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The Time Dependent Pricing (TDP) by Mobile Network Operators using Broad Band Pricing Systems

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***Abstract*—** The pricing schemes that are in practice today and analyze why they do not solve the ISPs problem from the growing data traffic. The Internet can incentivize users to spread out their bandwidth consumption more evenly across different times of the day, and thus help ISPs to overcome the problem of peak congestion. Congestion pricing is not a new idea in itself, but for IP network data plan we learn from our wired and wireless ISP collaborators that the time for its implementation has finally arrived.

Keywords**—***User Provided Networks, Internet Service Provider, Broadband pricing, Data plans, Network Economics.*

I. INTRODUCTION

According to several recent industry reports [1],[2], mobile data is expected to increase with an annual growth rate of 60% in the next several years, reaching 25 exabytes per month in 2020. This surging traffic places an unprecedented strain on cellular networks, which need to substantially expand their capacities. However, it is clear that the traditional capacity increase strategies of mobile network operators (MNOs), such as acquiring more spectrum or deploying additional network infrastructure, are often time-consuming, costly, and eventually inadequate to accommodate the traffic growth. Therefore, MNOs often end up offering services of low quality [3], or charging their subscribers very expensive usage-based fees [4]. This means that a large number of mobile users do not have access to the low-cost and high speed mobile Internet, and hence there are significant user dissatisfactions and frequent user churns. This leads to the growing consensus that more disruptive methods and forward-looking solutions are needed to resolve the growing gap between data supply and demand. At the same time, recent technological advancements have resulted in sophisticated user handheld equipments, such as smart phones with Wi-Fi (802.11) and Bluetooth (802.15.1) interfaces, 4G chipsets supporting cellular connections up to 150Mbps [5], and high-end processors that can execute complicated networking tasks. However, the conventional approach of using these devices as simple transceivers, which are completely controlled by the cellular base stations to serve only the needs of their owners, does not fully exploit their communication and computational capabilities. Clearly, these devices can also offer communication services to nearby users, by acting as mobile Wi-Fi hotspots or relays. This leads to the so-called user-provided networks (UPNs) [6],[7],[8],[9] which constitute a promising solution for alleviating network congestion, reducing network access costs, and improving the user satisfaction by enabling network control at the edge of the network.

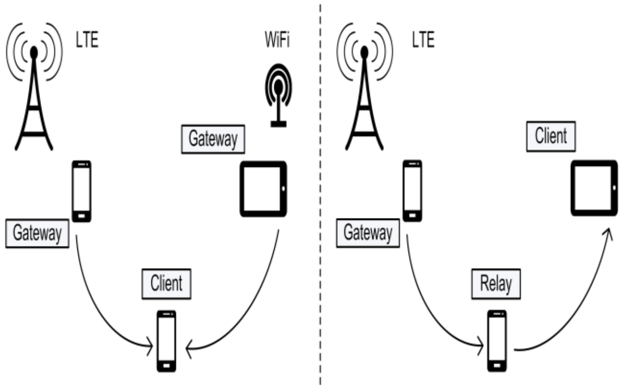

Fig.1 An example of user’s interactions in UPNs. Each user can concurrently consume data from multiple gateways, over multiple and possibly multi-hop paths, and serve as a relay or even a gateway for others. Left: concurrent downloading from two gateways. Right: multi-hop connection to Internet.

The Internet pricing paradigm is undergoing major changes a fact that is evident from its dominance in the technology news headlines in 2010-11. From AT&T's shift to usage based pricing for wireless access in April 2010 [6] to its March 2011 announcement of usage caps for U-Verse and DSL lines [10], from FCC's December 2010 statement giving the green light to usage-based pricing innovations [11], to Verizon's March 2011 announcement of a tiered data plan for iPhone [3], we are witnessing a transformative period in the interplay between pricing and network technology. According to Cisco's Visual Index prediction, wireless Internet bandwidth demand will increase at a compound rate of 108% over the next four years, reaching 4 Exabytes every month by 2014. Given this trend, relying entirely on technological advances such as LTE and WiMax is no longer viable going forward in the next decade [2].

