Enabling Free Internet Access at the Edges of Broadband Connections: A Hybrid Packet Scheduling Approach*

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Broadband connection sharing constitutes a network resource pooling technique that could evolve toward supporting the establishment of the “Free Internet for all” notion. This technique could be implemented through the User-Provided Network model in which end-users could become suppliers of Internet connectivity. In this paper, the behavior of such system is investigated from a queue-management perspective. A numerical analysis that takes into consideration both the high variability of broadband link speeds and different packet-size distributions is presented. Based on these results, we propose a hybrid packet scheduling scheme that enables the application of Less-than-Best-Effort services at the connection edges and allows for the development of different packet scheduling policies corresponding to different requirements. Some significant open issues and research directions are also highlighted.

I. Introduction

“Free Internet for all” is a notion introduced by Vint Cerf [1] that has not been realized yet although it could have a huge social impact. Recently, LCD-Net: Lowest Cost Denominator Networking [2] was proposed to realize this concept. It approaches the issue from various angles investigating possible infrastructural, networking and economic barriers. From a networking perspective, it proposes the exploitation of several existing resource pooling Internet technologies to enable free Internet. A basic prerequisite though to make such a scheme successful and sustainable is for the system to ensure zero impact on the users or network operators who share their resources and at the same time incentivised them for doing so. The work proposed here is towards this direction.

Our work departs from broadband connection sharing; a network resource pooling technique whose implementation can be based on User-Provided Networks (UPN). The philosophy behind this idea is well-developed in [1, 3], where the authors also present possible incentives for its use. The concept of UPNs comprises two main entities: i) the micro-provider, which is the home-user or group of home-users that own the broadband connection and ii) the group of guest-users. Guest-users are often considered to be wireless connected users that need to freely access the Internet by exploiting the available unused capacity. Such a type of access could be implemented by mandating Less-than-Best-Effort (LBE) services, which provide lower access priority to the available resources compared to the standard Internet Best-Effort (BE) services offered to typical subscribers. In the current study, we investigate the behavior of such systems from a queue-management perspective.

Unlike other type of services such as guaranteed and Better-than-Best-Effort (BBE), LBE service determines in its own right the target level of service. That is, LBE service clearly corresponds to low-expected quality, which however cannot be that low to violate the notion of service itself. Service in this case is the reason for the system to exist: no user, even free, would punish himself by attempting to access a system repeatedly that will, likely, not work. This last argument constitutes the main philosophy in the present work. In particular, we are seeking technically feasible approaches that could be used to design network tools that allow for BE- and LBE-traffic to coexist harmonically. However, prior to designing such tools, we study here the feasibility of such systems along with their potential to guarantee the corresponding level of services. Clearly therefore, we assume that even LBE service requires to guarantee some level of service.

In this context, we assess numerically the impact of LBE-traffic on BE-traffic in association with different packet-size distributions and varying network speeds. To the best of our knowledge, our study is the first one to report results in this topic for different packet-size distributions; a rather important network parameter that largely affects both the average service time of the system, as well as its modeling and analysis methodology. Based on our findings, we show that i) the approach followed by other proposed methods for LBE-traffic regulation is not optimal in several cases and ii) there is a certain bandwidth availability point over which the trade-off between allocating resources to serve LBE-traffic exclusively and increasing the impact on queueing delay for BE-traffic is efficiently balanced. This fact allows Priority Queueing-type schemes (PQ-schemes) to be replaced by Weighted Fair Queueing-type schemes (WFQ) in order to guarantee a certain level of service.

Along these lines, we continue our work on the recently proposed Hybrid Packet Scheduling Scheme (HPSS) [4] by introducing and analyzing the behavior of a more sophisticated packet scheduling policy, based on HPSS. The new policy allows for a more effective exploitation of the available resources by the guest-users. However, we also identify inherent limitations of current network architectures along with other issues that may damage efficiency.

