prod_{k\in\pi_{i,j}}(1 - p_k)\right) \quad (4.5)$$

The cost function C_{CP} of content provider is correlated to multimedia coding parameters such as compression ratio, quantization levels, or the IPB video frame coding mode selection. Generally speaking, the cost function of content provider would be increasing and concave in terms of source doing data [60], thus in our work we adopted the following cost function for UP:

$$C_{CP} = \beta * log\left(\sum_i \sum_j q_{i,j}\right) \tag{4.6}$$

where β is a preset system parameter to convert the data quality to the unit of utility. Similarly, we adopted the following cost function of wireless carrier:

$$C_{WC} = \gamma * log\left(\sum_i \sum_j \prod_{k\in\pi_{i,j}} (1 - p_k)\right). \tag{4.7}$$

That is to say, the wireless carrier's spending relates downlink information transmitting efficiency and the physical conditions among wireless carrier and mobile equipment. Here the term γ is also a preset parameter for the purpose of aligning packet error rate to utility.

To be the benefit decision making participant in the amusement, content provider – wireless carrier needs to determine the per-bit base cost y_0 for enhancing the union avenue, where the value rate should likewise fulfill the limitation $U_{usr} > 0$. At the end, the information cost must be sensible that client might want to purchase.

4.2.3 The Nash Equilibrium Analysis

Generally speaking, the strategy for user equipment to enhance its quality of experience equals to purchase larger information (i.e., ask greater $\sum_i \sum_j l_{i,j}$) or choose to buy content with cheap rates. Here we assume the packet error rate keeps consistent amid the administration time. Despite what might be expected, content provider – wireless carrier partnership might want to pick high value price while giving information administration to take care of their acquired expenses and addition high income. The circumstance among client and content provider – wireless carrier partnership frames the ordinary non-cooperative game, which is explained as

$$\left\{\left(L^i, y_0^j\right)|i, j \in S\right\} = argmax[U_{usr}, U_{CP-WC}] \tag{4.8}$$

s.t.

$$U_{usr} > 0, U_{CP-WC} > 0$$

where S denotes the set which includes all possible base price rate and required data amount that set up by content provider – wireless carrier. Equations (4.1) to (4.8) refer to [68]. More details, the L^i implies the amount of data consumed by user equipment at the $i - th$ frame set and the y_0^j denotes the $j - th$ base price strategy of content provider – wireless carrier. The set of $\left\{L^i, y_0^j\right\}$ is decided by content provider – wireless carrier and user equipment, but under their individual goal – enhance their own obtained utility. Our goal is to find the optimal set

$\{(L^i, y_0^j)\}$ where both user equipment and content provider – wireless carrier got satisfied.

4.3 The Smart Media Pricing Game

4.3.1 Equilibrium in the Pure Strategy

Instead of proving the concavity of the utility function of content provider – wireless carrier and user equipment, as shown in Equations (4.1) and (4.5). We proposed the concavity non-needed best response approach to find the most desirable output for any participant if other participants' policies were obtained. At this work, both content provider – wireless carrier and mobile equipment would not want to move far away from the equilibrium state $\{(L^i, y_0^j)\}$.

Definition 4.1: In the best response game category, a strategy set $\{(L^i, y_0^j)\}$ is called the NE if, for every j, $U_{usr}(L^i, y_0^j) \geq U_{usr}(L^*, y_0^j)$ for all $L^* \in S(*, j)$ and for every i, $U_{CP-WC}(L^i, y_0^j) \geq U_{usr}(L^i, y_0^*)$ for all $y_0^* \in S(i,*)$.

To obtain the NE for the content provider – wireless carrier and user equipment service situation, we provided the Best Response Nash Equilibrium (BRNE) algorithm. For the understanding of how BRNE works, we would like to start the interpretation with a simple example. As shown in the Table 4.1, we assume there are two data amount consumption choices for user equipment and there are two base price selection for the content provider – wireless carrier alliance. Based on the utility definition, the numerical utility gain of content provider – wireless carrier and user equipment can be calculated, as shown in the table.

Table 4.1: One Simple Example Showing How to Acquire the NE. Table refers to [68].

