An Economical Cost Model for Fair Resource Sharing in Virtual Home Environments

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***Abstract*—. Home networks are gaining importance due to their development from pure residential networks (e.g. Ethernet LAN) to interconnected home environments, by a convergence of legacy costumer premise equipment. Emergent scenarios offer services which are available across converged home networks, using decentralized architectures for service provisioning, and network control and management. We call such a form of home collaboration Virtual Home Environment (VHE). This contribution provides a service description and a corresponding traffic and cost model for a VHE. The objective of the proposed cost model is to allow an evaluation about the consumptions of each user participating in an VHE. An economic balance is achieved, where contributions are rewarded and consumptions are penalized. This economic balance serves for both, load distribution among users in the VHE, but also to limit users having a negative balance crossing a certain threshold. Users might even be eliminated from the VHE in those cases where negative balances are not equilibrated over a mean- or long time horizon.**

***Index Terms*—Overlay Networks, Peer-to-Peer, Cost Model, Home Networks, Virtualization, Energy Efficiency.**

I. Introduction

MODERN HOME ENVIRONMENTS are envisioned as multimedia homes consisting of a multitude of networked devices, intelligent home appliances, and sensors. In combination with the home computers, these devices form the home network, which is connected to the Internet.

Furthermore, more and more always-on services are requested by home users. Always-on services include multimedia services and home management with/without remote control abilities, in addition to distributed online applications (such as online gaming or P2P file sharing). These current and future always-on services rely on home computers running on a 24/7 basis.

Nevertheless, many of these services only require a limited portion of the available resources in modern PCs, and thus result in under-utilized hardware and causing massive energy wastage in a world wide scope.

The goal of the Specific Joint Research Project *Virtual Home Environments* (VHE), sponsored by the European Network of Excellence EuroFGI[1], is to enable home environments to share their computing resources among each other. This way, applications have access to those resources which are currently not fully utilized by other applications, or which would be idle otherwise. VHE allows the use of resources of other hom networks, and provision of own resources to other homes in a self-organized, decentralized and transparent way for both, users and applications. One important factor of such a give-and-take approach is *fairness*, i.e., a mechanism ensuring that only those homes have access to remote resources, which themselves provide resources to others. In this paper we present the VHE economic cost model for comparing and accounting for remote resource usage in order to ensure system-wide fairness.

[1] http://www.eurofgi.org/

II. Related Works

The demand for a multitude of always-on services in home networks fosters the attractiveness of resource sharing between different home networks. Resource sharing is driven by costs and benefits for the single home. Besides costs for investment in hardware, the operational costs will include *bandwidth* consumption. However, the always-on home computer increases the cost of energy consumption to a new dimension.

Koomey [10] reports a duplication of energy consumption from 2000 to 2005 of volume, mid-range, and high-end servers in the U.S. and worldwide. A similar tendency is to be expected for always-on home PCs. End devices in the home network are contributing to a large portion of the electricity consumption growth in the EU for instance [1].

Computer power can be saved by means of various well known techniques. First, the processor can be powered down using mechanisms like SpeedStep [6], PowerNow, Cool'nQuiet, and Demand Based Switching. These measures enable slowing down the clock speeds (Clock Gating), or powering down parts of the chips (Power Gating), if they are idle [5],[13]. These techniques are usually applied to notebooks and mobile devices but can be used for desktop PCs as well. Further energy saving methods relate to communication energy cost. Battery lifetime of wireless devices can be improved by addressing several layers of the network protocol stack (Physical, Data Link (LLC, MAC), Network, and Transport layers), operating systems, middleware, and applications [7],[14]. All of the above techniques must be regarded as *local* energy saving mechanisms.

Further green computing recommendations are also incited by the US Energy Star2 and the European TCO3 Certification, who rate IT products (mostly monitors) for their environmental properties. Energy has also been addressed in some projects, like the EU funded project SmartHomes [2], coming up with a simulation approach for large-scale energy management, and the approach of remote monitoring of e-energy services [8].

