Profit-Driven Cache Delegation: A Game-Theoretic Wireless Multimedia Offloading Solution

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***Abstract*—With increasing number of mobile users, leveraging economics in communications has been envisioned as a new paradigm to boost the network performance. However, the issues such as incentivizing offloading devices and improving end-user Quality of Experience (QoE) are still open challenges. The philosophy of the proposed algorithmic protocol lies in encouraging end-users to scavenge multimedia data from the neighbors (offloading users), and by doing so, maximize their QoE by taking advantage of shorter communication distance. The protocol also facilitates the wireless carriers to lower the network traffic congestion and to improve profits by setting up cache delegation communication among the offloading users and end-user for a nominal commission fee. Steadiness of the proposed game theoretic algorithmic protocol has been achieved by formulating the interaction between the service provider, offloading user and the end-user as a game. An algorithm has been developed to determine the Nash Equilibrium solution of the game which maximizes the utilities of all the parties. Simulation studies conducted using H.265 encoded multimedia data indicate a significance raise in end-user QoE and decrease in network congestion.**

***Index Terms*—Quality of Experience (QoE), Best Response Game, Network Economics, D2D Multimedia Communication.**

I. Introduction

The Cisco Visual Networking Index predicts the global IP traffic to reach 4.8 ZB per year by 2022. Of which, IP videos alone would contribute to 82 % of traffic and customer video-on-demand (VoD) traffic is projected to double between 2018 and 2022 [1]. This explosive growth in the market has mandated mobile network operators and content providers to seek new paradigms to reform the communication services in terms of providing Quality of Service (QoS) and improving revenue. One such prospective paradigm is for the base station to delegate the network load to user equipment in the network by leveraging cached multimedia content and promoting Device-to-Device (D2D) communication. D2D communication has a potential to improve throughput, energy efficiency, delay, and fairness [2]. However, there are several challenges lying ahead in terms of incentivizing users to offload content, promoting end user (EU) to scavenge data from the offloading user (OU) and boosting the revenue of the wireless carrier (WC). The aforementioned issues are jointly discussed in this paper.

Quality of Experience (QoE) of the EU has become an indispensable part of resource allocation in wireless systems. Researchers in the past have proposed several numerical models that are built upon rate-distortion and power-distortion. In this paper, we adopt the three-dimension resource allocation model [3] by incorporating network economics in wireless multimedia resource scheduling. By doing so, in an effort to maximize their utility, the EU is fostered to scavenge data from OU who vends high-quality multimedia at a lower price.

Mobile data offloading is the use of complementary network technologies for delivering data originally targeted for cellular networks [4]. For instance, a popular video recently uploaded to the internet could go viral and cause congestion in the entire mobile network infrastructure. These videos could be potentially cached and sold to users in vicinity, rather than retrieving the content repeatedly from the server. The benefits provided by the OUs are two-fold. From the WCs perspective, users can download content from offloading devices to reduce network traffic and from the EUs perspective, the QoE of the user is enhanced as the packet delivery time and jitter goes down while the overall application level throughput is improved [5]. The challenge OU is correctly determine the selling price for the cached multimedia content. If the selling price is too high, the EU would prefer to get the content from the WC through mobile network directly and if the price is low, the OU would lose money and resources. In this paper, we provide an optimal pricing strategy which maximizes the revenue of the OUs.

Wireless carriers are parties who own or lease the mobile network infrastructure and their primary responsibility is to provide QoS to the EUs by allocating resources and prioritizing network traffic. In this paper, we propose a protocol where the OUs in the network announce the catalogue of cached multimedia content to the WC. When the WC receives a request for the same content from other EUs, they set-up a D2D connection between the OU and EU for a nominal charge. The requests for multimedia contents that are not available with the OU are fetched from the content provider and is directly fulfilled by the WC.