Smartphones, tablets, and gaming consoles are driving up bandwidth demand even faster (e.g. 65% of 2014 wireless traffic will be video), and their heavy users are making the demand \tail" grow longer and heavier [16]. The problem will exacerbate as more users start to upload their content to the cloud to share and sync it across multiple devices. Although this `heavy tail' of usage largely drives the capacity investment and operational costs for ISPs, their revenue is based on the median user. Consequently, the ISP's current economic model will soon fall apart as the usage increases. To make it worse, the heavy usage concentrates over several peak hours in a day, forcing ISPs to overprovision resources according to the peak demand, and a large portion of the capacity is left unused in other time periods. Even charging by monthly overages, as AT&T started doing last year and Verizon Wireless intends to do starting in summer 2011, will not mitigate this problem. Moreover, usage-based plans that penalize heavy users by levying hefty overage charges [13], or by simply denying (throttling [12]) their service [15], only add to customer dissatisfaction and create more contentious issues involving net-neutrality [14]. Therefore, a purely usage-based charging is not a viable long term solution. Alternative pricing innovations that regulate demand while providing consumers with more choices must be considered. To this end, we propose a pricing system for data plans called Time-dependent Usage-based Broadband price Engineering (TUBE), which is positioned to overcome several key challenges and become a feasible way forward in broadband pricing innovation.

The basic idea behind TUBE is that in order to efficiently use the capacity all the time, ISPs should exploit the temporal variations in bandwidth demand (i.e., the big differential between the peaks and the valleys in usage over different times of the day). This can be accomplished by using a dynamic time dependent usage pricing (TDP) which charges users based on when they use the Internet, thus creating incentives to avoid certain applications during peak hours. The idea of time-dependent pricing has been practiced in several forms for quite sometime. The most common of these is the day-time (counted as part of minutes used) and night-time (free) pricing, which is a simple two-period TDP scheme. Some operators in India and Africa are even using TDP for voice calls. But these current schemes, which we discuss in greater detail in Section 2, suffer from the fact that they are not optimized to offer the right prices to users or to explicitly account for their reaction to these prices. Moreover, these plans are mostly applied to voice calls, which differ fundamentally from many data applications (e.g. movie downloads or file backups) in that voice calls are time-sensitive (real-time) applications (i.e., they cannot be completed in small chunks by waiting for periods when the prices get cheaper). Our consumer surveys conducted in India and the US, discussed in Section 4.1, also corroborate the common intuition that people have different delay tolerances and price sensitivities for different data traffics, and thus can be made to tradeoff between delays and monetary gains by offering rewards. Using these incentives, ISPs can motivate users to defer their non-critical usage from peak hours to lower priced periods, thus “flattening" out the demand curve and reducing costs. Willingness to defer application usage by a couple of hours, or even in the order of several minutes, can be enough to allow users to skip the top of peak hours. Therefore, we advocate a carrot-and-stick solution for better utilization of network capacity. Users who are willing to wait and avoid the peak congestion periods have the option of doing so and are rewarded in return, while those who don't pay a higher price. TDP creates a win-win scenario at a critical time: ISPs can better manage their revenue-cost balance, while consumers have more choices to escape hefty usage based penalties. Moreover, it can help to increase rural wireless coverage by reducing the peak capacity needed in the bottleneck middle mile. The main contribution of this work is to take the idea of time-dependent and congestion-dependent pricing to the next level by developing new analytical models and algorithms for efficiently determining right price incentives while taking into account the anticipated user reaction, and thus creating an integrated system design called TUBE for pricing of Internet data pricing. It provides a forward looking solution at a critical period of rapid pricing innovation, and takes a holistic approach by supplementing network economic theory with a real system implementation, field trial and simulation results that use inputs from large consumer surveys conducted in India and the US. We discuss TUBE's architecture, initial results, and preparations for a real-world trial that is currently underway at Princeton with help from AT&T and National Exchange Carrier Association.

II. BACKGROUND STUDY

Service and related customer Support significantly affect subscriber attrition. Conventionally, wireless service providers provide various conduits for a subscriber to request Support and to report network operation incidents. Subscriber reported problems related to network performance are a vital source of feedback to a network operator, or service provider, as certain subscriber reported problems are visible only to the subscriber, such as when the subscriber attempts to utilize a user mobile device in an area where the network operator does not provides coverage.

