

EEP2P: An Energy-Efficient and Economy-Efficient P2P Network Protocol

Ziqiao Zhou^{*¶}, Mengjun Xie^{+¶}, Ting Zhu[‡], Wei Xu^{*}, Ping Yi^{*},
Zhichuan Huang[‡], Qingquan Zhang[‡], Sheng Xiao[§]

^{*} Shanghai Jiao Tong University, China, [†] Binghamton University, USA

[‡] University of Maryland Baltimore County, USA, [§] Hunan University, China

[¶] Co-primary Authors

Abstract—Peer-To-Peer (P2P) file-sharing protocols have been widely used for distributing massive data over the Internet. To satisfy the requirement of P2P platforms, like BitTorrent, edge devices have to be powered on continuously to either download files or assist other peers to download files, which could lead to the wasted energy, especially for those time-insensitive files such as online games or high-definition movies. Energy problem is not only related to energy consumption, but also to economic problems in the smart grid area for P2P. In this work, we present a framework combining the Time-Of-Use (TOU) pricing model and P2P protocols in smart grid area. Peers adjust their energy consumption per unit time based on the TOU pricing model automatically, by switching between a dormant state and an active state in accordance with a time schedule sequence. Our simulation results show that our protocol is both economically efficient and energy efficient for transferring files of various sizes on different systems such as Personal Computers (PCs) and mobile devices.

Keywords—P2P, Green Computing, Economy-Efficient.

I. INTRODUCTION

In a P2P network, the more participating peers there are, the faster downloading speed an edge device can generally be obtained, which is the key idea of P2P – “share” [1]. For example, BitTorrent, one of the most popular P2P application, generates a substantial amount of traffic in all monitored regions, ranging from 43% in Northern Africa to 70% in Eastern Europe [2]. Because such idea advocates users to share files with others, many personal computer users leave their PC/laptop powering on to download or upload, which causes a significant waste of energy. Although P2P offers many attractive features, such as self-organization, load-balancing, availability, fault tolerance, anonymity, and relatively lower energy consumption [3], it still faces an energy challenge because it requires peers to participate.

While many researchers [4], [5] have built extended architectures, hardly any of them have focused on how to reduce economic cost. In [6], the authors present an energy-aware method to reschedule multiple real-time tasks in multi-processor systems which support dynamic voltage scaling. Their kernel is to evaluate the probabilistic distribution of the tasks’ execution time, in order to partition the workload and reduce energy consumption. In a later work [7], authors provide guidance on how to allocate program material to data centers by examining the trade-off between storage and transmission from a perspective of energy use. P2P [8] proposes to reduce

energy costs for file sharing with the BitTorrent technology, but only focuses on the power consumption and ignores the economic cost with a dynamic TOU table. Two important factors affecting the electricity fee are time and price. Decreasing downloading time is considered to be the energy conservation problem in [6], [8]. Different to our work, the authors discuss how long it will take instead of what kind of time period it is. Usually ignored, price is another key factor influencing the P2P economic cost. Time-of-use electricity pricing is analyzed in several papers [9], [10], though it is born 30 years ago in [11]. Cicek reported the only work – the RWA-Bill– [12] that cuts the electric bill with time-zones and TOU Prices, where the authors did a preliminary study to indicate the potential of bill cutting by using TOU.

In this paper, we introduce a novel P2P network protocol called Energy and Economy efficient Peer-To-Peer (EEP2P) that takes advantage of TOU tables in a smart grid area [13]–[23], to solve the energy and economy waste resulting from a large number of participating peers and numerous PC users who leave their PC/laptop powered on. Time-of-use decision is not a novel idea now that [24] uses it to optimize the pricing and service for urban transit and [25] estimates the electricity demand. In this paper, a TOU table is a way to shift energy consumption by charging a different utility price at different times. Based on the analysis in [26], energy at a different price means a different utilization; In other words, if an activity needs a certain amount of energy, it is more efficient for it to be conducted when the utility price is low. There are three states in the TOU table: on-peak, mid-peak and off-peak. When the utility price is on-peak, a full dormant mode is enabled; when it comes to off-peak, a full time downloading mode is enabled; and when the utility price is mid-peak, a partial time downloading mode is enabled. By detecting the three states (on-peak, mid-peak, off-peak) in a TOU table, we shift the downloading states of the peers in a P2P network. As a result, energy and cost are saved. To the best of our knowledge, this is the first work to tackle this problem in detail.

