Context-Aware QoE-Price Equilibrium for Wireless Multimedia Relay Communications Using Stackelberg Game

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***Abstract*—With the tremendous volume explosion of big data video contents in future wireless networks, ensuring Quality of Experience (QoE) of the End User (EU) by leveraging communication context becomes an important issue. In this paper, we propose a context-aware wireless multimedia relay solution to incentivize user devices participating in wireless relay services. In this proposed approach, QoE and price are jointly considered in a Stackelberg game model, providing economic rewards to the Relay Device (RD) which helps transmitting video contents between the Base Station (BS) and EU. The revenue of RD is numerically associated to the communication resource consumed by relaying video from the BS to the EU, while the utility of BS is quantitatively determined by the video QoE provided to the EU. We mathematically prove the existence of equilibrium state in the proposed Stackelberg game model. The simulation results show that players of EU, RD and BS in the system get desirable utilities in the QoE-Price equilibrium state.**

***Index Terms*—Quality of Experience, Stackelberg Game Theory, Wireless Relay**

I. INTRODUCTION

As the computing, communication, and storage functionalities are pushing to the edge in Network Function Virtualization (NFV) and Software Defined Networking (SDN), context-aware network protocol scheduling [1] [2] and content-aware multimedia resource allocation [3] [4] become critical research challenges. In the meanwhile, mobile video becomes the dominating traffic in future wireless networks, demanding variable communication resources in various contexts. In mobile video services, improving Quality of Experience (QoE) perceived by the End Users (EUs) is always the paramount objective in wireless multimedia communications [5] – [7]. However, this poses an essential challenge in modern NFV at the edge networks: how to optimally adapt the network functionality software and resource allocation algorithms to both the multimedia traffic content and wireless communication situations (i.e. context-awareness, leveraging user-provided mobile device for relay, providing incentives to encourage relays, etc)?

To address the stated challenge, we proposed a new context-aware wireless video downloading service virtualization scheme jointly considering Relay Device (RD) channel condition, video content importance, and transmission power consumption. Then we correlate these factors with economic pricing incentives in a Stackelberg game model to improve the players' utilities. In our work, the frame distortion reduction of multimedia content is considered as the pivotal factor of QoE while evaluating system profit. As shown in Fig.1, the RD is geographically located between Base Station (BS) and EU for relaying highly video frame quality. With the multimedia packet relaying of RD, the QoE of EUs can be ensured even in severe channel information.

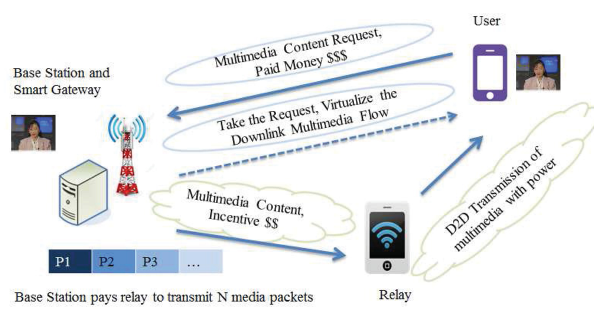

Fig. 1. The virtualized context-aware multimedia communication between BS, RD and EU: EU requests multimedia data from BS and pays money (c_{BS_u}) to BS depending on the pledged multimedia quality. BS pays RD money (c) for relaying data. RD chooses proper power (p_{BS}) to transmit multimedia data to EU.

QoE as an integration of Quality of Service (QoS) and individual human-related metrics becomes the new criterion for evaluating wireless multimedia services [8]. In [9], authors proposed the decision-theoretic context-aware QoE model, where the modeling, measurement and prediction parameters of QoE were jointly addressed. A context-adaptive cross-layer optimization approach was proposed in [10], to address the enhancement of video streaming over TCP for better QoE (i.e., adaptive reliability and smoother throughput). The pricing-driven game theory has been widely studied in wireless video services. In [11], the authors investigated the relationship between transmission power and packet price and modeled it as the classical Stackelberg game to find the optimal video service strategies. The Stackelberg game model was also studied in [12], where authors presented three service modes in a dynamic game to users for choosing proper transmission scheme based on performance and cost. The Stackelberg model was typically implemented in the leader-follower style, where the leader moved first and then the follower

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moved accordingly. Authors in [13] modeled multiple EUs as the leader and the single BS as the follower, where EUs set their prices according to rational transmission power response from the BS. Unlike most of the existing research in literature, we consider context-quality and profit-driven resource allocation in this paper, to model and solve the QoE-Price Stackelberg game between the BS and the RD, seeking optimal transmission power of RD and offered price of BS to maximize the utilities.