In our scenario however, the home PC is not a stand-alone machine but shares resources with other homes based on resource virtualization. Mechanisms for resource virtualization have been used in different contexts, like Grid computing, server virtualization, and virtualization as it is done in PlanetLab. In Grid and cluster computing (e.g., in Linux clusters) virtualization is used to aggregate a pool of hardware resources. In this context, virtualization aims at hiding the complexity of aggregating several machines in a Grid/cluster forming virtual organizations, like done by Condor [15]. Virtual machines have been introduced to share hardware among several applications and processes running in separated virtual environments. In data centers, energy saving mechanisms have been already been applied. There, servers [4] are consolidated via a central management process, to increase their computational load [9]. The work load per consumed energy is increased, which is the measure used for energy efficiency [12]. In our previous work [16], [17], a distributed P2P approach to interconnect home networks is proposed similar to a PlanetLab [11]. A global approach was taken to share resources and save energy in a large distributed architecture. In addition, we now add a cost model to achieve fairness among the homes contributing to the virtual home environment.

III. Virtual Home Environments

VHE is an architecture which enables energy efficient resource sharing amongst home networks. A (possibly large) number of home networks are interconnected via a P2P overlay. Every home network usually consists of a gateway and a small number of computers, e.g. PCs, home servers or laptops. The number of applications that requires "always-on" hardware (e.g. media-server or file-sharing client) in home networks is growing fast, leading to a high number of computers running on a 24/7 basis. Therefore the main goal of the architecture is to achieve a consolidation of load (e.g. in terms of bandwidth consumption, CPU-cycles or storage) that is generated by always-on applications. The general idea is (similarly to server consolidation as it is done in data centers) to shift load to a small number of computers, in order to relieve others from load. Unloaded computers can be hibernated in order to save energy. The VHE architecture has already been described in [3] and [16]. There we have shown that the VHE architecture actually is capable of enabling energy efficient resource sharing among home networks. Different scenarios have been evaluated concerning the saved energy and the availability of applications. VHE is based on a distributed management approach. The connected homes form a distributed pool of virtual resources, and the architecture uses a distributed management system to allocate resources to home PCs dynamically. To allow energy saving, a distinction is made between active and passive homes (contributing and not contributing homes). A home is called *active* if it contains at least a single computer which is turned on and actively shares its resources. In a *passive* home only the gateway is on-line, and other hardware is hibernated to save energy, i.e. passive homes are temporarily relieved from sharing resources. The (always-on) gateway can be seen as a Linux-based diskless computer with small energy needs. The gateway is able to maintain a permanent entry to the VHE P2P overlay and is continuously representing its home network in the overlay. The P2P overlay enables access to the active and passive home networks and provides services like identifying other peers or providing a system wide distributed database for storing node and user statistics persistently.

Applications are encapsulated in virtual machines (VM), which can be based, for instance, on full virtualization as it is provided by VMWare[2]. Resources are shared in the VHE by running VMs in a home network, that are actually belonging to other home networks. Since VMs can be stored in simple files, they can be moved from one home network to another easily. This way, VMs can be moved away from a slightly loaded home network, in order to relieve it from load and hibernate it.

A VHE is illustrated in Figure 1. In this example two active and a passive home are interconnected by the VHE overlay, and a single VM (with an encapsulated application) is migrated to another home. Home network 2 can change its mode to passive (an hibernate) after the migration, because it is unloaded afterwards.

Although the energy efficiency of a VHE has already been shown in general, some highly important constraints have to be considered. Unfortunately, a fair behavior of all participants of the VHE can not be assumed commonly. Thus it is essential to enforce a fair sharing of resources, and therefore a fair sharing of operational costs (e.g. energy costs). In this paper an economical cost model for fair energy and resource sharing is proposed. Statistics, generated by this model are stored in the P2P network and used to limit the resources a home network is able to request from the VHE.