II. ENERGY EFFICIENT AND ECONOMY EFFICIENT

As will be discussed in the next section, our EEP2P protocol takes into consideration these two aspects, and is proven to be both energy and economy efficient. Energy efficiency mainly focuses on energy conservation, as is shown in Equation 1.

$$Eff_{en} = \frac{E(with)}{E(without)} \quad (1)$$

where $E(with)$ refers to the energy with using EEP2P in kilowatt hours (kWh), $E(without)$ refers to that without using EEP2P. If $Eff_{ec} > 1$, using EEP2P can be more energy efficient than without. Economic efficiency mainly focuses on low expenses. Let's define it as Equation 2

$$Eff_{ec} = \frac{C}{E} \quad (2)$$

where C refers to the economic cost in dollars(\$), E_u refers to the total energy used in kWh. If $Eff_{ec}(with) > Eff_{ec}(without)$, using EEP2P is more economically efficient than not using it.

To further analyze the efficient features of EEP2P, we should understand a pair of phrases to describe a power plant's output: "baseload power" and "peak power".

- **Baseload electricity:** Generated by large nuclear or coal-fired plants, baseload electricity is provided to meet the minimum requirement around the clock with a low per kWh price.
- **Peak electricity:** Generated by solar and most gas-fired power plants that can be switched on for a short period, peak electricity is provided and purchased only at times of the day when a high level of power consumption is expected, and is usually associated with a higher price per kWh.

Different from peak electricity in source and production mode, baseload electricity is more energy efficient than peak electricity [26]. Usually, the baseload power is able to supply the grid, but when the demand of electricity is high, for example at 5:00-9:00 p.m., peak power is fed into the grid to supply the high demand. As a result, the per kWh price of electricity in a TOU table will rise, which forms the fluctuation of prices in the TOU table. The main purpose of EEP2P is to avoid periods with a high electricity demand, and to substitute baseload electricity for peak electricity. In addition to reduced electricity cost, EEP2P can also achieve the goal of energy efficiency, as will be discussed in Section III.

III. DESIGN OF EEP2P

Different from a traditional P2P protocol, our EEP2P protocol defines three states during file downloading/uploading, which are *active*, *partially active*, and *dormant*. All the peers are allowed to switch among these three states according to a TOU table. For a given P2P network, peers may hold different TOU tables based on their region utility charge policy. By processing the TOU table, each peer is associated with a time schedule sequence, which is an interchanging sequence between active, partially active and dormant states. Because the use of TOU tables could cause a deadlock situation among peers whose TOU tables bear a certain relationship, we designed a "deadlock breaking" algorithm to prevent this from happening.

A. TOU Table Processing

The primary goal of the TOU pricing model is to reduce the pressure on an electrical grid during peak demand by incentivizing peers to shift their consumption during different times. The unit price (\$/kWh) is divided into three categories (levels): on-peak (high), mid-peak (mid), and off-peak (low).

C	the economic cost in dollars(\$)
E_u	refers to the total energy used by users
$ F $	the size of the file
$ F_i $	the file size at time interval i
$\rho(i)$	the electricity price during the interval i
ρ^{high}, ρ^{low}	the highest and lowest price during 24h
U	Power consumption in a single time unit
D_i	Maximum download capacity at time interval i
T_{off}	Time to switch from active to dormant states
T_{back}	Time to switch back from dormant states to active
$T_l(i)$	Total time during interval i
$T_a(i)$	The active time during the interval i
P_{max}	Probability peers reached max download speed
n	Total number of chunks in network
C	Total electricity fee
U_c	Unit economic cost
$\rho^{with}, \rho^{without}$	Unit economic cost with and without using EEP2P
$f_i(m_i)$	Forwarding Peer Group i with m_i peers member

TABLE I. PARAMETERS OVERVIEW

The above on-peak, mid-peak and off-peak designations in a TOU pricing table correspond to the aforementioned dormant, partially active, and active states respectively. We disable all peers' functionalities ($T_a = 0$) when they enter the on-peak/dormant state, and enable their full-time download ($T_a = T_l$) when they enter the off-peak/active state, and similarly, partial time download ($T_a \propto T_l$) for the mid-peak/partial-active state.

In the rest of this section we will present a mathematical model of our work. For readability, the notations for all the parameters to be used are summarized in Table I.

Mathematically, we denote network status at time t as:

$$T_a(i) = \begin{cases} \frac{\rho^{low}}{\rho(i)} \cdot T_l(i), & \text{if } \rho(i) \in (\rho^{low}, \rho^{high}) \\ T_l(i), & \text{if } \rho(i) = \rho^{low} \\ 0, & \text{if } \rho(i) = \rho^{high} \end{cases} \quad (3)$$

In Equation 3, we denote $T_a(i)$ as the active time during time interval i which owns electricity price $\rho(i)$. And the notation $T_l(i)$ denotes the level time duration respectively. Three sub-equations in Equation 3 represent partially active, fully active and dormant states, respectively. So, in dormant and active states, the active downloading time is 0 and $T_l(i)$ respectively.