The rest of the paper is structured as follows: In Section II, we present the related work. In Section III, we discuss modeling concepts, outline the applied numerical analysis and present the results. In Section IV, we describe the design principles of Hybrid Packet Scheduling Scheme and propose an improved packet scheduling policy, based on HPSS. In Section V, we discuss a number of open issues and elaborate on the potential applicability of Delay Tolerant Networking (DTN) technology in UPNs. Finally, our study is concluded in Section VI.

II. Related Work

During the last few years, broadband connection sharing has earned a central role in the international research agenda of mobile networking due to high demand for seamless network connectivity anytime, anywhere. Several commercial and non-commercial efforts trying to address that issue have emerged, focusing primarily on broadband connection sharing through Wi-Fi technology. Hotspot, social-networking, mesh-based, mobile-based and provider-based UPN models are among the most common architectures of UPN. FON [5], OpenSpark [6], Wifi.com [7], Open-Mesh [8], and Netsukuku [9] are few of the most active communities currently operating across the globe. Despite the fact that each one of them presents different advantages and disadvantages (e.g. limited maximum speeds, manual configuration etc.), their common characteristic is that none of them is able to support the “Free Internet for all” notion. Their design and deployment philosophy of extending user’s paid services hinders their deployment under such broadband connection sharing schemes. Unlike the aforementioned efforts, Public Access Wifi (PAWS) [10] is a recent innovative research project that seeks to develop technology for enabling the “Free Internet for all” notion. It aims to achieve that target by providing LBE access to guest-users, enabling them to exploit the spare capacity in existing broadband connections in homes and public buildings. The key idea of this effort is that the LBE service could act as the foundation of a network architecture that implements the “Free Internet for all”.

Several research studies and technical reports have been published on the deployment and configuration of the LBE service on ISPs’ core network. In [11], Carlberg K. et al. present the design and implementation of a novel architecture that supports LBE traffic and propose the Persistent Class Based Queueing system (P-CBQ) as the preferred scheduling mechanism that determines the rate of service between BE- and LBE-traffic classes. P-CBQ degrades the service of a class at some specified rate according to a penalizing algorithm. After the incorporation of LBE service in well-known educational networks such as GEANT and Internet-2, authors in [12] and [13] have studied several possible packet scheduling configurations based on Weighted Round-Robin (WRR), Modified Deficit Round-Robin (MDRR) and Weighted Fair Queueing (WFQ) schemes. In most cases, they conclude in assigning a fixed weight (e.g. 1% of the total available bandwidth) on the service of the LBE traffic. In practical terms, scavenger flag has been defined in the DiffServ architecture for marking the LBE-traffic and networking companies, such as Juniper Networks and Cisco have already integrate it in their routers.

While there is a substantial number of studies for the deployment of LBE service and its related issues on ISPs’ core network routers, there is a lack of collaborative deployment studies for the APs of broadband ADSL connections. The proposed approaches so far are either based on specialized transport protocols [14] or on queue-management techniques for packet scheduling [15]. Based on the topic of our work, we focus on the second category. In [3, 15] the authors present UPNQ, a packet scheduling mechanism based on the non-preemptive priority queueing scheme (PQ). The ΣM/D/1 queueing model is used to analyse the behavior of the
system, as a result of assuming fixed packet sizes. By applying an algorithm that regulates the rate in which LBE-traffic is served, they show that a small rate of LBE-traffic packets can be served with statistically zero impact on the performance of the BE-traffic.

In this paper, our modeling philosophy adopts most arguments stated in [15]; we cancel, however, the fixed packet-size assumption by studying the impact of different packet-size distributions on the performance of the system. Furthermore, we propose a new approach for regulating LBE-traffic.

III. System Modeling

In a user-provided network, traffic can be classified into two major categories: home- and guest-traffic. For both groups we assume the following: i) traffic is generated by a large number of flows $^1$, ii) flow arrivals follow a Poisson distribution, iii) packet-size varies from 40-1500 bytes and iv) same packet-size distribution.