Fig. 1 shows the four-party interaction between the content provider, WC, OU and EU in next generation wireless multimedia communications. The users in the mobile network who are connected to complementary network technology such as IEEE 802.16 WiMAX, IEEE 802.11 Wi-Fi, Femtocells, etc. can pre-fetch, encode and store a set of popular media files from the content providers to serve as an offloaded user. WC is responsible for learning the list of contents cached by OU and setting up the D2D connection among the OU and EU.

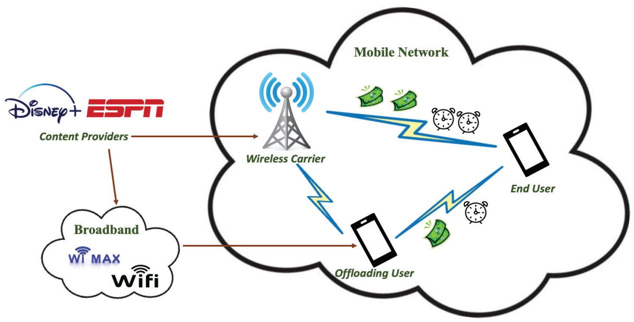

Fig. 1. Next-generation four party interaction for wireless multimedia communications.

Mobile data offloading is widely studied in the wireless communication field. However, most of the existing research can be broadly classified into infrastructure-assisted and infrastructure-free for implementation [6]. From the point of incentivizing the offloading user, benefit sharing [7] and unilateral benefit maximization [8] schemes have been proposed. These schemes benefit only the OU and do provide any direct benefit to WC. Therefore, WC starts behaving selfishly which in-turn affects the revenue of the OU.

Several studies in the past demonstrate how QoE of the user can be improved by incorporating economics. Pricing QoE-based multimedia resource allocation model for wireless relay communication [9], joint profit-maximization of wireless carrier and content provider [10] and incentivized caching [11] have been studied. In this work, we investigate the impact of PaaR on wireless next-generation video services model.

II. System Model

In this section, we illustrate our system model and formulate the utility maximization problem. The multimedia content available with the WC and OU are encoded using High Efficiency Video Coding (HEVC), also known as H.265 encoding. This encoding technique converts the video sequence into small frames (I, P and B) called Group of Picture (GOP) with unequal importance. For instance, the multimedia stream with just I frames will have high multimedia quality gain but the size of the stream would be relatively large. An alternate stream comprising of I, P and B frames will be smaller in size and offer much lesser multimedia quality gain. Several combinations of these frames for a particular video sequence is available with WC and OU. Since WC and OU have a common goal of maximizing their profit, they are jointly considered as one player in this research work. The interplay between the WC-OU and EU is illustrated in Fig. 2.

A. Utility of End User

The mobile users have diverse multimedia demands and are constantly striving to achieve high multimedia QoE at a lower cost. In this work, we propose a parameterized comprehensive QoE model which considers users personal preference for the multimedia content, the packet loss ratio and multimedia quality gain as shown in the equation below.

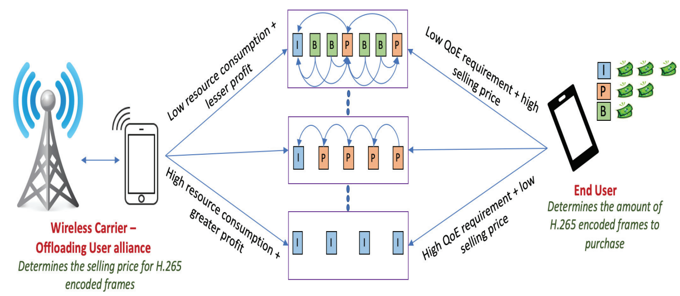

Fig. 2. Profit-driven system model leveraging offloaded multimedia

$$QoE = \frac{a_1}{1 + e^{-a_2\left(\sum_{j=1}^{M} q_j l_j \prod_{k\in\pi_j}(1-P_k)\right) + a_3 * \gamma + a_4}} \quad (1)$$

The PER $P_k = 1-(1-BER)^{l_k}$ is defined as the number of packets in error after forward error correction divided by the total number of received packets. P_k is related to the Bit Error Rate (BER) and the bit length of the corresponding packet l_k.