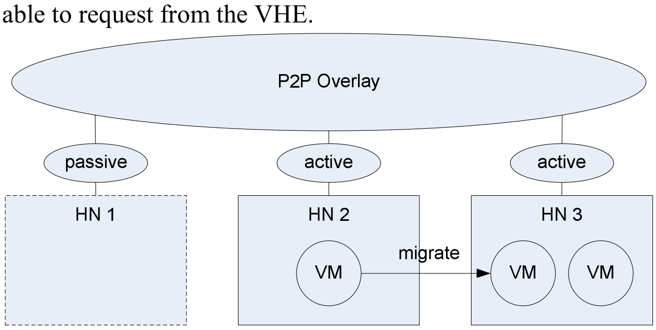


Fig. 1: VHE with one passive and two active Home Networks (HN), and one migrating Virtual Machine VM.

[2] http://www.vmware.com

IV. Cost Model for VHE environments

There are various cost models for communication services and the selection of an appropriate model depends on the corresponding application. The simplest models are based exclusively on the accounting scheme of an operator and such cost models do not have to consider technical parameters resulting from the underlying network.

As currently most networks handle various types of services, more advanced cost models are based on the long cost increment and are named Long Run Increment Cost models (LRIC). These models are mainly used for telecom regulation studies, considering in general the underlying network infrastructure. They assume a network, based on best current technology, which is implemented optimally by a "hypothetical" network operator, entering into the communication service market. Hence, LRIC models should provide the configuration of the network infrastructure for the cost calculation which could be given from the outside (top down approach) or be properly calculated inside of the model (bottom up approach).

A special variant of LRIC is the so called Total Element based Long Run Increment Cost model (TELRIC-model). The TELRIC calculates the cost of a service unit (cu_s) by the sum over the unit cost of all types of network elements ($cune_k$) k=1,…,K and its degree of use fu_{sk} of the corresponding service. Mathematically formulated this results in:

$$cu_s = \sum_{k=1}^{K} cune_k \times fu_{sk} \qquad (1)$$

Note that the use factor fu_{sk} might be even higher than 1 when a corresponding type of network element is used more than once (e.g. use of Base Transceiver Stations - BTS in Network mobile services) or 0 when a service does not use a corresponding type of network element. The unit cost per network element $cune_k$ is calculated by the total annualized cost of the network element ct_k divided by the total traffic $traf_k$ (as traffic mostly the occupancy of the network element over a certain time period is used like Business Hour or annual minutes) which uses the network element resulting:

$$cune_k = \frac{ct_k}{traf_k} \qquad (2)$$

As the total annual cost $CTan$ resulting from the network investment and its periodical renovation and cost part in the network operation must be covered by the results of all services:

$$CTan = \sum_{s=1}^{S} cu_s \times traf_s \qquad (3)$$

Using the formulas (1) and (2) results in:

$$CTan = \sum_{s=1}^{S} \sum_{k=1}^{K} ct_k \times fu_{sk} \times traf_s \,/\, traf_k \qquad (4)$$

This general model must be adapted to the characteristics of the communication network and its corresponding services to be considered in our case to the VHE. For this purpose the network architecture must be identified first, provided services and their corresponding traffic afterwards.

The VHE does not require the consideration of a classical telecom business model for cost and tariff calculation, which are mainly focusing at the point of view of an operator or service provider. Instead, rather objectives of peer-to-peer networks have to be followed, e.g. Chord, see [17], or other common overlays, see for example [18], [19] or [20]. Hence the objective of the TELRIC model is limited to estimate the participation and involvement of the VHE members and corresponding results are used to

- classify the users in a set of classes (at least two),
- determine the upstream velocity,
- determine the distribution of the service requirements over the different VHE.

For this purpose the model has to consider a number of parameters which might be classified into

i. *Fixed* parameters which in generally do not change over time while an user is member of the VHE. These are mainly the hardware equipment and the geographical situation of the user
ii. *Temporal* parameters which might be change through the time an user is member of the VHE. We can assume that over a short time period these parameters are stable. The change will happen in periods of weeks or months, e.g. the type of service an user is willing to provide
iii. Purely *time* parameters which might be measured in a short, medium or long range, e.g. the time a hardware or a service type is connected and available for other VHE members
iv. *Economical* parameters which provide a mean to estimate the degree of service contribution and consumption of a VHE member. These are the kernel parameters which use the values of the parameters i)-iii), and provide finally a numerical expression of the engagement of a VHE user. They are used to award or penalize an user, or if required its classification within a scale from "altruist" up to "leecher".