The rest of this paper is organized as follows. Section II presents the system model and defines the utility functions of participants in the game. In section III, we mathematically prove the existence of the equilibrium of the proposed Stackelberg game. It ensures our proposed transmission strategy will guide all players toward the equilibrium and achieve the optimal utilities. The simulation results that demonstrate the effectiveness of the proposed strategy are presented in section IV. We conclude this paper in section V. The key notations and nomenclature in this paper is summarized in TABLE I.

TABLE I
SUMMARY OF NOMENCLATURE

Symbol	Comments
U_{BS}, U_{RL}	Utility of BS and RD
D_i	Distortion reduction of the $i-th$ video frame.
N	The total number of frames sold by BS.
L	Total data consumed by EU through the relay.
e	The bit error rate in physical channel.
c_{BS_u}	The cost coefficient between EU and BS.
p_{RL}	The transmission power used by RD when sending data to EU.
R_s	Symbol rate in data communication channel.
b	The constellation size in data communication channel.
c	The price coefficient per unit of quality gain (the rate RD charges to the BS).
$\psi_{BS\_u}, \psi_{power}, \psi_{tran}$	The payments of received from EU, communication cost from BS to RD, and energy cost of BS in communication.
p_{BS}	Transmission power of BS when transmitting data to RD.
c_{BS}	Cost per unit of transmission power at the BS side.
c_{RL}	The energy cost coefficient of RD.

II. SYSTEM MODEL

A. QoE-Price Game Modeling Between EU, RD and BS

As illustrated in Fig.1, we consider a BS-RD-EU model of a set of frames $\mathrm{N} = \{1, 2, ..., N\}$ with unequal distortion reduction. The economic rationale behind the proposed system is: EU pays BS money for a certain QoE of video service. BS can "virtualize" this downlink video service by seeking help from a RD. BS shares a portion of its revenue to the selected RD (in the form of buying RD's transmission power). RD gets profit by subtracting the financial cost of energy consumption from its income. We use the terms of "relay" and "RD" interchangeably. We also use "EU" and "user" interchangeably in the rest of this paper.

EU requests video from BS and pays money to BS based on the BS-pledged multimedia QoE. QoE is a complex evaluation system framework including many factors. To simplify the numerical description, we use one of the most important distortion reduction factor. The multimedia QoE can be represented as the summation of frame's distortion reduction (shown in equation 1), multiplied by the probability of it being successfully transmitted. We consider three types of frames in this work, e.g. I/P/B-frames. Note that the I-type frame has the full information and could be encoded/decoded independently, while the probability of successfully transmitting P/B frames depends on their processor frames. Let c_{BS_u} denote the cost per unit of multimedia quality ($/PSNR – Peak Signal to Noise Ratio), then the money that the EU pays to BS can be formulated as:

$$\psi_{BS\_u} = \log\left\{c_{BS\_u} \times \left(\sum_{i=1}^{N} D_i\right) \times (1-e_1)^L (1-e_2)^L\right\} \qquad (1)$$

with the payment ψ_{BS_u} from user, BS shares part of it to relay and assign the transmission task to relay (to ensure the quality requirement of user). Let e_1 and e_2 denote the bit error rate between BS to relay, and relay to user respectively (generally $e_1 < e_2$, since BS uses larger transmission power comparing with relay device). When RD gets the video relay task from BS, it chooses the proper power to transmit data. We assume the modulation constellation size is 2 for QPSK. The bit error rate of the physical channel between relay and end user is calculated as

$$e_2 = \frac{1}{2} erfc\left(\sqrt{\frac{p_{RL}A}{N_0 R_s b}}\right). \qquad (2)$$

In this work we consider the channel attenuation (A), symbol rate (R_s) and noise power density (N_0) are not changed during the transmission progress in a way similar to [14]. That ensures there is no other factor in the system to affect the relay's power decision.