Such scenario can arise, for example, in areas in which the network operator has a license to a portion of electromagnetic radiation spectrum, but does not provide indoor coverage to a specific building deployed in an operating area for the license. Nevertheless, regardless of the various conduits, quality of the response of the service provider to a network performance incident is dictated primarily by a limited number of resources generally available for support services in the network; the number of resources is directly related to the number of employees the wireless service provider has in staff or has contracted. In addition, in conventional systems, resolution of network performance incidents that are submitted via the various typical conduits available to a subscriber involves recreating the network performance incident by dispatching technician(s) to a location at which the incident has occurred. Accordingly, customer service becomes costly and is based on rather limited input with respect to information necessary for expeditious and robust resolution of network operation issue(s) that caused the network performance incidents.

Analytical Model: We introduce a general mobile UPN service that incorporates users' communication needs, monetary costs, and energy consumption, which are the key factors affecting users' servicing decisions.

Incentive Provision & Service Allocation Mechanism: We design a resource sharing mechanism based on the Nash bargaining solution, that induces users' participations through fair allocation of the contributed resources. It is Pareto efficient and takes into account users' standalone performances. These aspects are very crucial to maintain a good performance of the service.

Distributed Algorithm: We propose a distributed algorithm, which combines the concepts of consistency pricing [17], and primal-dual Lagrange relaxation [18], and achieves the unique NBS. This enables the decentralized implementation of the service, without requiring central coordination or additional infrastructure.

Intelligence-at-the-edge: We discuss how the service can account for interference and congestion effects, by taking intelligent (at-the-edge) channel assignment, routing, and flow control decisions. We explain how the service can be used both for mobile data offloading and onloading, adapting on the congestion levels of the different networks as well as the Internet access costs.

Performance Evaluation: We evaluate the performance of the service for various system parameters and scenarios. We find that the benefits increase as users become more heterogeneous (diverse) in terms of their needs and resources, increasing on average by at least 30% the amount of served data in a typical scenario with 6 users.

Static Pricing: ISPs have traditionally used different types of predetermined pricing schemes, which we refer to as static pricing models in this work. These pricing plans include variations of `metered' [19], at price (unlimited) [20], and cap then metered (aka `usage based') [21]. Many operators also implement a traditional two-period “Time of Usage" pricing in which users are charged differently during day-time and night-time (or weekdays/weekends). Additionally, there are pre-paid and post-paid options, each of which has different price structure, penalties, and overage caps. But all these plans share in common the fact that the pricing is determined in advance and are not updated dynamically in response to traffic conditions on the network.

Dynamic Pricing: Much of the pricing innovation in recent years has occurred outside the US. Network operators in highly competitive and lucrative markets, such as those in India and Africa, have adopted innovative dynamic pricing for voice calls. Popular dynamic pricing schemes include congestion-dependent and time dependent pricing. The African operator MTN pioneered “Dynamic Tariffing”, a congestion-based pricing where the cost of call is adjusted every hour, in each network cell, depending on the level of usage. A similar congestion-dependent pricing for voice calls was also launched in India by Uninor. It offers discounts to its customer's calls based on the network traffic condition in the location from where they make the call (aka Location Based Tariff) [22]. Tango Telecom for Airtel Africa and Telcordia also offers real-time charging and dynamic pricing solutions to mobile operators in India for voice calls based on factors, such as cell load, time of day, location, and traffic patterns.

Shortcomings of current schemes: Pricing based on monthly bandwidth usage leaves a timescale mismatch: ISP revenue is based on monthly usage, but peak-hour congestion dominates its cost structure. Usage-based pricing schemes use penalties to limit network congestion by reducing demand from individual heavy users, but they still cannot prevent the concentration of peak demand across users during the same time periods. Simple two-period time-dependent pricing are also inadequate as they can incentivize only the highly price sensitive users to shift some of their non-critical traffic, and often end up creating two peaks - one during daytime and one at night. In general, all the static pricing schemes suffer from their inability to adapt prices in real time to respond to the usage patterns, and hence fail to exploit the limited levels of delay tolerance that most users have. Dynamic pricing, on the other hand, is better equipped to overcome these issues and do not need to pre- classify hours into peak and off-peak periods. Therefore, we develop an analytical model and a system implementation of dynamic time-dependent usage pricing for data, which addresses the needs of the hour and also lies lower in the radar of the neutrality debate. Fig 2 summarizes the projected evolution of pricing schemes. The large scale, nonlinear optimization problem that is at the heart of TUBE's is presented next.

