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Incentivize Non-Orthogonal Multiple Access In Wireless Multimedia Communications

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***Abstract*— To address the explosive growth of number of mobile users in future generations of wireless networks, Non-Orthogonal Multiple Access (NOMA) has received significant attention. In this work, we propose an incentive driven content shifting framework to reward users which push multimedia data content from an Orthogonal Multiple Access (OMA) link to a NOMA link. The objective of the framework is to benefit both the user and the base station by simultaneously improving the user's Quality of Experience (QoE) and the base station's profits. The key issue of strategically splitting the data among the available NOMA and OMA links are studied to attain the best possible service. According to our study, OMA could be leveraged for transmission of important frames while NOMA is suitable for frames with lesser importance. Using game theoretic methods, we develop a method to attain the Nash Equilibrium of the solution. Simulation studies showcase the merits and potentials of the proposed incentive mechanism to encourage users transmitting certain data through NOMA links.**

Index Terms*—*Non-Orthogonal Multiple Access (NOMA), Game Theory, Economic Pricing.

I. Introduction

Multiple access is essential in wireless networks to allow multiple mobile users to simultaneously share a finite amount of radio spectrum. Orthogonal Frequency Division Multiple Access (OFDMA) allots different sub-band frequencies, that are orthogonal to one another, to different users to access the network. The unparalleled increase in the number of mobile devices/users and their traffic require revolutionary technologies in cellular communications to cope with these requirements [1]. Non-Orthogonal Multiple-Access (NOMA) has been studied extensively in academia and recognized as one of the key-enabling technologies to fulfill the ambitious user data demands of beyond 5G networks [2].

In contrast to the family of conventional OFDMA or more general Orthogonal Multiple-Access (OMA) schemes, the key distinguishing feature of NOMA is to support a higher number of users than the number of orthogonal resource slots with the aid of non-orthogonal resource allocation [3]. Although NOMA has several advantages over OMA, it is possible to observe interference from some other users due of wireless channel sharing. Furthermore, in a multi-resource block NOMA network, Inter-Block Interference (IBI) becomes a major challenge as it can negatively affect the performance of mobile devices [4]. Therefore, researchers are proposing a hybrid NOMA-OMA multiple access technology for the next generation wireless communications [5].

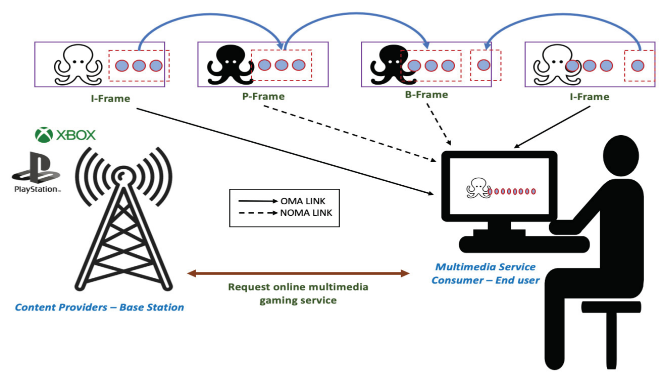

Fig. 1. Distribution of interactive multimedia traffic over a hybrid NOMA-OMA network.

Mobile devices have been generating over 60% of all Internet traffic, and the most significant proportion of this traffic comes from multimedia applications that involve streaming and interactive gaming [6]. Typically, the multimedia data are compressed using a suitable encoding technique and then transmitted over the wireless channel. For example, High Efficiency Video Coding (HEVC), also known as H.265 is the a popular video compression standard in which the content is broken down into I (Inter frame), P (forward predicted frames) and B (bi-directional predicted frames). The I-frames are the important frames and can be transmitted using the OMA link in a hybrid NOMA-OMA network to combat IBI. The P-frame and B-frame are lower quality and smaller frames with dependency on I-frames and can be transmitted using the NOMA link. The Fig. 1 illustrates an example of wireless multimedia communication in a hybrid NOMA-OMA network.