L (user) y_0 (CP-WC)	$L^1 = 1 \times 10^6$bits	$L^2 = 2 \times 10^6$bits
$y_0^1 = 1$	(20,6)	(22,**10**)
$y_0^2 = 2$	(**24**,4)	(**30**,**8**)

2

The process to find the game NE is addressed as follows:

Step 1: As the rationale and selfish player, the user equipment would like to choose the data consumption which leads to its utility maximization condition no matter what base price options provided by the content provider – wireless carrier. Based on this philosophy, as the example shown in Table 4.1, the data length L^2 would be selected by user equipment when the base price rate is y_0^1 and the data lenght L^2 would be selected again when the content provider – wireless carrier's price rate is y_0^2 as well. Since these two choices make sure user equipment obtain the best utility. The underline is used to highlight the best reply with regards to user's utility gain.

Step 2: Similar to user equipment, the content provider – wireless carrier is rationale and selfish as well. Regardless the data consumption options of user equipment, the content provider – wireless carrier alliance would always choose the base price rate which makes sure the content provider – wireless carrier reaches the maximization utility gain. Thus, the content provider – wireless carrier will choose the base price rate y_0^2 when user equipment prefers the data length L^1 and L^2 . The reason is that the content provider – wireless carrier would get the best utilities. We highlighted it with underlines as well.

Step 3: When the previous two steps are done, we know can determine the NE length-price set(s) $\{(L^i, y_0^j)\}$ for content provider – wireless carrier and user equipment two players. The $\{(L^2, y_0^2)\}$ would be the equilibrium set in Table 4.1 case, due to that L^2 and y_0^2 were highlighted with "underline" as the best response for two participants, the user and the content provider-wireless carrier.

More general, then it is possible that there were no best response results (i.e., commonly marked in the case shown in Table 4.1) in the non-cooperative situations. The possible outcomes are listed as: 1) No NE solution for the non-cooperative game. 2) There is and only has one NE. 3) There has more than one

NE solution. If the games end up with case 2 and 3, we will get the NE(s) through the stated process eventually, as long as the selection policy for players is finite. The NE(s) come out from such process is called pure strategy policy. It can't be ignored that it is possible there is no common best response solutions, such as the classical zero sum game mentioned in [61]. Thus we will study the mixed strategy mechanism to deal with the special case.

4.3.2 Equilibrium in Mixed Strategy

The simple example shown in Table 4.1 has pure strategy solution, where the common best response behavior is easily to obtain by both players. While when the game situation satisfies the case – No NE between two players, then the user equipment and the content provider – wireless carrier can choose to play the game called mixed strategy policy. More specifically, players would like to selection certain strategies with some probabilities. The outcome solution of such game is called mixed-strategy NE [62].

Definition 4.2: A mixed-strategy Nash equilibrium for user equipment and content provider – wireless carrier are two probability distributions for the available behavior sets: probabilities $\mu_1, \mu_2, \dots$ of the user equipment's consumed data lengths $L^1, L^2, \dots$ and the probabilities $\sigma_1, \sigma_2, \dots$ of the content provider – wireless carrier's base price options $y_0^1, y_0^2, \dots$. At the NE state, the content provider –

wireless carrier must be constant (with regards to the utility gain) among any pure strategies played by the user equipment with the probability μ_i, also, the user equipment must be constant (in terms of utility gain) among any of the pure strategies played by content provider – wireless carrier with probability σ_j. The summation of the probabilities are equal to 1, i.e., $\mu_i \geq 0, \sigma_j \geq 0, \sum \mu_i = 1, \sum \sigma_j = 1$.

Property 4.1: We claim that there exist mixed-strategy NE for user equipment and content provider-wireless carrier in the proposed SMP wireless service model.

Proof of property 4.1: Based on the definition of mixed-strategy NE, to prove property 4.1 is to justify that there has two probability vectors $\vec{\mu} = (\mu_1, \mu_2, \ldots)$ and $\vec{\sigma} = (\sigma_1, \sigma_2, \ldots)$ for user equipment and content provider – wireless carrier respectively. Through the probability vector, every option of user equipment or content provider – wireless carrier mechanism satisfies the same expecting outcomes [61]. We will show the proof of property 4.1 from a simple example to a general case.