B. Utility of Base Station

The goals of virtualized video relay task assignment of BS are to achieve its higher revenue and ensure the multimedia service quality at the same time. Based on equations (1) and (2) we can see that the multimedia quality is decided by two factors: the relay's transmission power p_{RL} and channel information g (defined in equation 8). To ensure the multimedia relay quality, RD will charge higher price for higher transmission power p_{RL} when the channel condition is bad between RD and EU. Let c denote the money per bit per unit quality gain ($/Bit/PSNR) that is successfully received by the user. Then we model the cost of BS for buying RD's transmission power as

$$\psi_{power} = c \times L \times \left(\sum_{i=1}^{N} D_i \right) \times p_{RL}. \tag{3}$$

In addition, the BS's energy cost on transmitting the original data to relay is also considered in our work. This part of cost is represented as

$$\psi_{tran} = c_{BS} \times \frac{L}{R_s b} \times p_{BS}, \tag{4}$$

where c_{BS} represents the cost per unit energy consumption (\$/Joule). With the preceding notations, the utility function of BS can be represented as the subtraction of its costs from the user's payment, shown as

$$U_{BS} = \psi_{BS\_u} - \psi_{tran} - \psi_{power}. \tag{5}$$

Two types of costs of BS are considered in our study, one is the incurred cost when BS transmitting data to RD, the other is the money that RD charges for retransmission. The incurred cost is explained as the price coefficient multiplied by the energy consumption. The second cost is the payment to relay. The logic behind this payment is: In order to improve the multimedia quality gain of EU, the BS should find a RD with a relative low level of e_2. With higher transmission power, the bit error rate decreases dramatically. The payment can be paraphrased as: BS purchases power p_{RL} from RD with price c, where c is decided by relay.

C. Utility of Relay

Relay plays a vital part in our system. As a profit-driven player between BS and EU, relay can control its cost and the multimedia data quality of EU by adjusting the transmission power. Let c_{RL} denote the relay's cost on energy consumption (\$/Joule), then the utility of relay is explained as its income subtracts the cost:

$$U_{RL} = c \times L \times \left(\sum_{i=1}^{N} D_i \right) \times p_{RL} - c_{RL} \times p_{RL} \left(\frac{L}{R_s b} + t_{overhead} \right) \tag{6}$$

s.t. $U_{RL} \geq 0$.

We assume the income of RD exclusively comes from BS, as explained in equation (3).

D. QoE-Price-Driven Relay Game System Description

Once the user's multimedia service is satisfied, there are two players left in our proposed BS-RD-EU system: the BS and RD. We formulate the system as a profit maximizing problem as:

$$\begin{array}{c} \{p_{RL}, c\} = \arg\max\{U_{BS}, U_{RL}\} \\ s.t. \quad U_{BS} \geq 0 \quad ; \quad U_{RL} \geq 0 \end{array}. \tag{7}$$

Where we consider the transmission power p_{RL} and price rate c on the left hand side are non-determined parameters. The goal of our work is find the solution set $\{p_{RL}^i, c^i\}$ that maximizes the utilities of BS and RD.

In our system, BS decides the amount c_{BS_u} to charge to the EU at the beginning of the video downloading service. Then it uses portion of its revenue (shown in equation 5) to buy power from RD for relaying to virtualize this video service. RD charges BS with rate c to complete the relaying service. We assume BS and RD are rational and selfish. This means RD would choose higher price rate c and lower transmission power p_{RL} when possible , while BS would go to the opposite direction. We model the interaction between BS and RD as a two-stage Stackelberg game [11]. The equilibrium in game theory is applied in such non-cooperative case between BS and RD. Equilibrium is a stable state of a game where BS and RD both achieve the optimal utility and will not deviate as long as they are rational players.

III. Stackelberg Game Solution between BS and RD

A. Stackelberg Game Equilibrium Analysis.

At the equilibrium state, both BS and RD achieve their utility optimizations. Let $\{p_{RL}^{opt}, c^{opt}\}$ denote this state, we need to prove the existence of p_{RL}^{opt} for BS. To simplify the terms in following proof, let g denote the wireless channel gain between RD and the EU, then we have

$$g = \frac{A}{N_0 R_s}. \tag{8}$$

In addition, let d denote the total multimedia quality gain of the group of video frames, here we have

$$d = \sum_{i=1}^{N} D_i. \tag{9}$$

In order to see the change of BS's utility along with the RD's transmission power p_{RL}, we assume the price c is fixed and $p_{\min} \leq p_{RL} \leq p_{\max}$. By taking the first order derivative of the utility function of BS respect to p_{RL}, we have

$$\frac{\partial U_{BS}}{\partial p_{RL}} = \frac{gLe^{-\frac{gp_{RL}}{2}}}{\sqrt{8\pi g p_{RL}} \left\{1 - \frac{1}{2}\left[erfc\left(\sqrt{\frac{gp_{RL}}{2}}\right)\right]\right\}} - cdL. \tag{10}$$