The hybrid NOMA-OMA network allows the base station to support higher number of users simultaneously and increase their revenue. The base station prefers the user to shift all the data to NOMA resource blocks to further improve the network capacity. However, the user is reluctant to compromise the Quality of Experience (QoE) by moving content from OMA

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to NOMA, due to the interference and the thus bit and packet errors impact the multimedia service quality. The key idea of this research is to introduce incentive in the pricing framework to promote users to shift content from OMA to NOMA. The philosophy of the pricing framework is to allow the base station to price the resource blocks based on noise, interference, and the available power. The base station also sets the prices of I, P and B frames unequally. The objective of the user is to determine which resource block to occupy, and amount of I, P and B frames to purchase, to maximize its utility.

There has been rapid evolution in pricing practices among the service providers to meet the QoE needs of the customers. Smart data pricing [7] and smart media pricing [8] have been proposed to include price as a resource in measuring the QoE subjectively. Strategic pricing of NOMA resources is an open-implementation challenge and is being widely investigated. Price-Based Resource Allocation in NOMA System with Hardware Impairments [9], Interference driven pricing for NOMA Fog networks [10], and Game theory driven pricing metric for cognitive radio NOMA [11] are some of the notable works. In our previous work, we proposed revenue maximization approaches for NOMA communication called NOMA Pricing [12-13]. As an extension, we are proposing a shift driven pricing model for NOMA-OMA hybrid network in this work.

The rest of the manuscript is organized as follows. In section II, we elaborate on the system model and discuss the problem formulations. The translation of the problem into a game theoretic problem and steps to derive the Nash equilibrium solution are shown in section III. An algorithm to solve the said game theory problem is also provided. Simulation results are showcased in section IV and conclusions are provided in section V.

II. System Model

The interaction between the gaming user and the base station in a hybrid NOMA-OMA network is shown in Fig.1. In a hybrid network, we envision the user to purchase partial data leveraging OMA and the rest of the data over NOMA. A meaningful split would be purchasing the content with higher level of importance over OMA to reduce the impact of inter block interference and retransmission delay. The content with lower importance could be purchased over NOMA. Such a split is generic and does not necessarily yield best utility to either the user or the base station.

The resources available with the base station are divided into NOMA and OMA blocks across time and frequency. In the proposed model, the base station dynamically decides the per bit transmission cost y_x for each resource block in the network. The cost on the user for occupying a single OMA block would be significantly higher because it is a dedicated link to one user. The NOMA block cost is split among all the users and so the cost per bit is smaller. This coupled with I frames being charged higher than P and B frames makes the user want to shift some of the content from OMA to NOMA blocks. Such a shift would also benefit the base station by increasing the network capacity. The proposed system model is shown in Fig. 2.

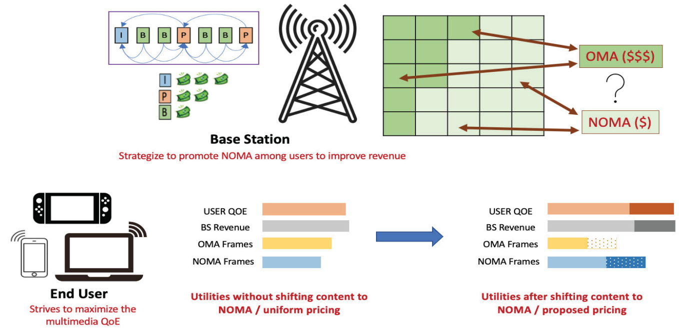

Fig. 2. System model for spectrum allocation in QoE centric wireless multimedia communications

A. Utility Definition of the Base Station

The base station allocates different prices for each of the resource blocks. For the sake of simplicity, we assume all the OMA blocks are priced at y_{oma} and the all the NOMA blocks are priced equally at y_{noma}. y_{oma} and y_{noma} denote the OMA and NOMA resource block prices (i.e., the per-bit price to transfer multimedia content), respectively. Traffic congestion and interference typically could be avoided by choosing higher priced OMA resource blocks since it is exclusively allocated to the user, and the base station may also allocate extra communication resource to accommodate the QoE of OMA traffic at higher costs. The revenue of the base station can be presented in three portions: the revenue from scheduled NOMA service at the price of y_{noma}, the revenue from scheduled OMA service at the price y_{oma}, and the additional revenue by encouraging OMA service to shift to NOMA service at the price $y_{oma2noma}$. For the user to be willing to shift the service from oma2noma,