The multimedia quality contribution and the length of j^{th} frame (in bits) is given by q_j and l_j. The variables a_1, a_2, a_3 and a_4 are positive system parameters used to fine-tune the QoE model and γ is the EUs personal content preference. Consideration of multimedia content preference in the QoE model allows the EU to pay less for not-so-important videos (e.g. lyric videos, cooking videos) and achieve much higher experience while watching high-preference content (e.g. FIFA world cup finals, super bowl).

Since the OUs are closer to EU than the WC, the user can achieve higher multimedia QoE by purchasing data from OU as the packet loss ratio is proportional to the communication distance. Therefore, the EU first purchase the multimedia content available with the OU and the remaining content (if any) from the WC. Let M denote the set of multimedia frames requested by the EU and x denote the number of packets in the PG purchased directly from the offloading user. The multimedia quality and cost-per bit of the frames to be delivered by the OU to EU is denoted by q_{uo} and y_{uo} respectively (u: end user; o: offloading user). Similarly, the multimedia quality and cost-per bit of the frames to be delivered by the WC to EU is denoted by q_{uw} and y_{uw} respectively (u: end user; w: wireless carrier). Thus, QoE of EU in equation (1) can be rewritten as equation (2).

Let ψ_{user} denote the cost paid by the EU to the WC and OU for their service and is proportional to the amount of data they transmit. It can be modeled as product of the cost per bit of data transmitted y_j and the amount of multimedia transaction bits l_j.

$$\psi_{user} = \sum_{j=1}^{x} y_{uo_j} l_j + \sum_{j=x+1}^{M} y_{uw_j} l_j \quad (3)$$

The overall utility of the EU can be defined as the QoE achieved subtracted by the financial cost paid to WC-OU and

$$QoE = \frac{a_1}{1 + e^{-a_2\left(\sum_{j=1}^{x} q_{uo_j} l_j \prod_{k\in\pi_j}(1-P_k) + \sum_{j=x+1}^{M} q_{uw_j} l_j \prod_{k\in\pi_j(1-P_k)}\right) + a_3\gamma + a_4}} \tag{2}$$

is shown in the equation (4) below. The objective of the EU is to find the find the right amount of multimedia bits to purchase subjected to the GOP length constraint $l_{min} < l_j < l_{max}$ that would maximize the overall utility.

$$U_{user} = QoE - \psi_{user} \tag{4}$$

$$st.\ U_{user} \geq 0$$

B. Utility of the Offloading User and Wireless Carrier

The OUs cache popular contents purchased from WC or directly from content provider through an alternative network connection. In our protocol, the WC adjusts the commission fee it charges the OU for setting up D2D communication. The commission charge should be low enough to give the OUS enough marginal profits. In practice, the commission rate $y_o w$ (o: offloading user; w: wireless carrier) could be a small percentage of the offloading rate.

$$y_{ow} = \varepsilon y_{uo} \tag{5}$$

Let ψ_{ofld} denote the expenditure of the OU and can be represented as summation of offloading cost spend on the communication resource and fee charged by the WC.

$$\psi_{ofld} = \sum_{j=1}^{x} r_{ou} l_j + \sum_{j=1}^{x} y_{ow_j} l_j \tag{6}$$

where r_{ou} denotes per bit cost of resource consumption incurred for OU to cache multimedia data. The overall utility of the OU is the income from the EU subtracted by the ψ_{ofld}.

$$U_{ofld} = \sum_{j=1}^{x} y_{uo_j} l_j - \sum_{j=1}^{x} r_{ou} l_j - \sum_{j=1}^{x} y_{ow_j} l_j \tag{7}$$