Traffic differentiation in an AP that implements a network resource sharing scheme can be aligned to a queue-management perspective by assigning each group of traffic to a different class of service. We consider the following traffic-classes: i) BE-class and ii) LBE-class. Packets of the home-traffic are assigned to the BE-class while guest-traffic packets are assigned to the LBE-class.

We expect that each micro-provider will share a single broadband link, so it is reasonable to assume that our system is supported by a single server. Since we are dealing here with packets produced by common Internet applications and due to the abundance in storage space that the new architecture will provide, we can safely assume that the buffering space of the AP is infinite. In this context, $\Sigma M/G/1$ is selected for our analysis.

III.A. Numerical analysis

Through the present analysis, we aim at evaluating the impact of guest-traffic on home-traffic in terms of queueing delay and average system time. Bandwidth availability on the transmission link and packet-size distribution of the flows are two critical factors for the overall behavior of the system, since their respective values have a direct impact on the average service time. In general, service time is proportional to the size of a packet. Based on the assumptions presented in the previous section, we expect from both classes to present equal average service times.

In particular, we are interested primarily in drawing conclusions for the upstream link, since its allocated bandwidth is usually low and highly variable. Typical values of the allocated bandwidth for the upstream link range from hundred Kbps to a few Mbps. Unlike upstream, the downstream link is significantly faster, with typical bandwidth values in the order of tens of Mbps.

As far as packet-size distribution is concerned, the particular choice of queueing model allows for investigating the behavior of queueing delay under general distribution service times. That said, we analyze the impact of different packet-size distributions on the queueing delay of the system. We consider several bimodal and trimodal packet-size distributions found in the literature [18, 19]. A list of the examined packet-size distributions is presented in Table 1.

<table>
<thead>
<tr>
<th>Model Descriptions (in bytes)</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-576-1500 (tri-m)</td>
<td>58% - 33% - 9% [18]</td>
</tr>
<tr>
<td>40-576-1500 (tri-m)</td>
<td>40% - 20% - 40% [19]</td>
</tr>
<tr>
<td>64-1300-1500 (tri-m)</td>
<td>60% - 20% - 20% [19]</td>
</tr>
<tr>
<td>64-1500 (bi-m)</td>
<td>60% - 40% [18]</td>
</tr>
</tbody>
</table>

Our numerical analysis is carried out in steady-state condition ($\rho<1$) and is completed in two stages. We start by analyzing the behavior of the system when it operates under a First Come First Served policy (FCFS) with no priorities. This part of the analysis allows for a rough estimation of the average global system time. In case the range of average global system time values exceeds an acceptable level the AP should apply proper scheduling mechanisms in order to guarantee that the impact in terms of additional queueing delay is statistically zero for the home-group users. Furthermore, the applied scheduling mechanism should also allow guest-users to fully exploit the capacity of the broadband link in case of zero home-traffic. In that context, the second stage of our analysis includes the investigation of system’s behavior under a non-preemptive priority queueing policy with BE-class traffic having full priority over LBE-class traffic.

Finally, also note that, for convenience, BE-class and LBE-class are denoted as classes 1 and 2, respectively, throughout the analysis. Our notation is summarized in Table 2.

---

$^1$ Several studies suggest that the packet arrival process for highly multiplexed environments tends to follow a Poisson distribution [16, 17].
Table 2. Notation table