$$y_{oma2noma} = y_{noma} \tag{1}$$

Typically, we assume y_{oma} is fixed and y_{noma} can be dynamically adjusted. Since the NOMA resource blocks cost are shared among all users in the resource block $y_{oma} > y_{noma}$. Let C_{oma} and C_{noma} denote the per-bit operational communication cost for occupying the channel at OMA and NOMA blocks, respectively. The total number of frames purchased by the user is given by l and the set of total packets requested is given by S. S_{noma} denotes the set of packets transmitted using NOMA blocks, S_{oma} denotes the set of packets in OMA blocks, and $S_{oma2noma}$ denotes the set of packets which are supposed to be transmitted in OMA block but shifted to NOMA blocks to save cost. The total $oma2noma$ packets plus the packets transferred in NOMA and OMA blocks are the total traffic of one user.

$$S = S_{oma} \cup S_{oma2noma} \cup S_{noma} = \sum l \tag{2}$$

Let i denote the index of user and j denote the index of multimedia packet. The utility function of the base station will be presented as the total revenue from all users subtracted by the communication costs incurred in OMA and NOMA blocks.

$$\begin{aligned} U_{BS} = y_{noma} \sum l_j|_{j\{S_{noma} \cup \ S_{noma}\}} \\ + y_{oma} \sum l_j \Big|_{j\{s_{oma}\}} \\ - C_{noma} \sum l_j \Big|_{j\{s_{noma} \cup s_{oma2noma}\}} \\ - C_{oma} \sum l_j \Big|_{j\{s_{oma}\}} \\ st. \ U_{BS} \geq 0 \end{aligned} \tag{3}$$

The optimization problem for the base station is to determine the cost of the NOMA resource block y_{noma} that would increase $S_{oma2noma}$ and yield the best utility.

B. Utility Definition of the Mobile User

The mobile user requests multimedia data S_{oma} and S_{noma} through OMA and NOMA links respectively from the base station. The QoE achieved by the user can be mathematically modelled as a parameterized comprehensive QoE model which considers users personal preference for the multimedia content γ, the packet error rate PER and multimedia quality gain q_j as shown in the equation below.

$$QoE = \frac{a_1}{1 + e^{-a_2 \sum_{j=1}^{M} q_j \prod_{k \epsilon \pi j}(1-PER) + a_3\gamma + a_4}} \tag{4}$$

The multimedia quality gain q_j can be defined as the amount of distortion reduction if this packet is received and decoded. PER is the packet error rate of the k^{th} packet, π is the decoding dependency set of the packet, and M is the total numbers of packets purchased by the user. The system parameters were chosen as $a_1 = 3.8$, $a_2 = 4.9$, $a_3 = 3.6$ and $a_4 = 3.5$ in research [14] based on empirical studies. These parameters can be re-adjusted and fine-tuned during implementation. The packet error rate PER is a function of the data length and the bit error rate and can be represented as follows

$$PER = 1 - (1 - BER)^{l_k} \tag{5}$$

The BER denotes the bit error rate in the NOMA resource blocks and can be estimated from the desirable multimedia packet Signal to Noise Ratio (SNR) [13]. P_t and h denote the power transmitted and Rayleigh fading channel gain between user and base station, respectively. The noise power in the communication channel is given by $R_s N_o$. The modulation constellation size is denoted by b.

$$\begin{aligned} & BER \\ & = \frac{2}{b}\left(1 - \frac{1}{2^{\frac{b}{2}}}\right) \text{ERFC}\left(\sqrt{\frac{3}{2(2^b-1)} \frac{P_t|h|^2}{\sum_{g=1}^{N-1} P_g|h_g|^2 + R_s N_0}}\right) \end{aligned} \tag{6}$$

The users closer to the base station than the end-user N in the NOMA resource block are represented by the set $g\{0, 1, N-1\}$. The set of users g introduce inter block interference to the end user's data. The user does not experience any interference from other users while purchasing data using OMA channel and so for OMA links,

$$\sum_{g=1}^{N-1} P_g \left|h_g\right|^2 = 0 \tag{7}$$

The overall utility of the user is defined as the QoE gain subtracted by the cost paid to the service provider. The user pays y_{noma} for per-bit of data transmitted over the NOMA link and y_{oma} for every bit of data transmitted using OMA. The utility definition for the user is shown down below.