Then, to show the utility function of BS maintaining concavity (in this condition BS will get its maximum), we perform the second order derivative of U_{BS} respect to p_{RL}. We have

$$\frac{\partial^2 U_{BS}}{\partial p_{RL}^2} = \frac{g^2 L(gp_{RL}+1)e^{-\frac{gp_{RL}}{2}}}{\sqrt{8\pi (gp_{RL})^3}\left[erfc\left(\sqrt{\frac{gp_{RL}}{2}}\right)-2\right]} - \frac{gLe^{-gp_{RL}}}{2\pi p_{RL}\left[erfc\left(\sqrt{\frac{gp_{RL}}{2}}\right)-2\right]^2} \tag{11}$$

Recall the properties of Gauss error function, we know that the value of the term $erfc\left(\sqrt{\frac{gp_{RL}}{2}}\right)$ is always lower than 2 by all means. Since $g > 0$, $L > 0$, $p_{RL} > 0$ and $\exp(\cdot) > 0$, which implies that the second derivative of U_{BS} satisfies $\frac{\partial^2 U_{BS}}{\partial p_{RL}^2} < 0$ all times. Therefore we reach the conclusion that the utility of BS is concave and it gets the p_{RL}^{opt} when $\frac{\partial U_{BS}}{\partial p_{RL}} = 0$.

For the convenience of further proofs, we let $F\left(c, p_{RL}^{opt}\right) = \frac{\partial U_{BS}}{\partial p_{RL}} = 0$. More specifically,

$$F\left(c, p_{RL}^{opt}\right) = \frac{gLe^{-\frac{gp_{RL}^{opt}}{2}}}{\sqrt{8\pi g p_{RL}^{opt}}\left\{1 - \frac{1}{2}\left[erfc\left(\sqrt{\frac{gp_{RL}^{opt}}{2}}\right)\right]\right\}} - cdL. \tag{12}$$

In the ideal case, we introduce $p_{RL}^{opt}(c)$ (i.e. acquired from the condition that $F\left(c, p_{RL}^{opt}\right) = 0$) into the utility function of RD in equation (6). By investigating the concavity of RD's utility function, (i.e., to show that $\frac{\partial^2 U_{RL}}{\partial c^2} < 0$), we can prove the existence of equilibrium state $\{p_{RL}^{opt*}, c^{opt}\}$ between BS and RD. It is worth noting that the $\{p_{RL}^{opt*}, c^{opt}\}$ state satisfies $\frac{\partial U_{BS}}{\partial p_{RL}} = 0$ and $\frac{\partial U_{RL}}{\partial c} = 0$ simultaneously. While as we can see from equation (11), the $p_{RL}^{opt}(c)$ is an implicit function in our case. We choose an alternative way to search for the maximum of relay's utility function.

Property 1: The utility of relay has a maximum value on the closed interval $[p_{RL}^{\min}, p_{RL}^{\max}]$.

Proof: With the optimal power we get from $F\left(c, p_{RL}^{opt}\right) = 0$, the utility function of relay can be rewritten as:

$$\begin{aligned} U_{RL} = & \frac{\sqrt{gp_{RL}^{opt}}e^{-\frac{gp_{RL}^{opt}}{2}}}{R_s b\sqrt{8\pi}\left[1 - \frac{1}{2}erfc\left(\sqrt{\frac{gp_{RL}^{opt}}{2}}\right)\right]} \\ & - c_{RL} \times p_{RL}^{opt} \times \left(\frac{L}{R_s b} + t_{overhead}\right) \end{aligned} \tag{13}$$

where p_{RL}^{opt} is an implicit function of c. It easy to proof that U_{RL} is continuous and differentiable when $p_{RL}^{opt} \in [p_{RL}^{\min}, p_{RL}^{\max}]$, since it generated by the product and summation of basic functions. Taking the first derivative with respect to c in (13), we have

$$\frac{\partial U_{RL}}{\partial c} = \frac{\partial U_{RL}}{\partial p_{RL}^{opt}} \cdot \frac{\partial p_{RL}^{opt}}{\partial c} = \frac{\partial U_{RL}}{\partial p_{RL}^{opt}} \cdot \left(-\frac{\partial F / \partial c}{\partial F / \partial p_{RL}^{opt}}\right), \tag{14}$$

where equations (15) and (16) are satisfied.