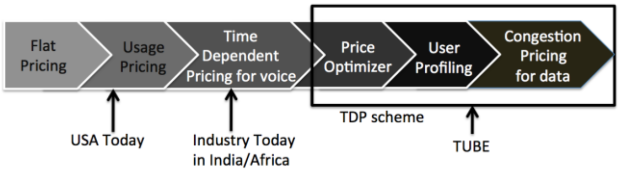

Fig 2: Projected progression of pricing schemes.

III. DYNAMIC-TDP FOR DATA TRAFFIC

TUBE's TDP pricing scheme divides a day into a certain number of time periods, say 48 half hour intervals. The price optimization unit of TUBE running at the ISP server uses historical usage data to compute the TDP price of a future time period and delivers this price information to all users in advance. The users can view the prices for the next 48 intervals on their handset's user interface and can respond to these prices by possibly deferring their usage to a later time. Their usage behavior is monitored by TUBE using network traffic measurements to create profiles for aggregate price-delay sensitivities across users.

IV. SUMMARY OF THE BACKGROUND STUDY

The Subject Summary is not an extensive overview of the disclosure. The sole purpose of the Subject Summary is to present some concepts of the Subject disclosure in a simplified form as a prelude to the more detailed description that is presented later. Reporting of network performance incidents can be characterized by location and time of occurrence, wherein this intelligence is provided by the user device. The reporting described herein enables a network operator to generate intelligence for network planning and for network performance improvement or optimization based on actual network performance as experienced at the subscriber level. Thus, allocation of resources for network optimization and development is based on objective data rather than mainly on simulations or management subjective input or perspective.

One of the various advantages of the subject disclosure is that pushing, or shifting, collection of network performance data to subscribers of a network operator allows the network operator to access network performance more broadly and with higher detail than through conventional approaches. Since the Subscribers that report an incident are experiencing the network issue, the subscribers can report the specifics of time, location, details of incident, related events, and environment of the incident that are difficult if not impossible to reproduce by a network engineer dispatched to the location to respond to the reported network performance incident. Aspects, features, or advantages of the Subject innovation can be exploited in Substantially any wireless telecommunication, or radio, technology; for example, Wi-Fi, Worldwide Interoperability for Microwave Access (WiMAX); Enhanced General Packet Radio Service (Enhanced GPRS): Third Generation Partnership Project (3GPP) Long Term Evolution (LTE); Third Generation Partnership Project 2 (3GPP2) Ultra Mobile Broadband (UMB).Additionally, substantially all aspects of the subject disclosure can include legacy telecommunication technologies.

It is noted that while various aspects, features, or advantages of the subject innovation are illustrated through Wi-Fi access point(s) and associated Wi-Fi coverage, such aspects and features also can be exploited in confined-coverage base stations (e.g., home-based access point(s), enterprise-based access point(s)) that provide wireless coverage through most any, or any, disparate telecommunication technologies Such as for example femtocell telecommunication or picocell telecommunication. To the accomplishment of the foregoing and related ends, the Subject disclosure, then, comprises the features hereinafter fully described. The following description and the annexed drawings set forth in detail certain illustrative aspects of the Subject disclosure. However, these aspects are indicative of but a few of the various ways in which the principles of the disclosure may be employed. Other aspects, advantages and novel features of the disclosure will become apparent from the following detailed description when considered in conjunction with the drawings.