Table 4.2: Simple Example to Show the Mixed Strategy for Two Players. Table refers to [68].

L (user)	$L^1 = 1\times$	$L^2 = 2\times$

y_0 (CP-WC)	10^6bits	10^6bits
$y_0^1 = 1$	(**<u>22</u>**,6)	(18,**<u>10</u>**)
$y_0^2 = 2$	(20,**<u>8</u>**)	(**<u>24</u>**,6)

3

First, we begin our analysis with a simple example shown in the Table 4.1, where the case can only be solved by obtaining the mixed-strategy NE. Let μ_1 and μ_2 are the probabilities that user equipment would like to select the data consumption options L^1 and L^2 respectively. On the other hand, let the σ_1 and σ_2 denote the probabilities that content provider – wireless carrier would select the base price rates y_0^1 and y_0^2 respectively. Based on the definition 4.2, content provider – wireless carrier alliance is getting the same utility when user equipment takes data consumption (L^1, L^2) with the probabilities (μ_1, μ_2). Thus, we numerically explain it as

$$22 \times \mu_1 + 18 \times \mu_2 = 20 \times \mu_1 + 24 \times \mu_2. \quad (4.9)$$

The left of the equation shows the utility gain of content provider – wireless carrier when it chooses base price y_0^1, while the right side implies the content provider – wireless carrier's gain at rate y_0^2. Recall the definition, we have

$$\sum_{i=1}^{2} \mu_i = 1, \mu_i \geq 0 \quad (4.10)$$

It is not hard to solve Equations (4.9) and (4.10) with substitution method. Then we could get the solution $\mu_1 = 3/4$, $\mu_2 = 1/4$ for user equipment. Following the same logic, we could obtain the following linear equations at content provider-wireless carrier side

$$\begin{cases} 6 \times \sigma_1 + 8 \times \sigma_2 = 10 \times \sigma_1 + 6 \times \sigma_2 \\ \sigma_1 + \sigma_2 = 1 \end{cases} \tag{4.11}$$

Equations (4.9) to (4.11) refer to [68]. By solving the equations 4.11, we could obtain $\sigma_1 = 1/3$, $\sigma_2 = 2/3$. Now we claim that the mixed-strategy NE for the simple example is the profile $(\mu_1, \mu_2; \sigma_1, \sigma_2) = (\frac{3}{4}, \frac{1}{4}; \frac{1}{3}, \frac{2}{3})$ is illustrated in Table 4.2.

Table 4.2 only shows the size of 2 by 2 system. Next, in Table 4.3, we show a basic case. For simplicity, suppose the content provider – wireless carrier and user equipment have equal expecting, i.e., $\{(L^i, y_0^j)|i, j \in [1, K]\}$. Such assumption ensures the utility value set $U_{1\le i,j\le K}^{i,j}$ is a square matrix (i.e., with size K by K). Similar to the previous proof process, we would easily get the probability vectors $\vec{\mu}/\vec{\sigma}$, for user equipment and content provider-wireless carrier, here each vector has K unknown variables. Then we will obtain the two vectors by solving K linear equations, with K-1 equations come from the conditions 1 or 2 in Definition 4.2, and the last equation comes from the constraints $\mu_i \ge 0, \sigma_j \ge 0, \sum \mu_i = \sum \sigma_j = 1$.

4.3.3 The Discussion of Algorithm

From the above investigation and evidences, we clarify our BRNE calculation (appeared in Algorithm 3) in subtleties in this segment, the algorithm refers to [68]. The algorithm thinks about circumstances of mixed strategy and pure strategy in sequence. In view of the utility set table, we can decide the presence of pure strategy solutions. The procedure set(s) will be put away in RESULT (if there is pure strategy) and returned toward the finish of the algorithm. Otherwise, the mixed strategy approach will be activated (if the RESULT is unfilled). The mixed-strategy solutions, i.e., the probability vectors $\vec{\mu}$, $\vec{\sigma}$ for two players, will eventually be stored in RESULT and returned by the algorithm. Thinking about the complexity of the algorithm, it is close to $O(K^2)$, due to that the NE(s) selection process or linearly system solving process can be completed in $O(K)$.

Algorithm 3: The Proposed BRNE Algorithm to Obtain the Pure and Mixed Strategy.