Apart from setting up the D2D communication, WC is also responsible for transmitting the video contents which is not available with the OUs to the EU. The overall utility of the wireless carrier it two-fold and it is the summation of total commission paid by the OU and the profit incurred from the downlink transmission to the EU.

$$U_{wc} = \sum_{j=1}^{x} \varepsilon y_{uo_j} l_j + \sum_{j=1+1}^{M} \tau y_{uw_j} l_j - r_{\mathrm{wc}} l_j \tag{8}$$

where r_{wc} denotes per bit cost of resource consumption incurred for the WC. ε and τ are small percentage values for offloading rate and multimedia service rate respectively.

C. Problem Formulation

With an intent to reduce the network congestion, the WC partially delegate their role to the OU, and by doing so, allows the OU to increase their revenue. Since both WC and OU benefit from one another, they are cooperative in nature and so their utilities are jointly considered, and their net profit is maximized. The transmission side utility $U_{ofld+wc}$ can be represented as a weighted combination of their individual utility definition.

$$U_{ofld+wc} = w * U_{ofld} + (1-w) * U_{wc} \tag{9}$$

The weight w in the utility equation is proportional to the quantity of data transmitted by each party with respect to the total data requested by the EU and can be described as $w = \frac{x}{M}$. The joint utility shown in equation (9) above can be maximized if the user purchases all available data from the OU and then buy the remaining data from WC. Therefore, the game is set up between the OU and EU. The optimization of the OU is set the optimal cost per bit of multimedia data that would maximize the utility equation shown below.

$$U_{ofld} = \sum_{j=1}^{x} y_{uo_j} l_j - \left(\sum_{j=1}^{x} \left(\mathrm{r_{ou}} + \varepsilon y_{uo_j}\right) l_j \right) \tag{10}$$

$$st.\ U_{ofld} \geq 0 \quad and \quad U_{ofld+wc} \geq 0$$

III. Best Response Game

In this section, we first normalize the PG level QoE-driven price setting to reduce the number of adjustable parameters. The OU is constantly trying to find the per-bit price y_{uo_j} for each packet that would obtain the optimal revenue. However, it would be practically infeasible for a large amount of multimedia packets within a user flow to be priced bit-by-bit. Therefore, we introduce Y as the normalized base price, i.e. the unit quality gain price for each bit. Let $\pi_{j'}$ denote the set of packets whose successful decoding depends upon packet j and the relationship between the per-bit price and normalized base price can be represented as

$$Y = \frac{y_{uo_j}}{\sum_{k\in\pi_{j'}} q_k} \tag{11}$$

The optimal multimedia flow truncation point for the EU is to find the amount of multimedia bits $\sum_l$. However, it is unreasonable and realistically impossible for the EU to demand each and every multimedia frame to be encoded and transmitted at the optimal length l_j. Therefore, optimality for the utility of EU subjected to total multimedia constraint $\sum_{j=1}^{m} l_j \leq L$ can be achieved by taking an equality condition.

$$\sum_{j=1}^{m} l_j = L \tag{12}$$

Normalizing the utility equations allow the EU and WC-OU to play with the total length and cost of PG as a whole respectively. The normalized utility equations are presented as equations (13) and (14) .

Once we have the normalized equations, there are multiple ways to obtain the game equilibrium, depending on whether the utility function is concave or not. If the utility functions are concave, the maximum stable point could be attained by getting the first order derivative of partys utility functions. Since it is difficult to prove the concavity of the utility functions in our problem, a generalized best response approach is developed which produces the most favorable outcome for a player when other players choices of strategies are known.