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\lambda_i)</td>
<td>Arrival Rate of Class-i</td>
</tr>
<tr>
<td>(\lambda = \lambda_1 + \lambda_2)</td>
<td>Total Arrival Rate</td>
</tr>
<tr>
<td>(E(S_i))</td>
<td>Average Class-i Service Time</td>
</tr>
<tr>
<td>(E(S))</td>
<td>Average System Service Time</td>
</tr>
<tr>
<td>(\rho_i = \lambda_i / E(S_i))</td>
<td>Utilization of Class i</td>
</tr>
<tr>
<td>(\rho)</td>
<td>Cumulative Utilization</td>
</tr>
<tr>
<td>(Cv(S_i))</td>
<td>Coefficient Variation of Service Times</td>
</tr>
<tr>
<td>(V(S_i))</td>
<td>Variance of Service Times</td>
</tr>
<tr>
<td>(E(W_i))</td>
<td>Average Class-i Waiting Time</td>
</tr>
<tr>
<td>(E(R_i))</td>
<td>Average Class-i System Time</td>
</tr>
<tr>
<td>(E(W))</td>
<td>Average Global Waiting Time</td>
</tr>
<tr>
<td>(E(R))</td>
<td>Average Global System Time</td>
</tr>
<tr>
<td>(E(RS))</td>
<td>Mean Residual Service Time</td>
</tr>
<tr>
<td>(K)</td>
<td>Percentage Impact of Traffic Class-2 on Traffic Class-1</td>
</tr>
<tr>
<td>(I)</td>
<td>Temporal Impact of Traffic Class-2 on Traffic Class-1</td>
</tr>
</tbody>
</table>

### III.A.1. FCFS policy (no priorities)

The total arrival rate of the system equals to \(\lambda = \lambda_1 + \lambda_2\), therefore, the average global waiting time equals to:

\[
E(W) = \frac{E(RS)}{(1-\rho)}
\]

(1)

Mean residual time for \(\Sigma M/G/1\) systems is given by:

\[
E(RS) = \frac{\lambda E(S^2)}{2}
\]

(2)

Since \(Cv^2(S) = \frac{V(S)}{E^2(S)}\) and \(E(S^2) = V(S) + E^2(S)\), we proceed in substituting \(E(S^2)\) with \(E^2(S) \ast (1 + Cv^2(S))\) and based on Eqs. (1) and (2), we get the average global waiting time:

\[
E(W) = \frac{\lambda E^2(S)(1 + Cv^2(S))}{2(1 - \lambda E(S))}
\]

(3)

The average global system time is given by:

\[
E(R) = E(W) + E(S)
\]

(4)

### III.A.2. Strict non-preemptive priority scheduling

The average waiting time for traffic classes 1 and 2, respectively, equals to:

\[
E(W_1) = \frac{E(RS)}{(1 - \rho_1)} \quad (5)
\]

\[
E(W_2) = \frac{E(RS)}{(1 - \rho_1)(1 - \rho_1 - \rho_2)} \quad (6)
\]

Then, the mean residual time is given by:

\[
E(RS) = \frac{\sum_{i=1}^{I} \lambda_i E(S_i)}{2}
\]

(7)

Since packet-size distribution is the same for both classes we get:

\[
E(S) = E(S_1) = E(S_2)
\]

(8)

\[
Cv^2(S) = Cv^2(S_1) = Cv^2(S_2)
\]

(9)

Based on Eqs. (5), (6), (7), (8) and (9) we calculate the average waiting time for both classes as follows:

\[
E(W_1) = \frac{(\lambda_1 + \lambda_2) + E^2(S)(1 + Cv^2(S))}{2(1 - \lambda_1 E(S))}
\]

(10)

\[
E(W_2) = \frac{(\lambda_1 + \lambda_2) + E^2(S)(1 + Cv^2(S))}{2(1 - \lambda_1 E(S)) (1 - \lambda_1 E(S) - 2E(S))}
\]

(11)

Average service times for each class and the average global system time, respectively, are given by:

\[
E(R_1) = E(W_1) + E(S)
\]

(12)

\[
E(R_2) = E(W_2) + E(S)
\]

(13)

\[
E(R) = \frac{\lambda_1 E(R_1)}{I} + \frac{\lambda_2 E(R_2)}{I}
\]

(14)

In order to calculate the impact of traffic class-2 on traffic class-1, we calculate the average system time of class-1 in case of zero traffic:

\[
E'(R_1) = E'(W_1) + E(S), \text{ where } \lambda_2 = 0
\]