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1. **Define the Input and Output of algorithm**:

Inputs: (1) The frame's quality q_i and length l_i. (2) The dependence set of frame. (3) The channel BER and preset parameters such as α, β, γ, $a_1 \sim a_4$. (4) The maximum value of consumed data length L^{max} and base price rate y_0^{max}.

2. Outputs: The NE state(s) $\{(L^i, y_0^j)\}$ for the pure strategy, or the probability vectors $\vec{\mu} = (\mu_1, \mu_2, \dots)$ and $\vec{\sigma} = (\sigma_1, \sigma_2, \dots)$ for the mixed strategy.

Searching NE

3. Let $L = linespace[0, L^{max}, K]$
4. Let $y = linespace[0, y_0^{max}, K]$
5. While $i = 1\!:\!K$ do
6. Set $l = L^i$
7. For $j = 1\!:\!K$
8. Set $y = y^j$
9. Compute the utility for user equipment and content provider-wireless carrier $(U_{CP-WC}^{i,j}, U_{usr}^{i,j})$
10. End for
11. Get the price base rate y^j that relates to the maximum U_{CP-WC}^{*}, and underlines it as the best price.
12. End While
13. Calculate the utility and decide the optimal U_{CP-WC}
14. For $j = 1\!:\!K$
15. Get the data length L^i that relates to the maximum $U_{usr}^{j,*}$, underlines it as the

base data consumption.

16.End for

17.Find the best U_{usr} for every price option.

18.RESULT = Strategies $\{(L^i, y_0^j)\}$ and the marked utility set(s) $(U_{CP-WC}^{i,j}, U_{usr}^{i,j})$

19.If RESULT is NULL

20. Set $\vec{\mu} = \vec{0}, \vec{\sigma} = \vec{0}$.

21. List the linear system of K equations based on the utility matrix. Obtain the $\vec{\mu}$, $\vec{\sigma}$ by solving the two linear equations respectively.

22. RESULT = $\vec{\mu}$, $\vec{\sigma}$

23.End if

24.Output the RESULT

4.4 Simulation Discussion

In this section, we carry out numerical simulations to test the system performance based on the proposed BRNE seeking solution.

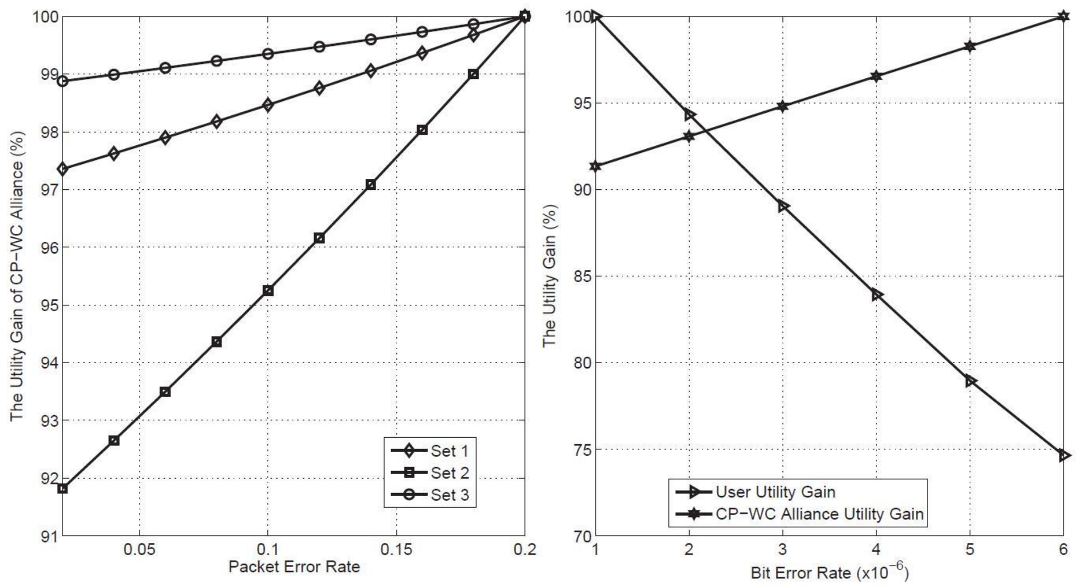

Figure 4.2: The illustration of content provider-wireless carrier and user equipment's utility gain. Figure refers to [68].