It is possible that peers in different regions own different TOU tables with different peak prices, and under this case, we would process the TOU table to normalize the price standard. Thus we define *time schedule sequence* in Definition 1.

Definition 1 (Time Schedule Sequence). *Given an interval i , its time schedule sequence, denoted $T_s(i)$, is $T_s(i) = \frac{T_a(i)}{T_l}$.*

B. Time and Energy Model

In the previous Section III-A, we described the model for calculating Time Schedule Sequence for a given the TOU pricing table. In this section, we will mathematically model energy efficiency with and without the adoption of EEP2P.

To illustrate the factors that influence the energy consumption in a P2P network, we assume a BitTorrent

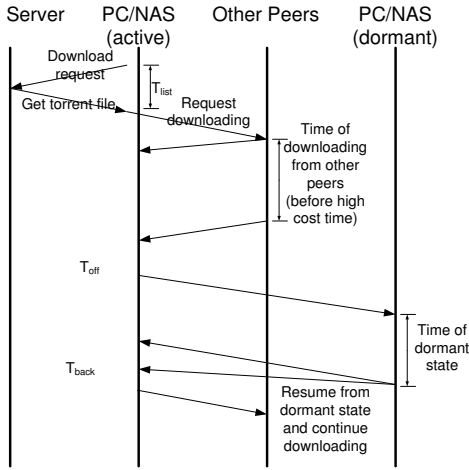


Fig. 1. Walking through table

network with a server that tries to distribute a file of size $|F|$ to a total of N peers. We further assume that it is a churn free network where no peers arrive or leave during the distribution. When a peer is in the active state, it can upload or download trunks of a file. When a peer is in the dormant state, it turns off all the functionalities except the timer that is set to wake it up according to T_s .

In Fig. 1, we provide a walk-through of a time-expanded network constructed from a time graph. As shown in Fig. 1, when a new peer p joins the torrent network, it starts downloading from the server the torrent file that contains the contact information of other peers with which p can establish TCP connections. Then p starts downloading (active) or sleeping (dormant) depending on the time schedule sequence till it finishes the downloading. According to the walk-through table, the total time, denoted T_{total} , to download a complete file for p is shown in Equation 4:

$$T_{total} = T_{list} + n_1 \cdot (T_{active} + T_{back}) + n_2 \cdot (T_{sleep} + T_{off}) \quad (4)$$

where n_1 and n_2 are the numbers of cycles of active and dormant intervals respectively, T_{list} is the waiting time for server as is shown in Fig. 1.

A file's size $|F|$ is given in Equation 5:

$$\begin{aligned} |F| &= n_1 \cdot (\hat{D}(i) \cdot T_{active}) + n_2 \cdot (\hat{D}(i) \cdot T_{sleep}) \\ &= (\hat{D}(i) \cdot \sum_{i \in active} (T_s(i) \cdot T_l(i))) + (\hat{D}(i) \cdot \sum_{i \in sleep} (T_s(i) \cdot T_l(i))) \\ &= \sum_{i=1}^n (\hat{D}(i) \cdot T_s(i) \cdot T_l(i)) \end{aligned} \quad (5)$$

$$\text{where} \quad \hat{D}(i) = P_{max}(i) \cdot D_i \quad (6)$$

Here P_{max} is the probability that the peer can reach the highest download speed. In Equation 5, P_{max} is proportional to $|F|$. If we let $|F|$ be a fixed size of a desired file, then the higher P_{max} we can achieve, the lower n_1 and n_2 will be. So, it is obvious that P_{max} becomes a key issue to economy. Fig. 1 gives a tree-like network graph topology. The max download or upload speed can be achieved by carefully arranged the feeding nodes with an optimal and efficient algorithm. But this topic is beyond the discussion of this paper. Work has been reported, e.g., [27], on how to maximize the download/upload speed.

Definition 2 (Downloading Finishing). A peer is considered as finishing downloading only if:

$$\begin{cases} |F| = \sum_{i=0}^N (|F_i|) \\ F_i \neq F_j \text{ where } i \neq j \end{cases} \quad (7)$$

where F denotes the file, then $|F|$ is the file size. So it means the received file size equals $|F|$, and no file received is duplicated.