A players best response is a strategy or a set of strategies that produces the greatest payoff given all the players strategies [12] [14]. There are three scenarios as a result of this interaction: 1) Existence of a unique strategy that maximizes the utility of both players, 2) Multiple strategies that maximize their utility, 3) No unique strategy exists. The solutions of games that result in a unique strategy (case 1 and 2), also known as Pure Strategy Nash Equilibrium (PSNE) are discussed in the subsection A. In most cases, there exists no unique strategy (case 3) which yield best utility. The key to achieve equilibrium relies upon mixing the strategies with the right probability that would simultaneously maximize the players utilities. The solution is called as Mixed Strategy Nash Equilibrium (MSNE) and is discussed in subsection B.

A. *Pure Strategy Nash Equilibrium Analysis*

The PSNE solution yields the best outcome to both EU and OU and has no-regrets property - as deviating from that strategy does not yield better outcomes to either players [12]. For the sake of illustration, we assume that the OU has cached multimedia content in three different encoded formats. The first encoded GOP has just the I frames ($IIIII$), the second GOP has I & P frames ($IPIPI$), while the third GOP has I, P & B frames ($IPBIBPB$). The utilities of the EU and OU calculated based on the utility equations (14) and (15) for some sample values of GOP size L_i and cost Y_j are tabulated below.

TABLE I
UTILITY MATRIX FOR PSNE ANALYSIS

	$L_1 = 1 * 10^9$ $Iframes$	$L_2 = 1 * 10^7$ $IPframes$	$L_3 = 1 * 10^5$ $IPBframes$
$Y_1 = 3$	**(14, 6)**	(1, 5)	(8, 4)
$Y_2 = 2$	(5, 2)	**(5,5)**	(7, 3)
$Y_3 = 1$	(0, 10)	(3, 9)	(9, 0)

The PSNE solution of the above three-dimensional table can be obtained through Iterated Elimination of Strictly Dominating Strategies (IESDS) [12]. IESDS is a three-step process which simplifies the game based on the strategies the players will never play and yields one or more PSNE for the players.

Step 1: Best response analysis from EUs perspective

Assuming the strategy of OU as given, we identify the best response for that strategy and underline the corresponding utility in the table. In table above, assuming OU declares the price as $Y_1 = 3$. Then the responses of EU: $L1$, $L2$ and $L3$ yield a utility of 6,5 and 4 respectively. Since $L1$ yields the highest payoff, it is the best response of the EU and so we underline the utility value 6. Similarly, we determine best response for strategies Y_2 and Y_3 as L_2 and L_1 respectively.

Step 2: Best response analysis from OUs perspective

The procedure in step 1 is repeated by assuming the strategy of EU as given. In step 1, we analyzed one row at a time, now we analyze one column at a time. By performing the analysis, we determine the best response for L_1, L_2 and L_3 as Y_1, Y_2 and Y_3 respectively and underline corresponding utilities.

Step 3: Determining the PSNE solution

Definition I: *PSNE of the best response game is the strategy set* $\{L^*, Y^*\}$ *that produces the greatest payoff given all other game strategies, such that* $U_{user}(L^*, Y^*) > U_{user}(L_i, Y^*)$ *for all strategies* L_i *of the EU and* $U_{ofld}(L^*, Y^*) > U_{ofld}(L^*, Y_j)$ *for all strategies* Y_j *of the OU respectively.*

As per Definition I, the mutual best responses of both the players yield the PSNE solution. In other words, we look for cells in the table where both the player utilities are underlined. For the table I above, we have two cells where both the unities are marked as best response. Therefore, $\{L_1, Y_1\}$ and $\{L_2, Y_2\}$ are the PSNE solution and the players can play either strategy to maximize their payoffs.

B. *Mixed Strategy Nash Equilibrium Analysis*

In most scenarios, we find no mutual best responses on applying IESDS. In absence of PSNE solution, MSNE solution can be derived as a set of probabilities with which the players should mix their strategies that the other player is indifferent between his or her pure strategies. Consider the table II below with a different set of utilities.