Based on Eq. (10) we get:

\[
E'(R_1) = \frac{\lambda_1 + E^2(S)(1 + Cv^2(S))}{2(1 - \lambda_1 E(S))} + E(S)
\]

(15)

Therefore, the average impact in milliseconds (I) equals to:

\[
I = E(R_1) - E'(R_1)
\]

(16)

Percentage-wise the impact can be calculated as:

\[
\frac{E(R_1)}{E'(R_1)} = 1 + \frac{\lambda_2 E(S)(1 + Cv^2(S))}{\lambda_1 E(S)(1 + Cv^2(S) - 1) + 2}
\]

(17)

From Eq. (17), we observe a K percentage increase on the average system time of class-1, equal to:

\[
K = \frac{\lambda_2 E(S)(1 + Cv^2(S))}{\lambda_1 E(S)(1 + Cv^2(S) - 1) + 2}
\]

(18)

### III.B. Results

#### III.B.1. Impact of different packet-size distributions and bandwidth capacities on average global system time

Based on Eq. (4), we obtain the results presented in Figure 1. It is clear that the longest queueing delays...
are produced by the bimodal packet-size distribution while the 58-33-9 trimodal packet-size distribution produces the shortest queueing delays.

The other two packet-size distribution models present statistically similar behavior, exhibiting performance close to bimodal distribution. As expected, bandwidth capacity significantly affects queueing delays, especially under high channel utilization. An interesting observation is that even in high-bandwidth configurations, average global system time remains close to the bound of 1 second; a rather significant delay especially for delay-sensitive applications. This fact constitutes a strong indication that time-sensitive applications ran by the home-group users might suffer intolerable delays and, hence, calls for a queueing scheme with priorities that classify packets according to some predefined level of service.

III.B.2. Impact of guest traffic on home-users’ traffic

The rest of the results presented in this paper are focused on the bimodal distribution, in which the system exhibited worst performance. It should be noted though that similar analysis could apply to other packet-size distributions, as well.

Figure 2 presents the average system time for both classes under several combinations of channel utilization. Priority queueing reduces significantly the average system time of traffic class-1 (under 50ms in most cases), even for high channel utilizations. Note that, in any case, maximum class-1 delay is equal or less than average global system time (see in Figure 2, case “Class-1, λ2=0, λ1=λ”), which reaches here up to 11 seconds for high channel utilizations.

Both the percentage and temporal impact of traffic class-2 on average system time of traffic class-1 are depicted in Figures 3 and 4, respectively. Various loads of total channel utilization for two highly-discrepant broadband link speeds are examined in order to understand how the system behaves under diverse network configurations. In particular, Figure 3 captures the increasing pace of the impact of traffic class-2 on traffic class-1. Figure 4 shows that the additional average delay imposed to traffic class-1 can reach, in the worst case, up to 11ms; a rather significant delay considering that typical round-trip times (RTT) between home-users’ ADSL APs and popular websites are ranging between 60 and 100ms. However, we also note that even for low-bandwidth links a corresponding area exists (see Figure 4, x-axis 0-10%), in which proper regulation of traffic class-2 can lead to significantly shorter delays. Therefore, packet scheduling appears in such cases to be a powerful tool to control the impact on traffic class-1. In the following, we present two potential options for regulating λ2: i) Based on Eq. (18) and setting K appropriately to confine λ2 (this is the method used in [15]) and ii) Based on Eq. (16), where λ2 is regulated by its actual impact on class-1 in milliseconds. A careful comparison of Figures 3 and 4 though, reveals that the percentage impact values do not correspond to the respective values in milliseconds. Consider for example the “99.9% Load” line for the 500Kbps and 6Mbps bandwidth availability cases in both graphs. Although the percentage behavior is exactly the same, the respective temporal impact differs by almost 10 ms. Therefore, the percentage-based approach for regulating the rate of LBE traffic can be suboptimal is some cases, since it does not provide any quantitative characteristics of the additional imposed delay, such as its order of magnitude. Having said that, we argue that Eq. (16) is more efficient for regulating λ2.
Finally, the results presented in Figure 5 indicate that a bandwidth availability point exists over which the impact on average system time for class-1 remains under a specific target value. For a target impact value of 1ms, this bandwidth availability point is estimated at 6Mbps, whereas if the tolerated impact by traffic class-1 was relaxed to 3ms, the corresponding bandwidth availability point drops at 2Mbps. This behavior constitutes a clear indication that over a low-bound value of bandwidth availability, a certain amount of bandwidth could be exclusively allocated to traffic class-2, without having any major impact on traffic-class 1. The value of such bound may be adjusted towards the level of home-users tolerance.