Clearly, the energy consumed by the users' PC or related devices in both original and EEP2P protocols is given by the total time it remains powered on, multiplied by its power consumption. So, by Definition 2, we can easily build a connection between the unit of economic cost and the file size.

$$U_c = U \cdot T_{total} = U \cdot \left(\frac{|F|}{D_{max} \cdot P_{max}} \right) \quad (8)$$

Suppose the TOU table has been divided into several levels which repeat over m times, as discussed in Section III-A. Then we can get the economy consumption **without** using EEP2P protocol in Equation 9:

$$\sum_{i=1}^m \rho_{without} = n \cdot \sum_{j=1}^m (P(j) \cdot T_l(j)) \quad (9)$$

$$\text{where} \quad \sum_{j=1}^m T_l(j) = \frac{|F|}{D_{max} \cdot P_{max}} \quad (10)$$

In the same way, we can model the economic consumption with EEP2P in Equation 11:

$$\sum_{i=1}^n \rho_{with} = n \cdot \sum_{i=1}^{r-1} (\rho_i \cdot T_a(i)) + n \cdot (T_{sleep} \cdot \rho_r) \quad (11)$$

(By Equation 3) where

$$\sum_{j=1}^n T_a(j) = \frac{|F|}{D_{max} \cdot P_{max}} \quad (12)$$

By Definition 1,

$$T_{all}(i) = \sum_{i=1}^{n_s} T_s(i) \cdot T_l(j) = n_s \cdot T_m \quad (13)$$

As for the total active time, by Equation 3, $\rho_1 = \rho_2 = \dots = \rho_{m-1} = \rho_{low}$. T_{active} is denoted as the time in an active state without EEP2P, then:

$$T_{active} = \left(\frac{|F|}{D_{max} \cdot P_{max}} \right) = \sum_{i=1}^f \left(\frac{|F_i|}{(D_{max} \cdot P_{max})} \right) \quad (14)$$

$$\sum_{i=1}^n U_c = n \left(\sum_{i=1}^x T_s(i) \cdot T_l(i) \cdot \rho_i + T_{sleep} \cdot \rho_{sleep} \right) \frac{r(a-1)}{m}$$

where

$$\sum_{i=1}^{n_s} T_s(i) \cdot T_l(i) \cdot (a-1) \cdot \frac{r}{m} = \frac{(\sum_{i=1}^n |F_i|)}{D_{max} \cdot P_{max}} = T_{active} \quad (15)$$

where n_s is the number of the same level utility price in the Time schedule sequence. The notation ' r ' is the repeated time with EEP2P which could be greater or equal to the ' m ' which depends on the size of the file.

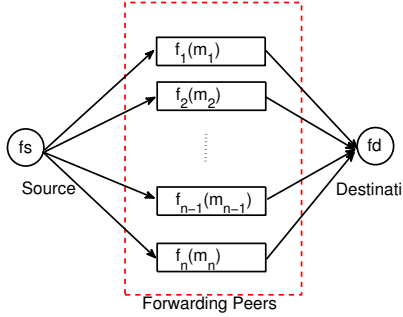


Fig. 2. Unsorted forwarding peers

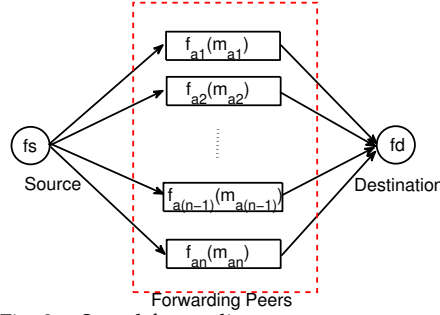


Fig. 3. Sorted forwarding peers

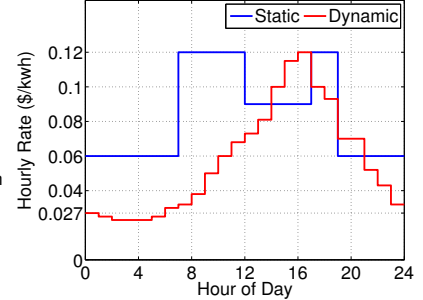


Fig. 4. dynamic and static TOU pricing table

C. Deadlock-Breaking Algorithm

Unlike a traditional P2P protocol such as BitTorrent, a peer in our EEP2P protocol can switch between active and dormant states. It is possible that peers with different TOU tables generate reversed time schedule sequence, a condition we call it "deadlock", as is defined in Definition 3.

Definition 3. *Deadlock happens in conditions where the source peer is active/dormant when destination peers are dormant/active. And this can be caused by two absolutely different TOU tables.*

In mathematics, deadlock happens if $(f_s \rightarrow T_s) \cdot (f_d \rightarrow T_s) = 0$, in which $f_s \rightarrow T_s$ and $f_d \rightarrow T_s$ is the time schedule sequence of source and destination peers respectively. For example, f_s with $f_s \rightarrow T_s = [1, 1, 1/2, 0, 0]$ and $f_d \rightarrow T_s = [0, 0, 0, 1, 1/2]$, then $(f_s \rightarrow T_s) \cdot (f_d \rightarrow T_s) = [0, 0, 0, 0]$. The opposite time schedule sequence makes f_s and f_d in different states all the time. What if f_s is holding some trunks of file that f_d cannot get from other currently activated peers in such an unexpected condition? Thus an efficient algorithm for file forwarding is extremely important and necessary.