TABLE II
UTILITY MATRIX FOR MSNE ANALYSIS

	$L_1 = 1 * 10^9$ $Iframes$	$L_2 = 1 * 10^7$ $IPframes$	$L_3 = 1 * 10^5$ $IPBframes$
$Y_1 = 3$	(13, 13)	(10, 14)	(10, 10)
$Y_2 = 2$	(12, 15)	(11, 11)	(12, 10)
$Y_3 = 1$	(5, 0)	(5, 0)	(10, 10)

Step 1: Apply IESDS to reduce the utility matrix

From the above table, it can be observed that the price $Y_2 = 2$ strictly dominates $Y_3 = 1$ for all values of L. Therefore, the OU would get a better payoff by selecting the price Y_2 and would never declare Y_3. So, we can remove the row Y_3 from the table. Similarly L_2 strictly dominates L_3 and column L_3 can be removed. The 3D table is now reduced to 2D as shown below and the best responses of EU and OU for all strategies have been identified and underlined.

TABLE III
IESDS BASED REDUCED UTILITY MATRIX FOR MSNE ANALYSIS

	$L_1 = 1 * 10^9$ $Iframes$	$L_2 = 1 * 10^7$ $IPframes$
$Y_1 = 3$	(13, 13)	(10, 14)
$Y_2 = 2$	(12, 15)	(11, 11)

Step 2: Determination of Mixing Probabilities

Definition II: *MSNE of the best response game is the set of probabilities* $\vec{\mu} = (\mu_1, \mu_2 ...)$ *and* $\vec{\eta} = (\eta_1, \eta_2 ...)$ *one for EU and one for OU such that the players get the same payoff*

$$U_{user} = \frac{a_1}{1 + e^{-a_2 L\left(\sum_{j=1}^{x} q_{uo_j} \prod_{k\in\pi_j}(1-P_k) + \sum_{j=x+1}^{M} q_{uw_j} \prod_{k\in\pi_j}(1-P_k)\right) + a_3\gamma + a_4}} - YL \sum_{k\in\pi_{j'}} q_k \tag{13}$$

$$U_{ofld} = L * (1 - (\mathrm{r_{ou}} + \varepsilon)) * Y * \sum_{k\in\pi_{j'}} q_k \tag{14}$$

(utility gain) when they play a strategy with probability μ_i *and* η_i *respectively.*

We define μ_1 and μ_2 as the probabilities for EU to choose L_1 and L_2 respectively. Also, we define that η_1 and η_2 as set of the probabilities for OU to choose Y_1 and Y_2. According to the Definition II, OU should get the same utility for both prices Y_1 & Y_2 regardless of EUs mixing strategy and EU should get same utility for playing L_1 & L_2 regardless of OUs mixing strategy. Therefore we have,