IV. Towards A Hybrid Packet Scheduling Scheme

Departing from these observations, we propose a hybrid queueing scheme for enabling LBE service in the APs of UPNs. Our scheme applies service differentiation on a per-packet basis and has two modes of operation. In the first mode, which is active when link speed is below a certain bandwidth availability point, the scheme applies a non-preemptive PQ policy between BE- and LBE-traffic. Unlike [15], our temporal-based packet scheduling approach confines the additional delay imposed on traffic class-1 (BE-traffic) under a specific target value. For example, in case the additional delay of 3ms is considered insignificant, the results presented in Figure 5 prompt for a bandwidth availability point of 2Mbps. The second mode of operation is activated for link speeds over that particular bandwidth availability point. In this mode, a class-based WFQ policy is applied, which allocates resources per class in order to guarantee a minimum service rate, as long as the total channel utilization is less than 98%. In case channel utilization exceeds that limit, the system cancels the CB-WFQ policy, and applies a non-preemptive PQ policy instead, to guarantee that the impact will not exceed a tolerable value.

The reasoning behind that strategy derives from the fact that in both 60-40 and 60-20-20 packet-size distributions the additional delay between applying a class-based WFQ and a PQ policy increases exponentially as channel utilization increases (see Figure 6). In particular, the additional delay imposed to the average system time of traffic class-1 remains under tolerable levels for channel utilizations up to 98%; for higher channel utilizations the impact grows further. The same results also suggest that an increase in the allocated resources for class-2 (LBE-traffic) of 0.5% per Mbps (e.g. 2Mbps: BW\_class-2 = 0.01*BW\_total, 10Mbps: BW\_class-2 = 0.05*BW\_total etc.) stabilizes the additional imposed delay around a particular target value, here 2ms, and guarantees a limited additional impact for traffic class-1 average system time, compared to the corresponding impact of non-preemptive PQ policy. Beyond that level, statistical impact becomes significant. (see Figure 6 - 1% per Mbps cases, e.g. 2% - 2Mbps case). All remaining resources, obviously, are allocated to the service of class-1.

In Figure 7, we present the actual average system time of traffic class-1 for various policies and bandwidth capacities. It becomes apparent that the advantage of CB-WFQ to allocate resources more...
efficiently is not achieved at the expense of a statistical significant impact.

It should be mentioned here that the suggested values are not restrictive; instead, HPSS provides high level of flexibility to adjust the specific parameters according to the administrator/home-user requirements. Therefore, other variants of HPSS may correspond better to other requirements. Such a conservative variant was proposed in [4], where bandwidth availability point was set to 6Mbps and the percentage of allocated resources for serving the LBE-class was decreased (see Figure 6, 0.5% - 6Mbps case), to guarantee further low impact on the BE-class traffic when the channel was fully utilized. The trade-off here is the low service rate (30Kbps) of the LBE-class.

Please also note that the average system time per class for the CB-WFQ policy is calculated using the lower-bound mean delay limit equation for the M/G/WFQ model presented at [20].

V. Open Issues - Discussion

Despite the clear conceptual and technical advances of the recent proposals, there are still open issues. Such issues are related primarily to traffic measurement and monitoring, network application requirements, and network architecture.