1) *What is deadlock?*: Fig.2 demonstrates the file distribution process between one sender f_s , which is holding some unique trunks of files required by f_d , and one receiver f_d through some intermediate peer groups $f_1, f_2, f_3 \dots f_n$, which can be called forwarding sequence peers as is shown in Fig. 2. Let m_i represent the number of peers that have a time schedule of $T_a(i)$. Initially, f_s wakes up at time t_1 , but f_d has not switched back from dormant till t_3 . With the help of forwarding sequence peers, these unique trunks of files can be distributed to f_d with tolerated delay and avoid the deadlock.

2) *How to resolve deadlock*: Formally, we define $f_{a_1}, f_{a_2}, f_{a_3} \dots f_{a_n}$, as a sequence of peers that can forward file trunks from source to destination. This sequence is sorted based on the Time schedule sequence as is shown in Fig. 3. Also let $t_w(f_{a_i})$ denote as the wake time of Peer f_{a_i} and $t_w(f_{a_i}) \leq t_w(f_{a_j})$ where $i < j$, $a_i \in [1, n], a_j \in [1, n]$. So we can group the peers as based on the sorted order of the upcoming wake-up time as Fig. 3.

Definition 4 (forwarding sequence group). *The Forwarding Sequence Group is composed of n groups of peers that are sorted based on upcoming wake-up time, each peer in the same group share the same upcoming wake up time.*

Using the Forwarding Sequence Group, we can break the deadlock between the source peer and destination peer by a reasonable delay in the forwarding process.

D. Economy and Energy Effect

Our goal is to improve the economic-efficiency and energy-efficiency, and this part will clarify how we will achieve the goal.

As a whole, the additional forms of energy consumption (like consumption on a power line) will be lower when the demand is lower during the baseload period. Another point is the fact that the TOU is usually designed according to the demand, which means during the lower demand, it is quite probable that the demand for the P2P network is lower. If the P2P speed stays the same, the total energy consumption without additional consumption with EEP2P will be the same than without EEP2P. In general, however, the average speed for uploading or downloading files is higher during that period for lower total P2P traffic [28]. Thus, the total energy consumption (even without the additional consumption) should be lower. EEP2P manages to avoid the peak electricity period with high prices by using the fuzzy optimal time period, which is proven to be more economical in our experience.

In the EEP2P, the economic and energy efficiency can be easily calculated based on Equation 1, which indicates the efficiency advantage of EEP2P.

$$E(\text{without}) > E(\text{with}), C_e(\text{with}) < C_e(\text{without})$$

$$\text{then } \begin{cases} E_{ff_{ec}}(\text{with}) > E_{ff_{ec}}(\text{without}) \\ E_{ff_{en}} > 1 \end{cases} \quad (16)$$

IV. EXPERIMENTAL RESULTS

A. Experiment Settings

Considering the complexity of conducting and evaluating in practical scenarios [29], we choose to evaluate the economic efficiency of EEP2P by a set of simulation experiments with our EEP2P protocol and the traditional P2P protocols. To increase the accuracy of the measurements, different TOU tables and file sizes are used.

File sizes affect downloading/uploading speed greatly. So, to get comprehensive and accurate results, experiments are conducted on a series of files with different sizes. Besides, different TOU tables generate different time schedule sequences which in turn can affect the experiment results as well, so this test simulates both the static TOU pricing model and the dynamic TOU pricing model. Fig. 4 shows a dynamic and a static TOU pricing Model. Our experimental settings are summarized in Table II. For the starting time, we choose the one with the highest electricity