$$\begin{aligned} U_{user} = QoE - y_{noma} \sum l_j \Big|_{j\{S_{noma} \cup s_{oma2noma}\}} \\ - y_{oma} \sum l_j \Big|_{j\{S_{\text{oma}}\}} \\ st. \ U_{user} \geq 0 \\ l_{min} < l_j < l_{max} \end{aligned} \tag{8}$$

The optimization problem for the user is to determine the total amount of data l_j to purchase and distribute among the OMA and NOMA links. The optimization is subjected to data length constraints where l_{min} and l_{max} represent minimum number of bits required for meaningful encoding of the multimedia data and the maximum number of bits that can be supported within a frame.

III. Nash Equilibrium Analysis

It is assumed that the base station and end user are both rational, selfish, and constantly strive to maximize their individual utility. Therefore, the focus of this section is to address the questions: *What is an optimal pricing strategy for the service provider to promote users to buy more NOMA data? How much data should the user shift to NOMA at a price set by the base station for the NOMA blocks?* Using game theoretic techniques, we show that the solution proposed exists in a Nash Equilibrium. Nash equilibrium of the game is defined as the set of strategies, one for user and one for the service provider such that both players have no incentive deviating from that strategy [16].

The total number of bits required to transmit the requested multimedia file is given by $L = \sum l_j$. The frames that the user must purchase over the OMA link can therefore be obtained as

$$\sum l_j \Big|_{j\{S_{oma}\}} = L - \sum l_j \Big|_{j\{S_{noma} \cup S_{oma2noma}\}} \tag{9}$$

Therefore, the objective of the user can be simplified to determine the total number of NOMA bits to purchase for the price set by the base station. The remaining bits can then be purchased over NOMA. Similarly, we also assume that the base station would keep the cost of OMA resource block y_{oma}

fixed and adjusted y_{noma}. The profit maximization problem is formulated as a game, and we determine the Nash Equilibrium solution $\left\{y_{\text{noma}}^*, l_j^*\right\}$.

The two-stage Stackelberg game is a strategic game in economics in which the leader firm moves first and then the follower firms move sequentially. The interaction between the base station and user can best be modelled using Stackelberg game and then the solution can be derived using backward induction method [16]. However, the game requires the utility equations to be concave. Since it is difficult to prove concavity of the equations (3) and (8), we have derived the solution using generalized best response method.

The best response of a player is a strategy or a set of strategies that produces the greatest payoff given all the players strategies [15]. The best response is the strategy (or strategies) which produces the most favorable outcome for a player, taking other players' strategies as given. A two-dimensional table is created with discrete values in the acceptable range for service cost $\{y_{min}, y_{max}\}$ and data length $\{l_{min}, l_{max}\}$. The two-dimensional table is then populated by evaluating the equations (3) and (8).

Step 1: Best response game - users perspective

For all prices set by base station (all rows in the table), the user computes the best data length to purchase that yields the highest utility. By doing so, the user would pick exactly one cell in each row as their response for that price.

Step 2: Best response game - base station perspective

The procedure in step 1 is repeated for the base station. For all possible data length combinations available for the user (all columns in the table), the base station determines the best price that yields the highest utility. The base station therefore would choose exactly one cell in each column as the best response to that data length.

Step 3: Mutual best response - Nash Equilibrium

The mutual best response of the game can be defined using the definition below.

Definition 1: *Nash Equilibrium in a best response game is the strategy set $\left\{y_{noma}^*, l_j^*\right\}$ that produces the greatest payoff given all other game strategies, such that $U_{user}\left(y_{noma}^*, l_j^*\right) > U_{user}\left(y_{noma}^*, l_j\right)$ and $U_{BS}\left(y_{noma}^*, l_j^*\right) > U_{BS}\left(y_{noma}, l_j^*\right)$.*

In simpler words, we look for cells in the table which were mutually picked by the user (step 1) and the base station (step 2). These cells exist in Nash Equilibrium and becomes the solution for the game. Both the user and the base station can agree to use any of the available solution to achieve best utility. Both the players would not have any incentive to deviate from the strategy derived. As a special case, there might be a scenario with no mutually selected cells. In such a situation, the players would have to mix between two or more combinations of cells to determine the equilibrium called Mixed Strategy Nash Equilibrium. Both the scenarios have been presented with worked out examples in our previous work [17].