Lemma 1: A real function which is differentiable must be a continuous function. [15]

Lemma 2: A continuous real function on a closed interval must contain a maximum value and a minimum value. [15]

Powered by lemma 1 and 2, we prove that the utility function U_{RL} has the maximum value in the interval $[p_{RL}^{\min}, p_{RL}^{\max}]$. Let p_{RL}^{opt*} denote the optimal transmission power, c^{opt*} denote the corresponding price. We can solve the utility maximization problem (i.e., $\arg\max\{U_{BS}, U_{RL}\}$) by finding the Stackelberg game equilibrium state $\{p_{RL}^{opt*}, c^{opt*}\}$ through genetic algorithm or global searching.

B. Context-Aware QoE-Price Search Algorithm

The quality and length of multimedia data consumed by user play the vital roles in the proposed BS-RD Stackelberg game. More specifically, the optimal transmission power p_{RL}^{opt*} and price c^{opt*} (i.e., let equations (10) and (13) equal to zero) are decided by the distortion reduction d and total consumed video data size L. Algorithm 1 shows the process of how to find the optimal power and price in such a QoE-Price-Driven downlink wireless video service virtualization via relay.

Algorithm 1 : The Context-Aware QoE-Price Stackelberg Game Algorithm.

1: **Initialization:** Define the I/O of algorithm. Inputs: (1) The total consumed data L and distortion reduction D_i of each frame. (2) The fixed incurred cost coefficients, such as c_{BS}, c_{RL} and c_{BS_u}. (3) Channel condition and transmission parameters, i.e., A, N_0, R_s and b. (4) The iteration steps M for searching the optimal transmission power. Outputs: (1) The optimal transmission power and price pair $\{p_{RL}^{opt*}, c^{opt*}\}$. (2) The corresponding utility of BS and RD at the equilibrium state.

2: **Stackelberg Equilibrium searching progress.** The outputted equilibrium state of this algorithm could be different with the variety of data requests.
Set U_{RL} and U_{BS} equal zero.
Based on $p_{RL}^{\min}$, $p_{RL}^{\max}$ and $F\left(c, p_{RL}^{opt}\right) = 0$, calculate the utility of BS and RD and mark the maximum as $\max\{U_{BS}, U_{RL}\}$.
For i=1:N
  Let $p = linespace[p_{RL}^{\min}, p_{RL}^{\max}, M]$;
  While k=1:M do
    Set $p_{RL} = p(k)$;
    Based on initial conditions and $p(k)$,
    calculate the payment and cost of BS, ψ_{tran} and ψ_{BS_u}.
    Based on $F\left(c, p_{RL}^{opt}\right) = 0$,
    calculate the price $c(k)$.
    Then calculate the $\{U_{BS}^k, U_{RL}^k\}$.
    If $\{U_{BS}^k, U_{RL}^k\} > \max\{U_{BS}, U_{RL}\}$
      $\max\{U_{BS}, U_{RL}\} = \{U_{BS}^k, U_{RL}^k\}$,
      store the $p(k)$ and$c(k)$.
    End if;
  End while;
End For.

3: **Output the Stackelberg equilibrium state** $\{p_{RL}^{opt*}, c^{opt*}\}$. Calculate the corresponding utility U_{RL}, U_{BS} of BS and RD.

We use global searching method in the algorithm to determine the optimal transmission power. Because the gap between $p_{RL}^{\max}$ and $p_{RL}^{\min}$ should be small, the runtime of finding the equilibrium state mainly depends on frame number N.