A wide range of network QoS management and engineering tasks rely on traffic measurement and monitoring techniques. In particular, traffic load monitoring has a vital role in the parameterization of queueing policy and directly affects system’s behavior. Although several passive and active bandwidth monitoring methods have been proposed in the literature, none of them has managed to adequately balance both accuracy and high-granularity [21, 22]. In practical terms, most routers/access points provide bandwidth monitoring statistics in 5 – 30 seconds intervals; therefore, they may fail with burstable traffic patterns that occur in shorter periods of time [23]. Some experimental access point firmwares, such as the tomato firmware [24], or some software-based bandwidth monitoring tools, such as the free bandwidth monitoring tool [25], are able to update the provided statistics in intervals of 2 and 0.5 seconds, respectively. However, those intervals might be adequate for general purpose network management tasks but not for queueing applications. Especially in LBE schemes, an undetected burst in traffic when the system operates under high channel utilization can cause severe impact on home-user service. Therefore,
the preferred bandwidth monitoring timescale for queueing-specific utilities, such as HPSS, is in the order of a few hundreds or even tens of milliseconds. In their effort to alleviate those limitations, current schemes are forced to introduce several protective measures, in order to guarantee the effectiveness of the applied policies.

The type of applications most commonly used by guest-users, as well as their bandwidth requirements, is another crucial issue that needs further investigation, in terms of statistical data collection and in the context of preserving home-users’ service quality. Most VDSL2 broadband connections provide an upload speed of 1 - 2Mbps; in rare cases this value might reach up to 10Mbps. HPSS in such case would lead to reservation for the LBE-traffic of around 40Kbps to 500Kbps. Although this bandwidth availability range might suffice for a few simultaneous web-browsing sessions or even a single low-quality skype video call, it cannot satisfy the requirements of an open communication system based on LBE service, in which the probability of more than one user requesting service at the same time is high. This analysis also suggests that current network architecture has some inherent limitations. Those limitations could be lessened by the deployment of alternative architectures that allow for more flexibility in allocating network resources and satisfy specific LBE service QoS requirements, such as preventing guest-users from starving. Such network architecture must accomplish a dynamic resource allocation and packet admission control policy that has to take into consideration the dynamic variations of the physical channel, a fact that is standing as a major challenge for modern communication systems.

In this context, the deployment of a Delay Tolerant Networking-based (DTN-based) architecture could provide several network-management benefits through appropriate use of storage; and capitalize on exploitation of overlapping multi-access/multi-homing, when available, through resource abstraction. The deployment of a DTN-based service layer could allow more leverage on the APs in making communication/storage tradeoffs, and, thus, dynamically adjust resource provisioning based on adaptive policies. The incorporation of storage into APs’ architecture will enable them to store larger amounts of data for long intervals in contrast to the short buffering time provided by current AP architectures, allowing for further flexibility of dropping policies. This fact, along with enabling DTN services to guest-users, would reduce the overall load of APs, since LBE-traffic could be efficiently imported into the main network flow in particular timeframes of low channel utilization. Idle time and the associated wasted resources can be exploited by guest-users’ applications that are mostly asynchronous and insensitive to large variations in delivery conditions such as web browsing sessions and email services.

Conclusively, we argue here that DTN mechanisms could be utilized not only by simple traffic offloading techniques but also as advanced traffic shaping mechanisms; therefore, we strongly support the deployment of DTN-based architectures by APs.

VI. Conclusions

In this study, we assessed the behavior of a queueing system that administers the resource sharing process of an AP between home and guest users. We highlighted several aspects of the examined model such as the various packet-size distributions and link speeds. We concluded that for low link speeds the application of a priority-queueing system alone is not sufficient: an additional mechanism for regulating the arrival rate of the low-priority traffic is required to guarantee non-significant impact on high-priority traffic. We also identified a traffic pattern for high link speeds that permits a hybrid packet scheduling scheme. HPSS entails low complexity, efficiency and high scalability.

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