A. *Primal characteristics vs. Behavioral characteristics*

This section considers the physical part of the VHE client environment. Each VHE client is considered to be a network element and associated with a related *unit cost*

$$cune = f\,(\text{fixed characteristics}) \qquad (5)$$

The physical configuration is used as primal cost calculation basis, consisting of CPU utilization, storage capability, network access capability (upstream + downstream), provided additional services (type of service and its quality) and on the availability of sensors. The parameter set is common to all VHE users and additionally, measures of the traffic allow estimating an associated cost ct normalized by the total costs t_{traf}. The values for each parameter act as a reference for behavioral character calculation.

$$cune = f\,(cu_1, cu_2, cu_3, cu_4, cu_5, cu_6, c_t \,/\, t_{traf}) \qquad (6)$$

Based on these values, each network element has to decide which behavior is shown by the user. Automatically the network element has to introduce corrections to the statistics of the user to accommodate his behavior towards a cooperative one.

The correction of the primal characteristics is based on the client's behavior. Depending on its behavior, the users increase/decrease their associated cost, introducing new facilities/requirements. Behavior modifies the unit cost by getting bonuses based on "altruist / cooperative" behavior or by getting penalties based on "leecher / non cooperative" behavior:

- Storage capabilities (*S*): the user shares his proper multimedia contents (music, video, applications) and all the downloaded files/parts/bytes accordingly to the storage capabilities of the personal VHE environment. VHE estimates the ideal case of full sharing of the total shared space. However, the occupancy varies between 0 and the maximal available space depending of the considered periods. The utility factor varies considering the average occupancy over short range periods CI_S (days) and their correction over medium or long range periods CH_S (weeks, months or years). Over the maximal collaboration premise the user suffers a penalty estimated with the expression
- Access capabilities (*A*): Depending on physical access, the behavior of the users could be measured considering basically the amount of exchanged bytes both in upstream and downstream directions. Usually downloaded bytes mean that shared resource is obtained (using & consuming resources of the VHE environment). The upstream channel sends both control flow and data flow, the last one corresponding to share a resource. The used bandwidth varies depending of the considered periods *t*, over short range periods CI_{up} / CI_{dw} (days, weeks) and their correction over long range periods CH_{up} / CH_{dw} (years). Maintaining similar relations between consumed bandwidth and shared bandwidth equilibrates the factor utility. Collaborative users increase the upload ratio and then increasing the factor utility, and "leecher" increase the relation between download/upload, obtaining a penalty decreasing the utility factor.
- Provided Services / Processing Sharing (ψ): Additionally all the users can increase their collaboration by providing specialized services, based on storage or sharing of CPU cycles. Depending of the type of implied application, a user increases his shared resources, modifying the previous factors of Storage (*S*) and Access (*A*) with a positive tendency towards a possible bonus. The utility factor varies considering the average occupancy over short range periods (month) and their correction over long range periods (year, investment period). Users collaborate with the VHE environment using the resources included into the VHE equipment when $\psi>0$. Over the maximal collaboration premise the user behavior could be awarded.
- Sensor capabilities (*P*): The VHE equipment includes several sensors/probes (temperature, power consumption, etc.) used to obtain additional facilities. Users share these devices accepting requests from centralized servers and other users. In the same way, users can request information from other users about their probes. For each sensor a utility factor appears as the relation between received & accepted requests R_{in} and sent requests R_{out}.

B. Cost Schemes

Table I shows all the main parameters related with the VHE network equipment primal characteristics. "Cost/unit" is the assigned value by the VHE operator/management entity. Each primal characteristic has a static value depending of the physical characteristics of the VHE gateway. Initially the model considers five main parameters which are directly related with the cu_k costs previously explained. The table shows an initial set of values assigned into the calculated scenarios, but their values vary depending of the considered optimization problem, for example, avoiding to obfuscate all the available core bandwidth, or reducing the energy consumption associated with each individual element of the VHE node.

