# TDCS: A New Mechanism for Automatic Channel Assignment for Independent IEEE 802.11 Networks

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***Abstract*—In the last few years, IEEE 802.11 applications has experienced a significant growth. This expansion creates scenarios where distinct administrators manage wireless networks. These scenarios lack of a unique authority to perform an adequate channel allocation that minimizes the performance degradation generated by medium access sharing and co-channel interference. This work proposes a new dynamic channel selection mechanism that focuses on the restrictions imposed by scenarios with independent IEEE 802.11 networks and adapts faster to the interference pattern variations. Besides, the performance of the new mechanism is evaluated and compared to others through simulations.**

## I. INTRODUCTION

Nowadays, the deployment of IEEE 802.11 WLANs can be considered an astounding success. According to [1], the number of access points (APs) sold during the third quarter of the year of 2004 was of 4,5 million, and it is estimated that the sale of equipments should triplicate in 2009. However, this rapid popularization creates an important performance problem related to the scarcity of channels available in the unlicensed frequency bands. When neighboring cells use either the same channel or overlapping channels, they suffer interference from each other, and this can seriously degrade their performance.

The scarce number of non-overlapping channels in the 2.4GHz ISM band, as much as three in the case of the 802.11b/g networks, makes this problem even worst. It becomes still more serious and common in scenarios known as chaotic [1], non-coordinated [2] or independent. In these scenarios, 802.11 WLANs usually composed by only one AP and some few clients are deployed at home and office environments and are managed by different administrative entities. In dense urban regions, these networks may attain a great density of nodes with more than 1000 nodes deployed per square kilometer.

The independent administration of these WLANs may lead to severe performance degradation. This is due to the facts that the placement of the APs and the channel assignment are done in an uncoordinated way. Normally, administrators of these networks share little familiarity with the technology and do not possess any knowledge of already existing WLANs in the region. According to [3], around 45% of deployed WLANs use the same channel. Since channel assignment is performed in a disordered way, networks suffer from interference due to the overlapping in their coverage areas. This can make these networks share media access or experience a reduction in their SINR (Signal to Interference plus Noise Ratio) and, consequently, an increase in their reception error rate. These problems can cause a bad use of medium resources generating a decrease in the coexisting independent networks' performance.

In the literature, there are several mechanisms and techniques for channel assignment with centralized administration, such as [4], [5], [6]. In most of the cases, the problem of the channel allocation is modeled as a problem of coloring graphs, and what differs an allocation mechanism from another are the imposed restrictions and the objective functions that one want to minimize. In the case of independent networks, some few works have tackled the problem [7], [2], [8], [9], [10], [11]. These works will be discussed later in the paper.

This work proposes a new mechanism for the dynamic channel assignment for independent 802.11 networks. Such mechanism allows the channel allocation in a faster way to the changes in the interference patterns that affect WLANs. The mechanism uses information obtained locally through measurements standardized by the IEEE 802.11k [12], which is an enabling standard for gathering and exchanging information about 802.11 channels and radio.

In the Section II, the existing mechanisms for automatic channel allocation to independent networks scenarios are presented. The Section III describes the new mechanism of automatic channel assignment and the Section IV presents the simulations accomplished to evaluate the performance of some of the mechanisms and discusses results obtained. Finally, the Section V draws the conclusions obtained from the accomplished work.

## II. RELATED WORK

To the best of our knowledge, the first proposal for channel allocation mechanism applicable to independent network scenarios is presented in [7]. In that work, Mishra *et al.* propose a decentralized mechanism that operates in the APs, automatically assigning operating channels for the BSSs. The proposal, denominated Hminmax, is based on the construction of a localized interference graph among BSSs of a certain

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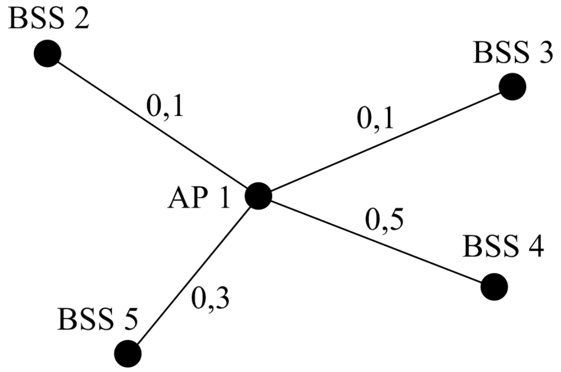