IV. SIMULATION

In this section, we perform simulation to evaluate the system performance. We use the MPEG-4 H.264 codec to compress a "*Foreman*" standard video sequence. The video sequence type $IIIII...$ is taken as the independent data set and $IPIPIP...$ is used when simulating interdependent data set. We set $e_1 = 1 \times 10^{-6}$. We assume the channel condition between BS and RD is relatively good. The BS is supposed to choose the optimal RD for to virtualize the video downloading, and the BS has unlimited transmission power. The symbol rate is $R_s = 2 \times 10^7 Hz$.

First, we evaluate the video quality gain of EU in different channel conditions. We take the $g = A/(N_0 R_s)$ (from equation 8) as the x-axis. All I-type multimedia video sequence is taken in the simulation (result is shown in Fig 2). From the result we understand that: First, better

$$\frac{\partial U_{RL}}{\partial p_{RL}^{opt}} = \frac{g e^{-\frac{g p_{RL}^{opt}}{2}}}{2^{\frac{5}{2}} R_s b \sqrt{\pi g p_{RL}^{opt}} \left[1 - \frac{1}{2} erfc\left(\sqrt{\frac{g p_{RL}^{opt}}{2}}\right)\right]} - \frac{g \sqrt{g p_{RL}^{opt}} e^{-\frac{g p_{RL}^{opt}}{2}}}{2^{\frac{5}{2}} R_s b \sqrt{\pi} \left[1 - \frac{1}{2} erfc\left(\sqrt{\frac{g p_{RL}^{opt}}{2}}\right)\right]}, \\ - \frac{g e^{-g p_{RL}^{opt}}}{8 \pi R_s b \left[1 - \frac{1}{2} erfc\left(\sqrt{\frac{g p_{RL}^{opt}}{2}}\right)\right]^2} - c_{RL} \times \left(\frac{L}{R_s b} + t_{overhead}\right) \tag{15}$$

$$-\frac{\partial F / \partial c}{\partial F / \partial p_{RL}^{opt}} = -\frac{F_c}{F_{p_{RL}^{opt}}} = \frac{1}{\frac{g^2 (g p_{RL}^{opt} + 1) e^{-\frac{g p_{RL}^{opt}}{2}}}{2^{\frac{3}{2}} \sqrt{\pi} d (g p_{RL}^{opt})^{\frac{3}{2}} \left[erfc\left(\sqrt{\frac{g p_{RL}^{opt}}{2}}\right) - 2\right]} - \frac{g e^{-g p_{RL}^{opt}}}{2 \pi d p_{RL}^{opt} \left[erfc\left(\sqrt{\frac{g p_{RL}^{opt}}{2}}\right) - 2\right]^2}}. \tag{16}$$

channel will ensure higher service quality. Second, when the channel parameters are fixed, the bigger transmission power is, the higher multimedia quality end user will gain. As we mentioned before, BS or EU cannot request RD to increase the transmission power to improve BS's utility or multimedia quality unilaterally (because it will dramatically increase the energy cost of RD).

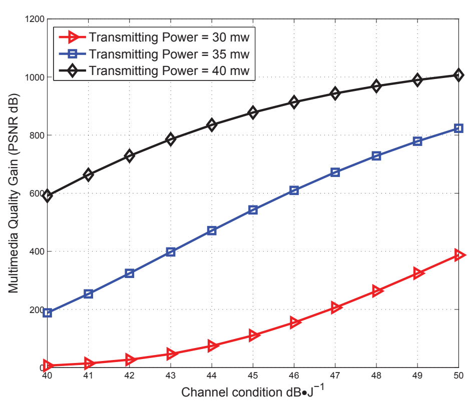

Fig. 2. The multimedia quality gain of EU in the different channel factor (g) and transmission power (p_{RL}).

In our work, we define three price coefficient factors (c_{BS_u}, c_{BS} and c_{RL}) to universalize the unit of two utility functions. This makes it convenient for quantitative analyzing the game players' profit or revenue. These coefficients are set as constants. We explore the utility performance of BS and RD versus the data consumed by EU in Fig 3. The result illustrates how the three combinations of price coefficient factors affect the utility gain of BS and RD. Three combinations are listed as follows:

Case 1: $c_{BS\_u} = 2$,$c_{BS} = 1$ and $c_{RL} = 1$.
Case 2: $c_{BS\_u} = 1$,$c_{BS} = 2$ and $c_{RL} = 5$.
Case 3: $c_{BS\_u} = 3$,$c_{BS} = 1$ and $c_{RL} = 1$.