The mutual best response for problem was determined computationally as prescribed by the algorithm 1 below. The algorithm can be used an implementation reference for multimedia applications by fine tuning the system parameters $a1 \sim a4$. The two-dimensional searching table can be updated with the new values during sparse time periods between the multimedia transmission. The computation complexity and the latency between the data transmission can be reduced by determining the mutual best response directly by searching the table whenever the game needs to be performed.

Algorithm 1 Computation of mutual best response

1) **Setup:**
   - 1.1. Initialize the known parameters in the utility definitions.
   - 1.2. The optimal price range of the base station is divided into 500 intervals between y_{min} and y_{max}, and is given by u. Similarly, the data length range between l_{min} and l_{max} is divided into 500 segments and is denoted by v.
2) **Computations:**
   A utility matrix of size 500x500 is created with the prices as rows and data lengths as columns
   For: all rows in the table
      choose v: one data length that yields the highest utility for the user using equation (8)
   For: all columns in the table
      choose v: one price that yields the highest utility for the base station using equation (3)
   For: all rows in the table
      For: all columns in the table
         Look for all the mutual best responses cells in the table and declare them as Pure Strategy Nash Equilibrium (PSNE) solution. The user and BS can choose to adopt any of the available PSNE solutions.
3) **Results:** The optimal $\left\{y_{\text{noma}}^*, l_j^*\right\}$ is declared as the game solution and the corresponding utilities for the user U_{user} and base station U_{BS} are computed.

IV. Simulation Study

In this section, we evaluate the performance of the proposed profit-driven data shifting protocol. The multimedia data used in this simulation is obtained using MPEG-4 H.265 codec. The $Foreman$ standard video sequence and $NetflixPier-Seaside$ video were encoded into a Group of Pictures (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. We assume that the I frames will be transported over OMA links and less important P and B frames would be transmitted over NOMA channels in the NOMA+OMA environment. The key objective of our work is to strategic determine the data (I frames) that can be shifted from OMA to NOMA channel to achieve higher utilities.

The bit error rate (BER) was set at 1e-6. The user personal preference γ was set at 0.5 and the cost parameters C_{oma} and C_{noma} are set at 1 and 0.2 respectively. The break-even between the NOMA and OMA resource block happens when the base station caters 5 users in a NOMA block. The base station would be able to make more money in a NOMA resource block if the block is utilized by more than 5 users. The total number of users in the NOMA resource block was set to 8 with 4 users introducing interference to the users data. The modulation constellation size b was set to be 2.

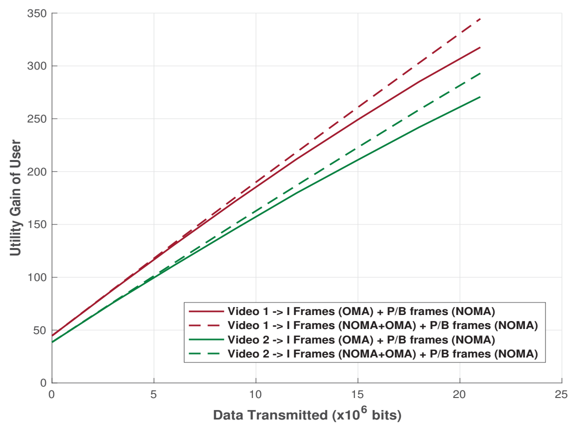

Fig. 3. Analysis: utility gain of the user.

The utility gain of the user has been evaluated using the equation (8) for two different video sequences. In Fig.3, the graphs in bold line denote the overall utility achieved without using the proposed pricing approach. All the I-frames were transmitted using the OMA link and remaining frames were transmitted using the NOMA link. For the curves with dashed lines, we used the game solution to determine the split. The total number of bits NOMA bits was determined using mutual best response game. All P and B frames, along with a portion of I frames contributed to the game solution y^*_{noma}. The remaining I frames were transmitted through the OMA link. From the Fig.3, it can be observed that the user is able to achieve higher utility by shifting some of the content to NOMA.