Fig. 1. Example of a localized interference graph from Hminmax mechanism.

coverage area. To build this graph, each BSS uses only local information obtained by the AP, which requests all its clients to scan available channels to detect frames from other BSSs. At the end of the scanning, the AP gathers clients' information conveyed by periodical reports. By the reported clients' measurements, each AP gets knowledge about: in which channels the BSS would suffer interference; which BSSs interfere with it and in which channel; and the amount of stations of its own BSS that suffers from interference. That information is enough to set up a localized interference graph for each available channel. An example of this graph is presented in Figure 1. The weights of the outgoing edges of an AP represent the percentage of its own BSS clients that detected the associated BSS. The channel selection algorithm is a heuristic that minimizes the maximum of BSS clients that suffer interference from the same BSS.

An interesting characteristic of this proposal is the fact of using clients, and not only the APs, in the process of detecting interferences that affect the BSS. This way, each BSS is able of detecting interferences that only affect clients, in situations where clients share the medium with stations of other BSSs.

In another work [2], Mishra *et al.* proposed a new approach for the channel allocation problem in order to improve fairness in channel allocation between BSSs. Due to the reduced number of non-interfering channels for allocation in 802.11 networks and the high densities in independent networks scenarios, it will exist cases where a static channel allocation can cause unfairness in the use of the resources of the communication medium. To solve this problem, [2] proposes a new mechanism based on synchronous changes of channel by the BSSs, denominated MAXchop. This mechanism also builds a localized interference graph in order to define channel-hopping sequences for the BSSs that make the fairest allocation sharing of available channels.

Both proposals, Hminmax and MAXchop, have some limitations concerning the interference graph construction. To build the graph, stations perform a channel scanning looking for traffic from other BSSs. This scanning allows only the detection of interference generated by stations from other BSSs that are within reception range. It happens because the origin of interfering frames needs to be identified and, hence, the frames need to be decoded. However, stations also suffer with medium sharing problem when they are within the carrier sensing range but this interference is neglected during the construction of the interference graph.

Another work that focuses the automatic channel selection problem in independent scenarios is [9]. It proposes a mechanism to be executed by APs that performs measurements of MAC transmission delay at the operating channel to dynamically select the channels with fewer load. The AP consecutively measures the transmission delay of the MAC frames that are sent to clients and keep a table with a moving average of the results. Periodically, it checks if this average crossed a certain threshold to decide whether to keep or to switch the operating channel. The main singularity of this proposal is that it performs measurements in the operating channel only. It is a restriction imposed by the metric selected to estimate load. Measuring MAC transmission delay requires traffic from the AP to its clients in the assessed channel.

When the acquired load in the operating channel surpasses the threshold, the AP select a new operating channel based on the age of the measurements kept in the table. If there are entries older than twice the minimum time to gather measurements in all channels (three non-overlapping in this case), the AP selects the channel with the oldest entry. Only if all table measurements are up-to-date, the AP selects the channel with lowest load value. Therefore, the channel selection mechanism uses the channel selection not only to select the best operating channel, but also to aid the monitoring task.

In [10], the authors also proposed a distributed channel selection mechanism based on a simulated annealing technique called the *annealed Gibbs sampler*. It uses measurements of interference suffered by the AP to select the best channel. One shortcoming of the proposal is that the measurements are performed by the AP only. In this way, the interference suffered by the clients is neglected in the channel selection process.

A recent work from Drieberg *et al.* proposed a distributed mechanism that selects the best operating channel based on the number of clients associated with the neighbor interfering APs [11]. However, some kind of coordination between the APs is required to exchange information regarding the number of clients associated. In independent scenarios, this kind of cooperation between BSSs is not possible.

In the next section we present the evolution of our previous mechanism of dynamic channel selection [8]. The main objective of this new proposal is to improve the detection of changes in the interference pattern of the operating channel. This way, the channel selection mechanism can respond faster, triggering adaptation through channel switches. Besides that, the two versions are fully distributed and aim to select channels were interference caused by media access sharing and co-channel interference is minimized in the AP and its clients.