The behavior of the VHE user is captured statistically. The VHE element stores the statistics of all the interesting values corresponding to each parameter over a concrete time period, e.g., one hour. For each specific parameter the VHE element captures its offered numbers ("Offered" column) and its used numbers ("Σ(used)" column). The corresponding "use factor" column is obtained following the previous calculations.

The individual behavior of the users is stored along different time scales (statistics), following three main periods: *short range* statistics, *medium range* statistics and *long range* statistics. The basic unit of the statistics is calculated during the short range period, typically one hour. Then the model makes a service weighting per user and period, depending of the collaboration rate and obtaining the values showed in the table II.

The "Offered" column shows the statistical value of the *shared* resources during the short time period, and its value is corrected using the use factor (introducing the historical behavior of the user related to the parameter). The "Received" column shows the statistical value of the *consumed* resources during the short range period.

Parameter	*Name of cost/unit*	*e.g. cost/ unit*	*Offered*	*Σ (used)*	*Units*	*Use factor*
Storage	cun_S	0.1	S_{max}	S_U	GB/time	$f_p(S)$
Upstream Access	cun_{Au}	1	A_{u0}	A_{up_U}	GB	$f_p(A)\|_{up}$
Downstream Access	cun_{Ad}	0.2	A_{d0}	A_{dw_U}	GB	$f_p(A)\|_{dw}$
Probes/Sensors	cun_P	0.1	R_{out}	R_{in}	1/time	$f_p(P)$
Processing	cun_Ψ	0.5	Ψ_0	Ψ_U		$f_p(\Psi)$

Table 1: Parameterisation of the primal characteristics associated with each VHE NE use

Parameter	*Offered*	*Used*	*Received*
Storage	S_{U0}	$S_{Uc} = S_{U0}\, f_p(S)$	S_{Ur}
Access (Up/Down)	A_{up_U0}	$A_{up\_Uc} = A_{up\_U0}\, f_p(A)\|_{up}$	A_{up_Ur}
	A_{dw_U0}	$A_{dw\_Uc} = A_{dw\_U0}\, f_p(A)\|_{dw}$	A_{dw_Ur}
Probes/Sensors	P_{U0}	$P_{Uc} = P_{U0}\, f_p(P)$	P_{Ur}
Processing	Ψ_{U0}	$\Psi_{Uc} = \Psi_{U0}\, f_p(\Psi)$	Ψ_{Ur}

Table 2: Main statistic values and their corrections based on temporary penalty factors

A. *Short range Cost by Unit*

With all, the model applies the acquired knowledge to measure the *total cost* of one particular VHE *network element* as a function of the primal costs conditioned by the user behavior:

$$cu = \begin{cases} cun_S\left[S_{Uc} - S_{Ur}\right] \\ +cun_{Au}\left[A_{up\_Uc} - A_{up\_Ur}\right] + cun_{Ad}\left[A_{dw\_Uc} - A_{dw\_Ur}\right] \\ +cun_P\left[P_{U0} - P_{Ur}\right] + cun_\psi\left[\psi_{U0} - \psi_{Ur}\right] \end{cases} \quad (7)$$

Applying the calculation to *all the network elements* of the VHE environment (let be *U* the set of VHE users) allows to compute the respective minimum and maximum values, which bound the *cost by network element* :

$$\begin{matrix} c_{\min} = \min\limits_U[cu] \\ c_{\max} = \max\limits_U[cu] \end{matrix} \quad \text{with} \quad \begin{matrix} c_{\min} \le 0 \\ c_{\max} \ge 0 \end{matrix} \quad (8)$$

B. *Normalized Cost by Unit: Users classification*

Using the estimated bounds, the *normalized* cost for each network element is calculated using

$$cu_{nor} = \begin{cases} 1/2 & if \quad c_{\min} = c_{\max} \\ \dfrac{cu - c_{\min}}{c_{\max} - c_{\min}} & if \quad c_{\min} < c_{\max} \end{cases} \quad (9)$$

i.e., $cu_{nor} \in [0,1]$. Let be

$$c_{\lim} = \frac{-c_{\min}}{c_{\max} - c_{\min}} \quad (10)$$

which denotes the bound between altruistic users and leechers. Then, if for a particular network element, its cost unit $cu_{nor} < c_{\lim}$, the user has consumed more resources than offered resources and is thus considered as leecher and must be penalized.