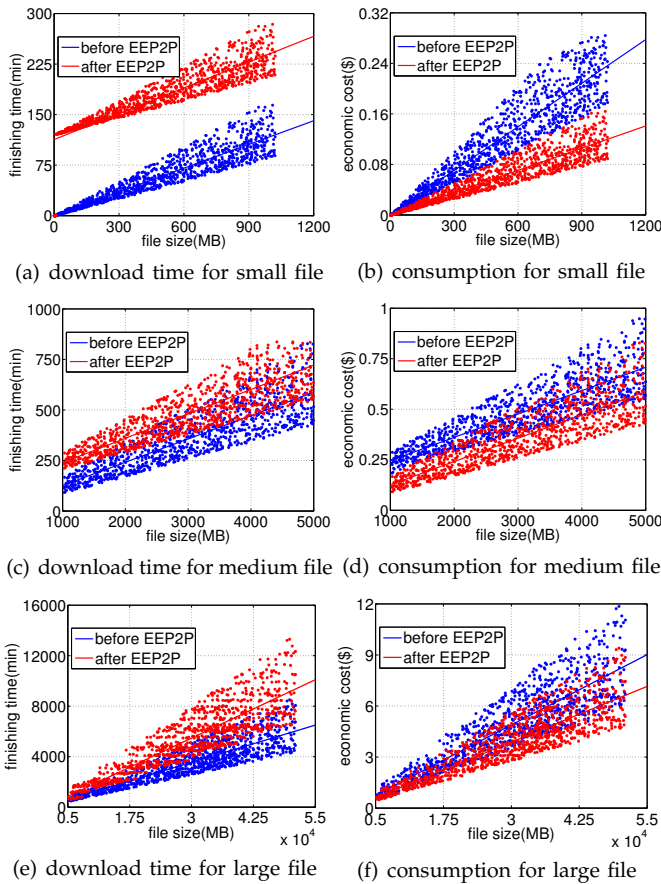


Fig. 5. Evaluation with Static TOU table

price in a different TOU table for two reasons. First, the on-peak period is the one with most users; Second, it unifies the starting time with the same level of price (on-peak) to reduce the effect on the result from the active/dormant state in static/dynamic scenarios.

TOU Type	Starting	Speed(Kbps)	File Size	Test Times
dynamic	16:00	100 ~ 200	200 MB ~ 10 GB	1000 × 3
static	17:00	100 ~ 200	1 GB ~ 30 GB	1000 × 3

TABLE II. SIMULATION PARAMETERS

B. Evaluation Criteria

In order to evaluate the performance of our protocol, we bring in an economic factor: Electricity Expense Per Megabit. It is self-evident that a larger file means longer downloading time and a larger amount of electricity cost, so we abstract the relationship between the electricity cost and file size to a linear one. Thus, we need to make a linear fitting for time and cost with a series of downloading simulations. Then we get a parameter:

$$R = \frac{\bar{C}}{|\bar{F}|} \quad (17)$$

where E is the energy consumption(\$), while $|F|$ is the file size. If $R_{p1} > R_{p2}$, protocol $P1$ is more economically efficient than protocol $P2$.

C. Experiment Result

With experimental settings shown in Table II, EEP2P is proven to be an effective protocol in economy. And

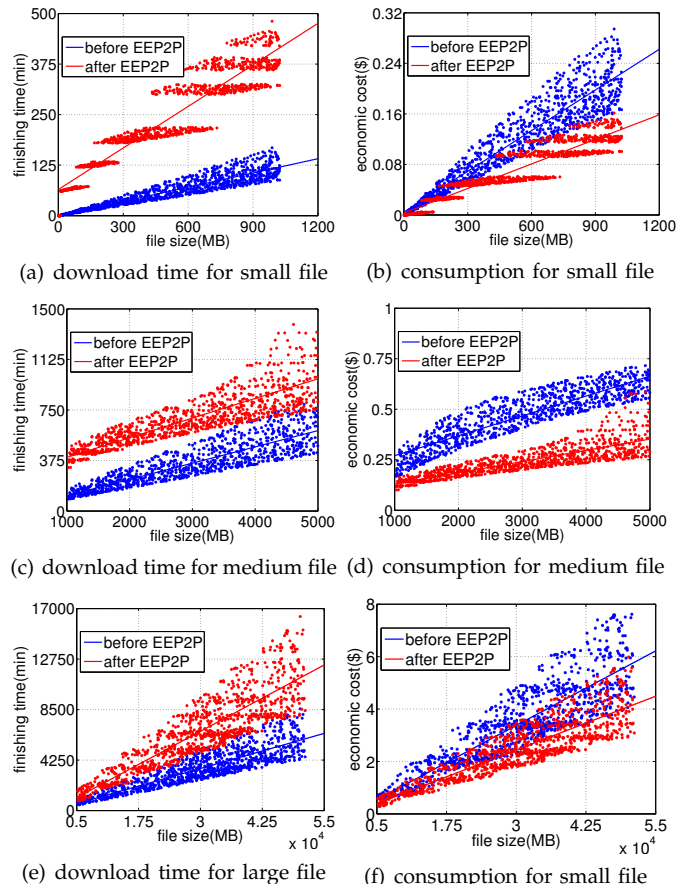


Fig. 6. Evaluation with Dynamic TOU table

a downloading with relatively larger file size is more favorable for EEP2P.

For a dynamic TOU table, the frequency of price changes is relatively high compared to that of a static TOU table, so, even within a short period EEP2P can make a significant difference in economic savings. As shown in Fig. 6, for dynamic TOU tables, EEP2P gains considerable energy and economic efficiency at the cost of longer downloading time, which is reasonable for time-insensitive files.