From the simulation result we can see that the coefficient factors won't significantly change the utilities of BS and RD. The utility of RD is mainly decide by its transmission power p_{RL} and the price c it charges to BS. Meanwhile, with more payment (which means higher c_{BS_u}) from user, BS would improve its revenue directly (around 10%). We

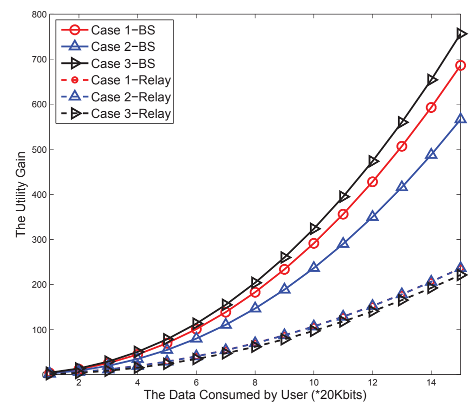

Fig. 3. The illustration of BS and relay's utility gain under different price coefficients.

will take $c_{BS\_u} = 2$, $c_{BS} = 1$ and $c_{RL} = 1$ in our following simulations.

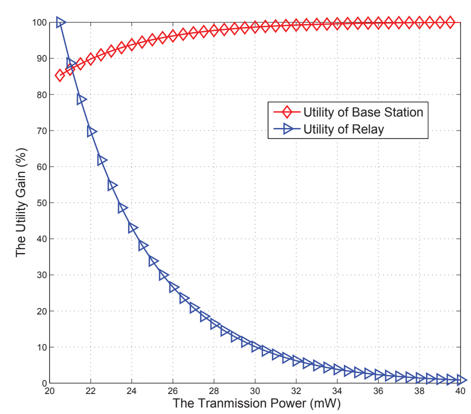

Fig. 4. The utility curves of BS and RD versus the changing of RD's transmission power.

We have mathematically proved the existence of equilibrium in the proposed BS-RD Stackelberg game and use global searching algorithm to find the optimal $\{p_{RL}^i, c^i\}$ set in our work. Fig 4 shows the utility gain of BS and RD with varying transmission power p_{RL}. It illustrates how the global searching process affects two players' utility gain. As we can see from the result, the utility of relay will decrease gradually with the increase of transmission power, since RD pays more on energy cost. For BS, its income comes from the payment of EU directly, which is mostly decided by the downlink wireless video QoE. Generally speaking, higher transmission power will reduce the BER and then improve the multimedia quality gain. So it is reasonable that the utility curve of BS goes up with the higher transmission power.

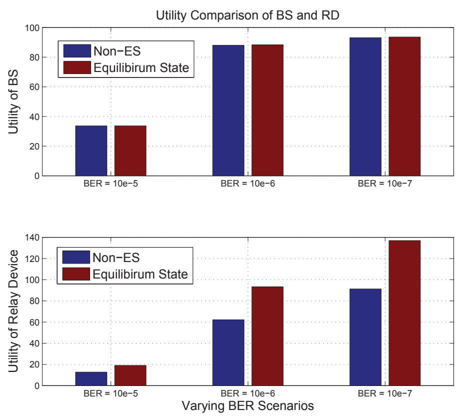

Fig. 5. The illustration of utility gain of BS and RD, when facing various channel conditions between relay and user (e2).

Finally, we show the overall system performance when we take the price and transmission power from the equilibrium state. We compare the fixed price and transmission power (Non-ES) to the proposed approach, and show the results in Fig 5. As we can see that although the utility of BS increases very little bit in all cases, the utility of RD gets dramatically improved when we consider the Stackelberg game solution. The result indicates that when RD helps to relay data between BS and user, the high service quality that RD provides, the bigger utility BS and RD will get. Even in bad channel condition ($e2 = 10^{-5}$), the BS and RD still obtain relative high utilities.

V. Conclusion

In this paper, a profit-driven and context-aware relay game solution is proposed to solve the QoE assurance problem in virtualizing the downlink video services between the BS and the EU. The transmission power of RD and the cost of BS are considered as two factors that the Stackelberg game leader and follower can adjust. Through the mathematical derivation, we proved that the existence of the equilibrium between the RD and the BS. Simulation results show that at the equilibrium state, the EU gets desirable QoE, and RD and BS obtain their desirable utilities, even in the channel environment with high bit error rates.

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