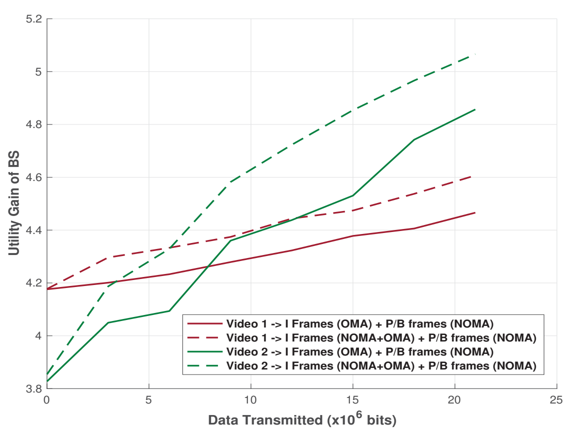

Fig. 4. Analysis: utility gain of the base station.

The Fig.4 demonstrates the utility gain of the base station, evaluated using the equation (3). For both the videos $Foreman$ and $NetflixPierSeaside$ used in the simulation, it can be observed that the proposed method yields higher utility to the base station. This is because the base station would be able to cater more users whenever the shift their content from OMA to NOMA resource blocks. The operating cost of NOMA resource blocks C_{noma} is cheaper than the operating cost of OMA resource blocks C_{oma}. Therefore, the shift of data from NOMA to OMA benefits the base station significantly.

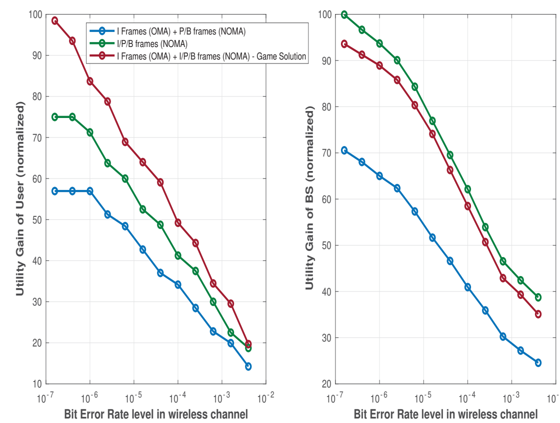

Fig. 5. Analysis of utilities under varying bit error rate levels

The Fig. 5. captures the utility gains of the user and base station versus the bit error rate of the wireless channel. The utility drops with increase in error rate and this behavior could be observed for both the user (5a. (left)) and the base station (5b. (right)). From Fig. 5b, it can be observed that the base station achieves highest profit when the user shifts all the data (I frames) from OMA to NOMA. This result shows that the base station prefers NOMA link over an OMA link, due to the improved spectral efficiency, higher cell-edge throughput, relaxed channel feedback, and low transmission latency. On contrary, the user does not achieve highest utility by shifting all the data NOMA. From Fig. 5a, it can be observed that the user greatly benefits from the combination of NOMA+OMA scheme. Since the user and base station have a bias towards different schemes, Nash Equilibrium solution has to be adhered to obtain mutual satisfaction.

V. Conclusion

The next-gen of wireless communications technologies has been envisioned to have hybrid multiple access network with OMA and NOMA options. In such a hybrid access network, the split-up of user's data among the NOMA and OMA block is an open research topic. In this work, we are proposing an incentive scheme to promote NOMA communications for mobile multimedia users. OMA could be leveraged for transmission of important video frames while NOMA is suitable for video frames with lesser importance. In this work, we present the utility definitions for both the base station and the user. The profit-driven interplay between the two parties was formulated as a game theory problem, and the Nash Equilibrium was attained in the solution. Simulation studies were carried out to evaluate the efficiency of the proposed framework for OMA-NOMA multimedia services. The results show that both the base station and the wireless user can achieve desirable utilities using the proposed NOMA incentive mechanism.

VI. Acknowledgement

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