For static TOU tables, EEP2P can still improve energy and economic efficiency, even though the time delay is relatively long in static TOU tables when the file size is small, for the first interval with the highest price, EEP2P makes downloading dormant while the P2P makes it finish within that period.

From the simulation results shown in Fig. 5 and 6, we can conclude that EEP2P can improve the economic efficiency in both static and dynamic TOU tables, but a more dynamic TOU table is more flexible and favorable for EEP2P.

D. Comparison with Existing Scheme

We compare the performance of EEP2P with the only existing and relatively simple work in [12] where Ciek optimizes the RWA [30], an energy-aware routing and wavelength assignment, with a complete mathematical method. EEP2P can reduce the electric bill by 30 to 40 percent, while RWA-Bill reduces by around 14 percent, as is shown in Table IV-D. Besides, RWA-Bill hardly

Scheme	EEP2P	RWA-Bill
Performance in bill cutting	30-50%	14-40%
Deadlock	✓	.
Unified TOU	✓	.
Tested with dynamic/static TOU table?	both	only dynamic

TABLE III. COMPARISON OF EEP2P WITH [12]

mentions how to unify the TOU from different time-zones and how to resolve the deadlock.

V. CONCLUSION

Although energy management techniques have been extensively studied [31]–[37], This paper proposes a novel energy-efficient P2P (EEP2P) protocol that shifting active/dormant states based on TOU pricing models. EEP2P protocol is both economically-efficient and energy-efficient. We also proposed a deadlock-breaking algorithm and theoretically proved the efficiency of EEP2P protocol. Our extensive simulation demonstrates that the electricity cost can be reduced by 30% - 50% in a high-frequency dynamic TOU table.

VI. ACKNOWLEDGEMENT

This work was supported by NSF CNS-1217791.