Initially a leecher will be penalized by decreasing his downloading capacities, service requesting, etc. But this behavior could be related to temporary situations. This is the reason because the cost model uses three temporal horizons, and the cu_{nor} is calculated over three time periods, using all the stored statistics:

Range	*Parameter*	*Used as:*	
Short	$cu_{nor}\|_s$	c_{nor}	e.g. 1 hour
Middle	$cu_{nor}\|_m$	$\underset{M}{avg}(c_{nor})$	e.g. 1 day
Long	$cu_{nor}\|_l$	$\underset{L}{avg}(c_{nor})$	e.g. 1 month (30 days)

Table 3: Observation time periods

Leechers have to receive a penalty accordingly with their historical behavior. Penalties are applied to the upstream access that a user can obtain (limiting the downstream of the proper user).

As final classification of the users introducing a corrector factor ε:

- *nU* the total number of users
- *nUd* the number of users with $cu_{nor} < c_{\lim} - \varepsilon$
- *nU0* users with $cu_{nor} \in [c_{\lim} - \varepsilon, c_{\lim} + \varepsilon]$
- *nUu* the number of users with $cu_{nor} > c_{\lim} + \varepsilon$

C. *Penalization based on users behavior*

Into the "short" period for each *nUd* users, the VHE network element has to limit the corresponding numbers for each behavioral parameter to promote the collaborative behavior of the users. For example, downloading capacities are penalized for each short range period using the following expression:

$$A_{dw\_max}^{\;S+1} = A_{dw\_u}^{\;S} \cdot f\left[cu_{nor}^{S}, \underset{M}{avg}(cu_{nor}), \underset{L}{avg}(cu_{nor}) \right] \quad (11)$$

with $f[\;] \in [0,1]$.

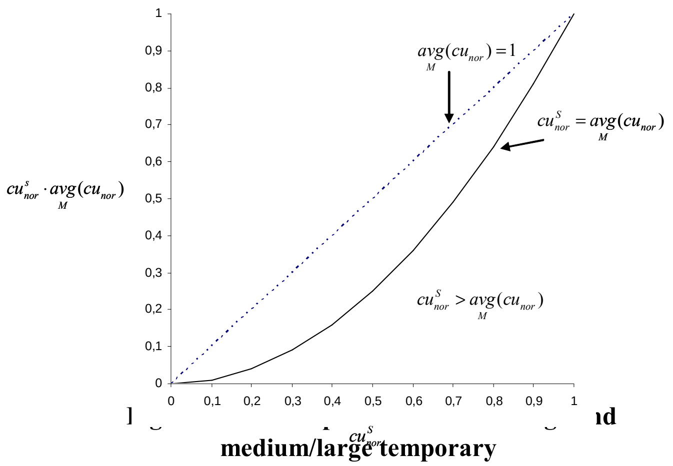
This function applies a penalty in proportion to the immediate statistic but correcting its value with the historical statistics. In this way, only persistent behaviors suffer important reductions into its downloading capacities.

Let be

$$f\left[cu_{nor}^{S}, \underset{M}{avg}(cu_{nor}), \underset{L}{avg}(cu_{nor}) \right] = \begin{cases} 0 & if \quad \underset{L}{avg}(cu_{nor}) < \gamma \\ cu_{nor}^{S} \cdot \underset{M}{avg}(cu_{nor}) & otherwise \end{cases} \quad (12)$$

with γ as limit decided by a "*VHE manager*" to impose a cancellation of the VHE service.