As delineated in Fig. 4.2 (left) with the content provider-wireless carrier utility versus packet error rate, the decision of framework parameters won't change the pattern of utility execution however it influences utility's value range. The justification behind the expanding content provider-wireless carrier utility is that the installment from client and wireless carrier's transmitting costs both would diminish with expanding PER (as indicated by the utility function 4.5), yet the last one decreases faster. We pick "Set 2" framework parameters in the following simulations as it has the biggest value range. At that point we assess the utilities performance of user equipment and content provider-wireless carrier in various BER situations. As portrayed in the Fig. 4.2 (right), the utility of user equipment drastically diminishes alongside the expanding of BER while the utility of content provider-wireless carrier keeps step by step expanding. This outcome exhibits that under the fixed value rate and consumed data, the content provider-wireless carrier gets one-sided profits by the wireless data service with lower asset prompting higher BER.

In addition, the quality of experience gain versus channel BER simulation result is illustrated in Fig. 4.3, where we can observe that the user equipment's quality of experience gain provided by wireless carrier would have the same trend with the enhancing of BER. Conclude from Fig. 4.2 and 4.3 that if we choose the fixed price/data service, there only content provider-wireless carrier would gain benefits. The user equipment has to pay more money in order to obtain better service quality, especially when the channel is getting worse.

23

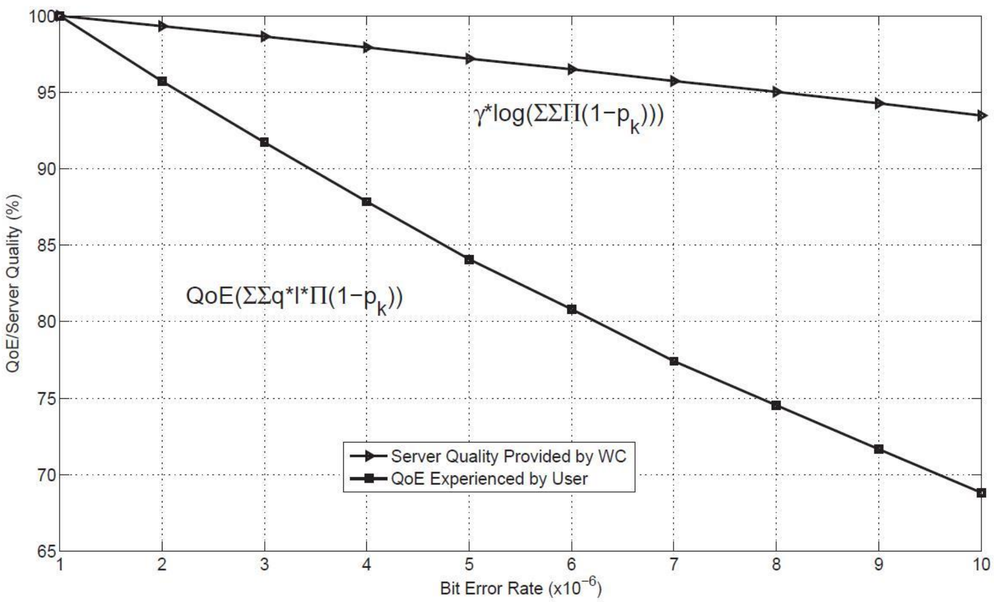

Figure 4.3: The illustration of the service quality provided by wireless carrier and the user equipment's quality of experience gain. Figure refers to [68].

In Fig. 4.4, we assess the utility performance of user equipment and content provider-wireless carrier in various base price rates. Different transfer speeds are considered, with the goal that we can get the user equipment's utility as far as expended consumed data. The utility of content provider-wireless carrier has stable patterns, and high value rate beats every single other alternative. For user equipment, there exists an ideal length-value set that boost its utility. The ideal length-cost point(s) are created from our best response strategy and the no players go amiss from them.