TUBE needs a way to update its estimate of the patience indices, and hence the waiting functions. In the initialization phase of TUBE, ISPs choose a certain number of traffic classes, or groups of application sessions known to have similar patience indices (e.g. their initial value can be determined by pre-deployment surveys, or alternatively, users can explicitly notify about their delay sensitivity for a class of apps from their GUI). All sessions within a traffic class are assumed to have the same patience index. TIP records to find the fraction of traffic corresponding to each traffic class in any given period. The sum of waiting functions for all traffic classes, weighted by these fractions, is then the aggregate waiting function for that period. In this section we demonstrate the benefits of TUBE's pricing by comparing the TIP (i.e., pre-TDP) temporal demand curve with that of TDP to analyze the latter's success in attening out the `peaks' and `valleys'. An operational TUBE system should measure the TIP and TDP traffic volume difference in each time period to estimate user patience indices for different traffic classes. But for the purpose of simulation, estimates of these patience indices had to be gathered by conducting consumer surveys, and then using these on the TIP data obtained from AT&T, we analyze how the TDP demand curve should look. The survey records how long users are willing to defer for a given reward, using which we determine a cumulative distribution function over time for the fraction of users deferring their usage. We interpret the corresponding probability density function as the net willingness of users to defer this given type of session for the given reward, and fit the patience indices accordingly. The two main components of the TUBE prototype are the TUBE GUI (graphic user interface) for the user's device and the TUBE Optimizer & Measurement units running on the server side. Individual users install the TUBE application on their machines; the GUI shows them their bandwidth usage, price history, and prices offered by the ISP for the next day. The prices offered from the ISP are synced with the TUBE GUI display in every period over a secure SSL/TLS connection.

The TUBE application also maintains a local profile for the user's usage patterns and his/her monthly budget to recommend session deferrals that can help the user avoid consuming bandwidth at expensive time periods. Depending on the user's decision, the TUBE Application monitor on the user's device can allow or block the ports for certain traffic classes at particular times when the prices are high. Note that the user does not need to always make the decision of deferral manually; the TUBE application can be authorized by the user to run in an `auto-pilot' mode to make these judicious choices, with the user having the power to disable it anytime at his/her wish. On the server side, the TUBE Optimizer measures difference in TIP and TDP usage and computes the future prices being offered to the ISP users using Section 3's algorithm. It consists of measurement, profiling, and price determination engines. The measurement engine uses a Round Robin Database (RRD) [23], to keep track of each user's usage history and passes this information to the profiling engine, which estimates a patience index (in the waiting function) for different traffic classes. Given the patience indices, the price determination engine calculates the optimal reward and publishes it to each user.

V. CONCLUSION

User-provided networks take advantage of the technical capabilities of handheld user-owned devices; and connect different and possibly heterogeneous networks in a bottom up fashion. This constitutes a paradigm shift with the potential to increase the effective capacity of wireless networks by unleashing dormant network resources. One of the main challenges in UPNs is to incentivize the participation of users, on the basis of a fair resource contribution and capacity allocation. In this work, we proposed an optimization framework which maximizes the UPN efficiency, and allocates the produced capacity in a fair fashion. In this paper, we highlight the problem that ISPs face: unlike the costs, their revenues does not scale with user's ever increasing demand for bandwidth. As a result, ISPs across the world are experimenting with different pricing schemes, including usage based and congestion based pricing. However, pricing based just on monthly bandwidth usage still leaves a timescale mismatch: ISP revenue is based on monthly usage but the peak-hour congestion dominates its cost structure. ISPs would like bandwidth consumption to be spread out more evenly over all hours of the day. We show that a dynamic time-dependent usage pricing (TDP) for data traffic can significantly help towards realizing this by exploiting the user's tradeoff between price-sensitivity and delay-tolerance. This pricing system, called TUBE, provides a dynamic way of computing and delivering the right TDP price incentives, and it creates an integrated feedback loop from an operator computing the prices to consumers reacting to them. We also provide a survey of existing pricing practices, and discuss the TUBE architecture and preparations for a field trial at Princeton.

VI. FUTURE ENHANCEMENT

One of the critical factors in enhancing user experience is the user interface we provide. Our team is developing UIs for iPhones, Android, and iPads which allow users to easily monitor their usage and price history, and provides useful recommendation on deferring high bandwidth applications. The UI will allow users to simply select certain applications to specify if the user is delay tolerant for those applications, and the recommender system in its auto-pilot mode of operation can schedule the applications while incorporating this feedback. To remove uncertainity in the monthly bills, an ISP could provide a few options for tiered plans under TDP pricing. The TUBE application running on the user's handset can initially monitor and learn the user's activity patterns, duration, and TDP prices at the time of usage to find the minimum budget that the user needs to allocate each month for his/her data plan. The user can use this suggestion to sign up for the tier which suits him/her usage under TDP pricing.

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