The following figure shows the limits of the penalty associated to temporary behaviors. Higher values of the statistics reduce the penalty considering that the objective tends to 1 for a normal behavior of the user. Large periods of non desirable behaviors influence drastically the short range statistics.



medium/large temporary

V. Experimental results

The proposed analytical solution considers the behavior of VHE users over time, with periodic recalculation which could include corresponding penalizations. Considering all results along relatively long time periods, penalizations follow a smoothed tendency directed towards the correction of the non collaborative users. Based on this idea, the cost model uses all the statistics of each VHE node, obtaining its proper associated cost, which is exchanged with the rest of the nodes (supposing a distributed cost management VHE environment), or sent towards VHE management nodes. Combining all unitary costs, the c_{lim} value allows determining the cutting value of the normalized individual costs, and then, the decision of penalization. All processes begin with a configuration of VHE nodes, initializing the unitary primal costs (imposed by a VHE management entity). During short range periods (typically each hour) VHE nodes collect statistics of their primal parameters, to calculate all corresponding behavioral factors, and finally the proper unitary costs. When a node knows the unitary costs of all the other nodes inside its VHE cluster[3] it calculates the cutting value which determines, if a penalization is done. Penalization supposes establishing new limits for maximal values of all the primal characteristics, which the VHE node has to apply in the next short range period.

To evaluate the performance of the proposed cost model, the explained process has been emulated using a statistical simulator, which generated the supposed statistics corresponding to N VHE nodes. The resulting scenario allows the evaluation of individual costs in the short range period for each node, obtaining the global statistics of a cluster and estimating cutting values to calculate corresponding penalizations. The calculation of the next period uses this penalization values as new input parameters for statistic generation.

A simple scenario of five VHE nodes allows the estimation of the effects of the proposed cost model within a VHE cluster, exchanging contents with a typical P2P application. The evaluation includes two different types of users: Three users have symmetrical Internet accesses showing a very *aggressive* behavior, represented by high downloading rates. In contrast, two other users have also symmetrical Internet accesses, but are showing *normal* behavior, by only doing sporadic downloads. Figure 3 shows the difference between a P2P environment without control over the consumed bandwidth and the same P2P environment using the proposed VHE cost model to establish fair resource sharing schemes. Without control, the aggressive users consume all bandwidth of the network, without restriction (a). Normal users acquire their proper resources but they consume three or four times less than the aggressive users (c). Introducing penalizations based on the proposed cost model, the aggressive users suffer a drastic penalization, reducing the consumed bandwidth 3:1 (d). Normal users indirectly decrease their bandwidth, because the normalized value considers the compounded results, but usually the reduction is less than 2:1 (b). This simple example does only consider the penalization of access rates, the complete VHE cost model establishes penalizations for each primal characteristic, making it an adaptive solution independently of its application.

[3] VHE cluster is the set of nodes related one to the others because all exchanges resources during a short range period.