$$13 * \mu_1 + 10 * \mu_2 = 12 * \mu_1 + 11 * \mu_2 \tag{15}$$

$$13 * \eta_1 + 15 * \eta_2 = 14 * \eta_1 + 11 * \eta_2 \tag{16}$$

Algorithm 1 Best Response Game Algorithm

1) **Functionality:**
   The algorithm first looks for PSNE solution $\{L^*, Y^*\}$ that yield maximum payoff to OU and EU. When PSNE solution does not exist, it returns a probability vectors $\vec{\mu} = (\mu_1, \mu_2 ...)$ and $\vec{\eta} = (\eta_1, \eta_2 ...)$ using which the players should mix strategies to achieve best payoff.
2) **Initialization:**
   - 2.1. Initialize the system parameters a_1, a_2, a_3 and a_4.
   - 2.2. Define channel and GOP characteristics: bit error rate BER, multimedia quality q_j and their corresponding lengths l_j
   - 2.3. Set the user preference value for given multimedia content $\gamma \in [0, 1]$ and define other cost parameters ε, τ, r_{ou}.
3) **Iterations:**
   - 3.1. Define GOP length $L = linespace[0, L_{max}, N]$ and GOP price $Y = linespace[0, Y_{max}, N]$
   - 3.2. Compute the best response from EU's perspective
     - 3.2.1 For i=1:N : $Y_{temp} = Y_i$
     - 3.2.2 For j=1:N : Set $L_{temp} = L_j$ & Compute EU's utility.
     - 3.2.3 Mark the length L_{temp} that yields highest payoff as best response length for Y_i's strategy.
   - 3.3. Repeat the step 3.2 from OU's perspective to determine the best response prices Y_i for L_i's strategy.
   - 3.4. Pick out the mutual best responses for utilities table and output as PSNE Solution. If multiple solutions exist, the players can agree to play either of the strategies.
   - 3.5. IF NO mutual best response exist:
     - 3.5.1 Initialize the probability vectors $\vec{\mu} = \vec{0}, \vec{\eta} = \vec{0}$.
     - 3.2.2 Generate N equations from the utility matrix using Definition II as illustrated in equations (16) and (17).
     - 3.2.3 Solve the linear equations to obtain $\vec{\mu}, \vec{\eta}$.
     - 3.2.4 The players achieve the MSNE solution by mixing their strategies with probabilities $\vec{\mu}$ and $\vec{\eta}$.

Since probabilities $\sum \mu_i = \sum \eta_j = 1$, we have 4 equations and 4 unknowns, and so, we can solve the equations to determine mixing probabilities that yield MSNE solution. For the example above, we determine the mixing probabilities for EU $\{\mu_1 = 0.5,\ \mu_2 = 0.5\}$ and OU $\{\eta_1 = 4/5,\ \eta_2 = 1/5\}$ as MSNE solution of the game.

In reality, the dimension of the utilities table is n x n and so we need a computationally sound algorithm to determine the PSNE/MSNE solutions on-the-fly. We have presented an algorithm that can be built into the network to determine the Nash Equilibrium solution as Algorithm I.

IV. Simulation Study

In this section, we evaluate the performance of the proposed profit-driven traffic delegation protocol. The multimedia data used in this simulation is obtained using MPEG-4 H.265 codec. The ”Foreman” standard video sequence has been encoded into a GOP with I frames $(IIIII)$ for the independent data set and with I and P frames $(IPIPI)$ for forward-dependent set. Inter-dependent data set has been obtained by encoding the GOP with I, P and B frames $(IPBIPB)$. The q_j and l_j values are determined from these data sets. The systems parameters used to fine tune the QoE model $a1 \sim a4$ were chosen as 3.8, 4.9, 3.6 and 3.5 respectively based on video quality tests conducted by K. Yamagishi, et.al [12]. The bit error rate (BER) was set at 1e-6. The user personal preference γ was set at 0.5 and the variable cost parameters r_{ou}, ε and τ are 0.1, 1 and 4 respectively.

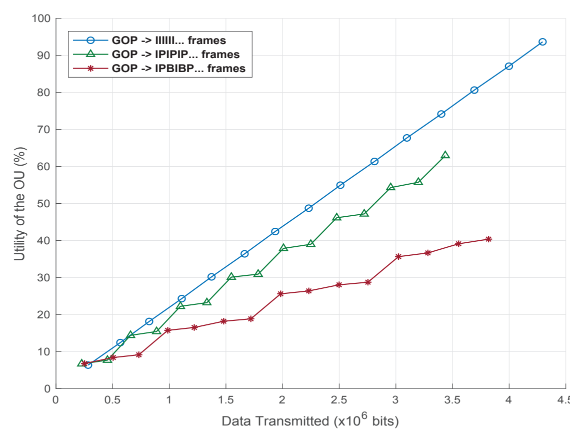

Fig. 3. Utility of the OU for various GOPs.

The utility of the OU as shown in equation (11) is compared against the amount of data transmitted to the EU for the three sets of GOP configurations in Fig. 3. It can be observed that the GOP with just I frames yield the maximum payoff while the GOP with I, P and B frames yield the least profit. The irregular shape in the utility graph depicts the unequal contribution of I, P and B frames to the payoff.