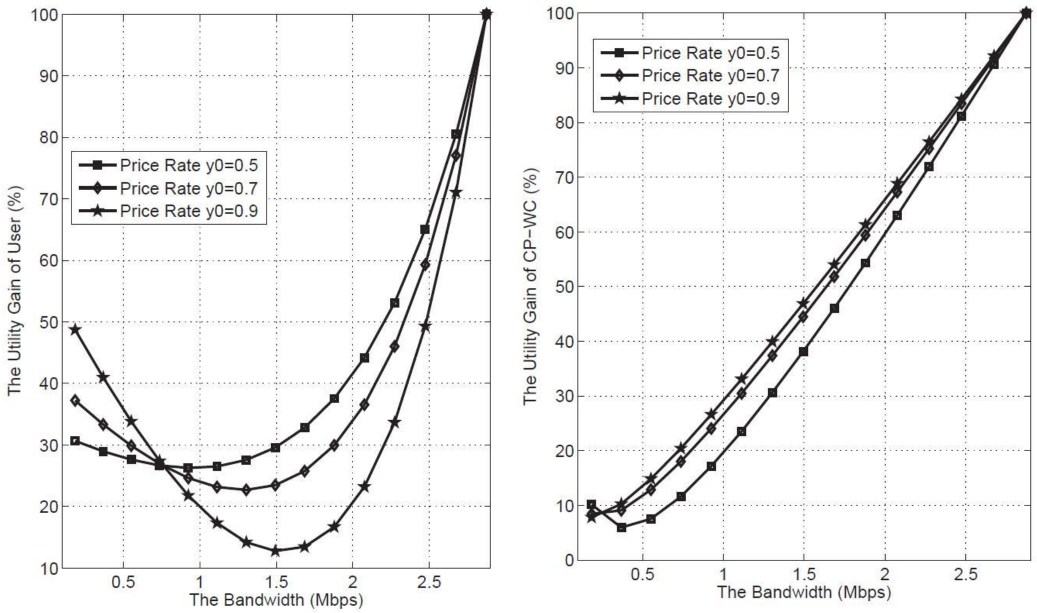

Figure 4.4: The illustration of the user equipment's utility gain and content provider-wireless carrier alliance's utility along with the enhancing of bandwidth. Figure refers to [68].

The general system performance based on the proposed BRNE algorithm is appeared in Fig. 4.5. The accumulated PSNR goes about as the quality of experience measurements. It is important that in this simulation, the NE arrangement created from BRNE algorithm is constantly pure strategy and the mixed strategy game hasn't been activated. As showed in the figure, both user equipment and content provider-wireless carrier get altogether enhancements for utility gain when taking the NE arrangement. The reason for this is the price rate and consumed data length are both the best reactions for every player as indicated by other's alternative.

25

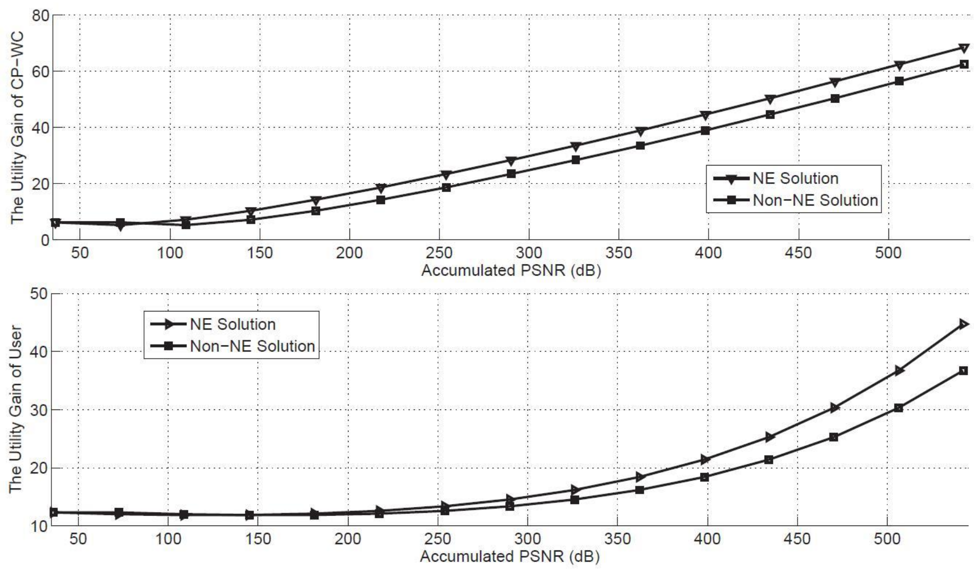

Figure 4.5: The proof of content provider-wireless carrier's utility gain (up) and user equipment's (bottom) with different price rate set up and consumed data length. Figure refers to [68].