REFERENCES

- [1] M. Parameswaran, A. Susarla, and A. B. Whinston, "P2p networking: an information sharing alternative," *Computer*, vol. 34, no. 7, pp. 31–38, 2001.
- [2] H. Schulze and K. Mochalski, "Internet study 2008/2009," *IPOQUE Report*, vol. 37, pp. 351–362, 2009.
- [3] J. K. Nurminen and J. Noyranen, "Energy-consumption in mobile peer-to-peer-quantitative results from file sharing," in *Consumer Communications and Networking Conference. CCNC'08*.
- [4] J. Li and S. Vuong, "An efficient clustered architecture for p2p networks," *Journal of Interconnection Networks*, vol. 5, no. 03, pp. 279–298, 2004.
- [5] R. Jurca and B. Faltings, "Reputation-based pricing of p2p services," in *Proceedings of the ACM SIGCOMM workshop on Economics of peer-to-peer systems*, 2005.
- [6] C. Xian, Y.-H. Lu, and Z. Li, "Energy-aware scheduling for real-time multiprocessor systems with uncertain task execution time," in *ACM DAC*, 2007.
- [7] J. Baliga, R. Ayre, K. Hinton, and R. S. Tucker, "Architectures for energy-efficient iptv networks," in *Optical Fiber Communication Conference. Optical Society of America*, 2009.
- [8] A. Aikebaier, Y. Yang, T. Enokido, and M. Takizawa, "Energy-efficient computation models for distributed systems," in *Network-Based Information Systems. International Conference on. NBIS*, 2009, pp. 424–431.
- [9] P. Yang, G. Tang, and A. Nehorai, "A game-theoretic approach for optimal time-of-use electricity pricing," *Power Systems, IEEE Transactions on*, vol. 28, no. 2, pp. 884–892, 2013.
- [10] M. Filippini, "Short-and long-run time-of-use price elasticities in swiss residential electricity demand," *Energy policy*, vol. 39, no. 10, pp. 5811–5817, 2011.
- [11] D. W. Caves and L. R. Christensen, "Econometric analysis of residential time-of-use electricity pricing experiments," *Journal of Econometrics*, vol. 14, no. 3, pp. 287–306, 1980.
- [12] C. Cavdar, A. Yayimli, and L. Wosinska, "How to cut the electric bill in optical wdm networks with time-zones and time-of-use prices," in *European Conference and Exposition on Optical Communications. Optical Society of America*, 2011, pp. 8–10.
- [13] A. Mishra, D. Irwin, P. Shenoy, and T. Zhu, "Scaling distributed energy storage for grid peak reduction," in *e-Energy '13*.
- [14] P. Yi, T. Zhu, B. Jiang, B. Wang, and D. Towsley, "An energy transmission and distribution network using electric vehicles," in *ICC '12*.
- [15] P. Yi, T. Zhu, G. Lin, and Q. Zhang, "Routing renewable energy using electric vehicles in mobile electrical grid," in *MASS '13*.
- [16] P. Yi, T. Zhu, G. Lin, X. Jiang, G. Li, L. Si, and M. M. Begovic, "Energy scheduling and allocation in electric vehicle energy distribution networks," in *ISGT '13*.
- [17] P. Yi, Y. Tang, Y. Hong, Y. Shen, T. Zhu, Q. Zhang, and M. M. Begovic, "Renewable energy transmission through multiple routes in a mobile electrical grid," in *ISGT '14*.
- [18] T. Zhu, S. Xiao, P. Yi, D. Towsley, and W. Gong, "A secure energy routing protocol for sharing renewable energy in smart microgrid," in *SmartGridComm '11*.
- [19] T. Zhu, Z. Huang, A. Sharma, J. Su, D. Irwin, A. Mishra, D. Menasche, and P. Shenoy, "Sharing Renewable Energy in Smart Microgrids," in *ICCPs '13*.
- [20] A. Mishra, D. Irwin, P. Shenoy, J. Kurose, and T. Zhu, "SmartCharge: Cutting the Electricity Bill in Smart Homes with Energy Storage," in *e-Energy '12*.
- [21] T. Zhu, A. Mishra, D. Irwin, N. Sharma, P. Shenoy, and D. Towsley, "The Case for Efficient Renewable Energy Management for Smart Homes," in *BuildSys '11*.
- [22] A. Mishra, D. Irwin, P. Shenoy, J. Kurose, and T. Zhu, "Green-Charge: Managing Renewable Energy in Smart Buildings," in *IEEE Journal on Selected Areas in Communications: Smart Grid Communications Series*, vol. 31, No. 7, 2013.
- [23] N. Sharma, J. Gummesson, D. Irwin, T. Zhu, and P. Shenoy, "Leveraging Weather Forecasts in Energy Harvesting Sensor Systems," in *SUSCOM '14*, 2013.
- [24] M. Kraus and Y. Yoshida, "The commuter's time-of-use decision and optimal pricing and service in urban mass transit," *Journal of Urban Economics*, vol. 51, no. 1, pp. 170–195, 2002.
- [25] M. Filippini, "Electricity demand by time of use an application of the household aids model," *Energy Economics*, vol. 17, no. 3, pp. 197–204, 1995.
- [26] J. C. Palacios, G. Alonso, R. Ramirez, A. Gomez, J. Ortiz, and L. Longoria, "Levelized costs for nuclear, gas and coal for electricity, under the mexican scenario," Instituto Nacional de Investigaciones Nucleares (MX), Tech. Rep., 2004.
- [27] Z. Liu, Y. Shen, K. Ross, and Y. Wang, "Substream trading: Towards an open p2p live streaming system," in *ICNP '08*.
- [28] S. Suri, C. D. Tóth, and Y. Zhou, "Uncoordinated load balancing and congestion games in p2p systems," in *Peer-to-Peer Systems III*. Springer, 2005, pp. 123–130.
- [29] M. Schlosser, T. Condie, and S. Kamvar, "Simulating a file-sharing p2p network," Stanford InfoLab, Technical Report 2003-28, 2003. [Online]. Available: <http://ilpubs.stanford.edu:8090/589/>
- [30] A. Coiro, M. Listanti, and A. Valenti, "Dynamic power-aware routing and wavelength assignment for green wdm optical networks," in *ICC*, 2011.
- [31] Y. Gu, T. Zhu, and T. He, "Esc: Energy synchronized communication in sustainable sensor networks," in *ICNP '09*.
- [32] T. Zhu, Z. Zhong, Y. Gu, T. He, and Z. Zhang, "Leakage-aware energy synchronization for wireless sensor networks," in *MobiSys '09*.
- [33] T. Zhu, A. Mohaisen, Y. Ping, and D. Towsley, "DEOS: Dynamic energy-oriented scheduling for sustainable wireless sensor networks," in *INFOCOM '12*.
- [34] L. He, Y. Gu, J. Pan, and T. Zhu, "On-demand charging in wireless sensor networks: Theories and applications," in *MASS '13*.
- [35] L. He, P. Cheng, Y. Gu, J. Pan, T. Zhu and C. Liu, "Mobile-to-mobile energy replenishment in mission-critical robotics sensor networks," in *INFOCOM '14*.
- [36] Z. Dong, L. Kong, P. Cheng, L. He, Y. Gu, L. Fang, T. Zhu, and C. Liu, "REPC: Reliable and efficient participatory computing for mobile devices," in *SECON '14*.
- [37] T. Zhu, Y. Gu, T. He, and Z. Zhang, "eShare: A capacitor-driven energy storage and sharing network for long-term operation," in *SensSys '10*.