The objective of the proposed protocol is to promote the EU's to scavenge data from OU and WC to delegate their service requests to OU by setting up D2D communication. From Fig. 4 (left), it can be observed that EU's achieve higher multimedia quality gain while buying data from OU and so it can be concluded that, whenever possible, EU would prefer to buy data from OU. Similarly Fig 4 (right), illustrates that WC would make more money by allowing OU to fulfill the multimedia requirements of EU. This is because the protocol allows WC to make free-money in terms of commission fee by delegating the traffic. On the contrary, the WC would have to spend on resources and transmission charges if they handle requests by themselves. Therefore, WC's are motivated to aggressively promote D2D communication. From Figures 3 and 4., it can be established that the proposed protocol benefits all parties of the game simultaneously.

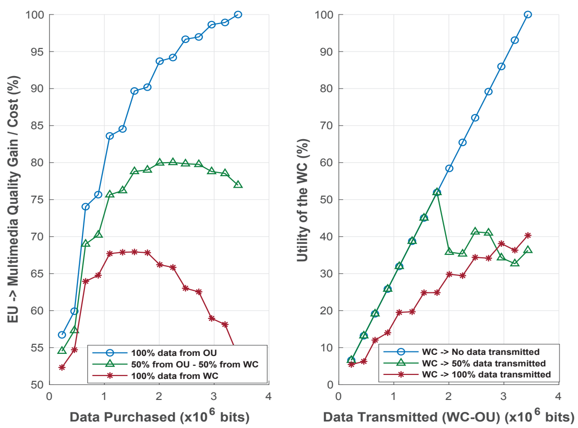

Fig. 4. Multimedia quality gain of EU for various transmission strategies and utility of WC with respect to the amount of data transmitted.

The impact of channel conditions on the various GOPs and utilities of players are illustrated in Fig. 5. The utility of the EU decreases as the BER increases due to the interdependence nature of the frames. If one of the frame in a GOP is corrupted, the subsequent frames cannot be decoded, thus reducing the overall utility significantly. The OU is greatly benefited by the proposed protocol as the EU needs to pay more money to get service if they channel condition deteriorates.

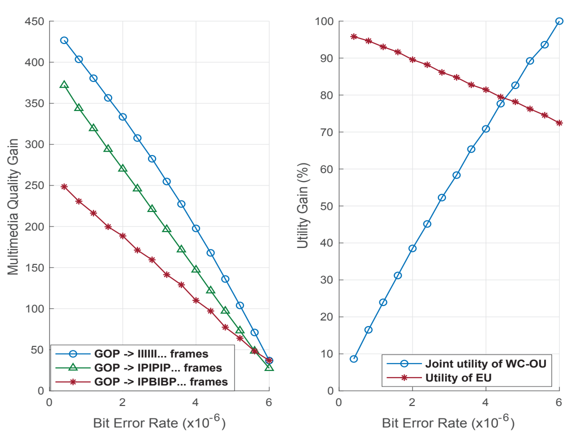

Fig. 5. Impact of BER on the multimedia quality gain and player utilities.

V. Conclusion

A profit-driven traffic delegation protocol enabling multimedia offloading and D2D communication has been proposed in this paper. Incentivizing OUs and motivating mobile users to buy multimedia from OUs have been enormous challenges for service QoE. By introducing profit in multimedia offloading communication, EUs are able to scavenge cached multimedia data directly from the OU. Such game-theoretic offloading protocol also benefits the WC as they are able to not just reduce the network load, but also achieve greater payoff by charging the OU a nominal commission fee. PSNE and MSNE solutions for the best response game have been derived to identify the optimal cost charged for the GOPs by the OU and amount of data to be purchased by the EU. Simulation results indicate that both EU and WC both achieve higher utilities as the amount of data sold by OU increases.

VI. Acknowledgement

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