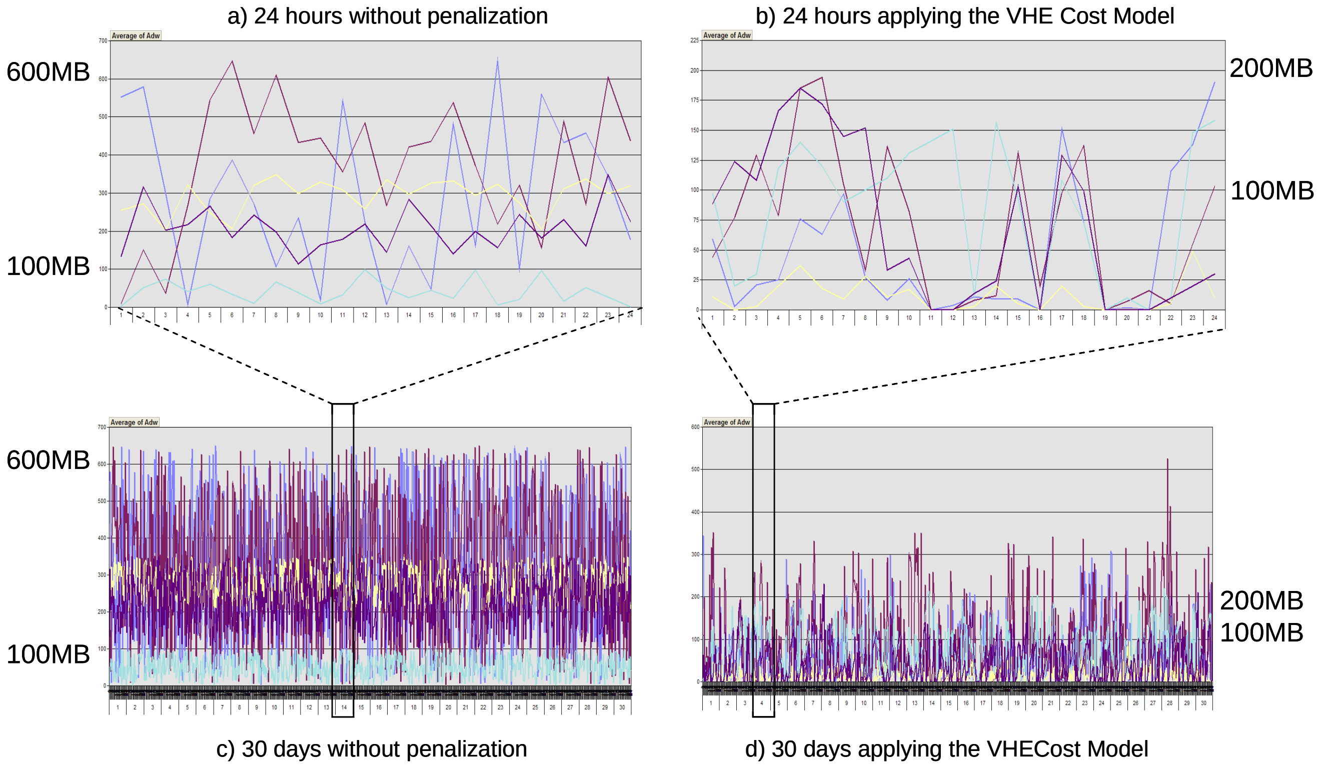


Fig. 3: Statistical results for a VHE scenario based on 5 nodes using P2P applications. (a) and (b) shows details of 24 hour of the statistics, without any restrictions and using the VHE cost model respectively. (c) and (d) shows the same statistics but for 30 consecutive days.

I. CONCLUSIONS AND FUTURE WORKS

The VHE defines a new resource sharing environment based on multiple applications. In VHE the collaboration between users considers both, the proper benefits in terms of resource sharing and the reduction of the significant related cost, e.g. in terms of bandwidth, or more important, in terms of energy consumption. The proposed VHE cost model estimates the main working parameters for each network element into the basis of collaborative behaviors. Following this idea the resource sharing environment adapts its primal characteristics depending of the use of the network, establishing penalizations for all “dangerous” behavior and allowing a fair sharing of the resources.

In this sense, selfish users decrease automatically their statistics, granting other users access to the rest of the unused resources. Depending on their activities over time, this situation could finish with the elimination of all privileges of the user.

However the application of the cost model implies to solve some additional questions. Each node is autonomous in making calculations of periodical statistics, the unitary costs, the bounds of the normalized costs and the penalization threshold. However, in order to complete this process, each node has to know the cost values for all other nodes as well. The implementation needs to evaluate mechanisms for the exchange of short range period costs, first. Two possibilities are possible, a centralized solution, using monitoring nodes which obtain directly the cutting limit for the penalization decision, or a distributed solution, making exchanges between direct related nodes only, by establishing the corresponding VHE clusters.

Another question is the concrete application of the cost model, to obtain a real benefit in reducing the total consumption of a set of VHE nodes. More intensive studies are necessary, and only multiple simulations could obtain concrete conclusions. Statistical emulation is insufficient in this case, because the progress of the environment depends exclusively of the analytical calculations. A fully modeled environment is necessary. A complete simulation is needed, including all the logical parts of the VHE network elements, applications, and services, together with an implementation of the presented cost model.

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