4.5 Summary

In this chapter, a generalized best response SMP game hypothetical model is created to address the quality of experience – profit boost issue for wireless media correspondences. The model loosened up conventional presumption that utility function need to be concave. In light of the SMP idea to value quality of experience not the data, we break down the non-cooperative circumstance between the two players and build up the BRNE algorithm to obtain the equilibrium solution for both user equipment and content provider-wireless carrier. Moreover, both pure strategy and mixed strategy are examined in our examination, where the comparing NE solutions from the two procedures are tended to. Simulation thinks about show the proposed BRNE algorithm works successfully to get NE solutions by taking players’ utility increase into consideration.

Chapter 5

Conclusion

A conclusion of this dissertation will be given in the chapter, and some important future work will be discussed after the conclusion.

This dissertation investigates big challenges in wireless multimedia services and proposed several optimal wireless multimedia transmission schemes to address these challenges. Such as, the D2D relaying approach is investigated in the typical BS to user equipment two entities multimedia service system. How to properly apply the MIMO technology in the D2D communication is introduced, through which the transmission efficiency and energy efficiency will be improved simultaneously. In addition, factors such as the multimedia content distribution, the power allocation strategy, and modulation size are jointly considered in the research presented in this dissertation. In addition, the power allocation strategies and their associated constraints are investigated in detail in the wireless system where the traditional OMA technology and the promising NOMA technology in this dissertation as well. At the multimedia content level, the dynamic video Quantization Parameter (QP) adaptation method is utilized. The quantitative analysis of the impact of power allocation and QP control on user equipment's utility gain and system performance is conducted in this dissertation. To extend the conventional BS-user equipment two entities research model to the content provider-wireless carrier-user equipment three entities model, a generalized best response Smart Media Pricing (SMP) method is studied in this dissertation at last. Where the content provider and wireless carrier are treated as the service provider alliance, the SMP approach and the game theoretical model are utilized to determine the consumed data traffic of user equipment and the media price charged by the content provider-WC alliance. It is worth pointing out that the concavity of utility function is no longer necessary for seeking the game equilibrium under the proposed best response game solution.

After the conclusion of this dissertation, there is some work plans for the future. By aiming at improvement of the user equipments' quality of experience utilities in the next generation of wireless multimedia service, i.e., 5G wireless service, through combining all the technologies or schemes mentioned before, a "price-aware", "reinforcement Q-learning" based, "optimization achievable resource allocation method", is supposed to proposed which would approximate the optimal power allocation policy of BS in the NOMA downlink scenario in the our future work. More specifically, for the purpose of quantitatively analyzing the user equipment's quality of experience or utility gain, a profound quality of experience mathematical model of user equipment and BS will be given in the work, i.e., the light-weighted two level logarithmic mathematical quality of experience model we already adopted in our previous work. In addition, all the environment factors such as the channel conditions, the mutual interference among UEs during the data transmission, and the attainable transmission data rate of UE (as receiver), are supposed to be jointly considered when we define the State in the learning process. Furthermore, due to the massive UEs in the wireless network, the machine learning method will work in both cases: single agent scenario, i.e., Single Agent Reinforcement Learning (SARL) and multiple-agent scenario, i.e., Multiple Agent Reinforcement Learning (MARL). Eventually, the BS would be able to approximate the optimal price-aware power allocation policy for each UE according to the learning procedure. Another challenge we need to keep in mind when we considering the multi-agent learning system is that: how to properly set up the learning goal for the machine learning method. In the multiple agents system, the relationships among UEs can be either cooperative or competitive, no matter in resource requests or focusing on their own utility gain. How do choose between "maximizing individual utility gain" and "optimal overall system resource allocation efficiency" is the core and it is supposed to be determined by the applications in the real cases.

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