## III. TRIGGERED DYNAMIC CHANNEL SELECTION

In [8], we proposed and evaluated a mechanism for automatic channel selection denominated here as DCS (Dynamic Channel Selection). Such proposal allows the AP to detect, through measurements performed by its client stations, the interference levels caused by medium sharing and co-channel interference that affect its BSS. Thus, the AP chooses an operating channel with the smallest interference levels. This process is repeated periodically, in a time interval of $T$ in the order of minutes, allowing that possible changes in the interference patterns be detected by the BSS and that the channel allocation is adjusted in order to mitigate the impairments generated by these changes.

To obtain the interference levels due to sharing and co-channel interference, the AP initially requests their client stations to perform measurements of the current occupation and noise level in each channel available for allocation. The occupation level is the percentage of the time that the channel is considered busy by the carrier detection of the measuring node, discounting from this time the occupation generated by packets originated in the BSS of the measuring node. In this way, the occupation level specifies the percentage of time that the channel was busy by traffic generated by other BSSs, indicating the sharing level of this channel. While the noise measured by the clients gives an idea of the co-channel interference level since transmissions of other BSSs outside the carrier-sensing range raise the noise level.

The measurements previously described as well as the messages used by the AP for requesting them and by the clients to report them are under standardization by 802.11k working group of IEEE [12]. The 802.11 devices that incorporate features of this new standard will be able to perform measurements of several 802.11 radio and channel characteristics such as occupation and noise levels of a specific channel. The 802.11k standard aims at providing tools for the development of new features for the 802.11 networks, such as automatic channel selection mechanisms.

When obtaining information previously described, the AP use two vectors: $O_i$, with the mean occupation of each channel, and $N_i$, with the current noise in each channel. Once these two vectors were gathered, the AP executes a channel selection algorithm (Algorithm 1), which is a heuristic that tries to select a channel with the low sharing and co-channel interference levels.

In Algorithm 1, the AP of BSS $i$ first verifies if the mean occupation level of the current operating channel surpasses a tolerance threshold ($\alpha$). If this occupation level is not reached, the AP decides to maintain the current operating channel. This threshold is an adjustable parameter of the channel selection algorithm that defines the aggressiveness of the algorithm, maintaining the current operating channel if a tolerable level of occupation is registered. However, if the channel occupation surpasses the level of tolerance $\alpha$, then it selects $n$ channels with smaller mean occupation levels and after that, among these channels, it selects that with the smallest noise level. This way, the algorithm looks for an operating channel where the interference level for sharing and co-channel interference is low, looking for a configuration for channel allocation that allows a better performance for BSS.

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Notation:
$i$ = BSS identifier.
$k_i$ = channel of BSS($i$).
$O_i$ = vector with mean occupation measured by node $i$.
$N_i$ = vector with mean noise measured by node $i$.
Algorithm in BSS $i$:
if $O_i(k_i) < \alpha$ then
    maintains the operating channel;
else
    selects $n$ channels with smaller occupation;
    selects, among $n$ channels, that with smaller noise;
end
```

**Algorithm 1**: Dynamic Channel Selection (DCS) Algorithm

If the selection algorithm chooses a channel for the BSS that is different from the current operating channel, its decision is informed to the client stations through a beacon message. This way, the clients can start to use the new channel chosen by the AP for their transmissions.

The DCS mechanism presents theoretical improvements in relation to the Hminmax and MAXchop proposals since it captures the interference neglected in the construction of the localized interference graph performed by those mechanisms. It is also better than the mechanism proposed in [9] because the measurements used to select the channel do not depend on the traffic pattern of the BSS and are performed in all channels. However, with the development and the initial evaluation of the proposal it was possible to identify limitations that can harm its' performance in some scenarios. The next section describes such limitations and proposes a new mechanism for automatic channel selection that solves the limitations presented by the DCS mechanism.

The new mechanism, namely TDCS (Triggered Dynamic Channel Selection), is an evolution of the DCS, which was modified to obtain and use a larger amount of information and to allow channel switching triggered by an increase in the level of sharing of the current operating channel. Figure 2 presents a comparison of the operation of both mechanisms as a function of time. As can be seen from the figure, there are large time intervals between consecutive executions of the DCS mechanism. During this time, the interference that affects the BSS operation is not detected. The measurements on available channels for allocation are gathered only when the mechanism is executed. Thus, variations in interference patterns that harm BSS performance cannot be detected and variations that occur just after the selection of a new operating channel will only be detected in the next execution of the algorithm.

Abrupt variations in interference patterns are very common in independent networks scenarios as the appearance of new

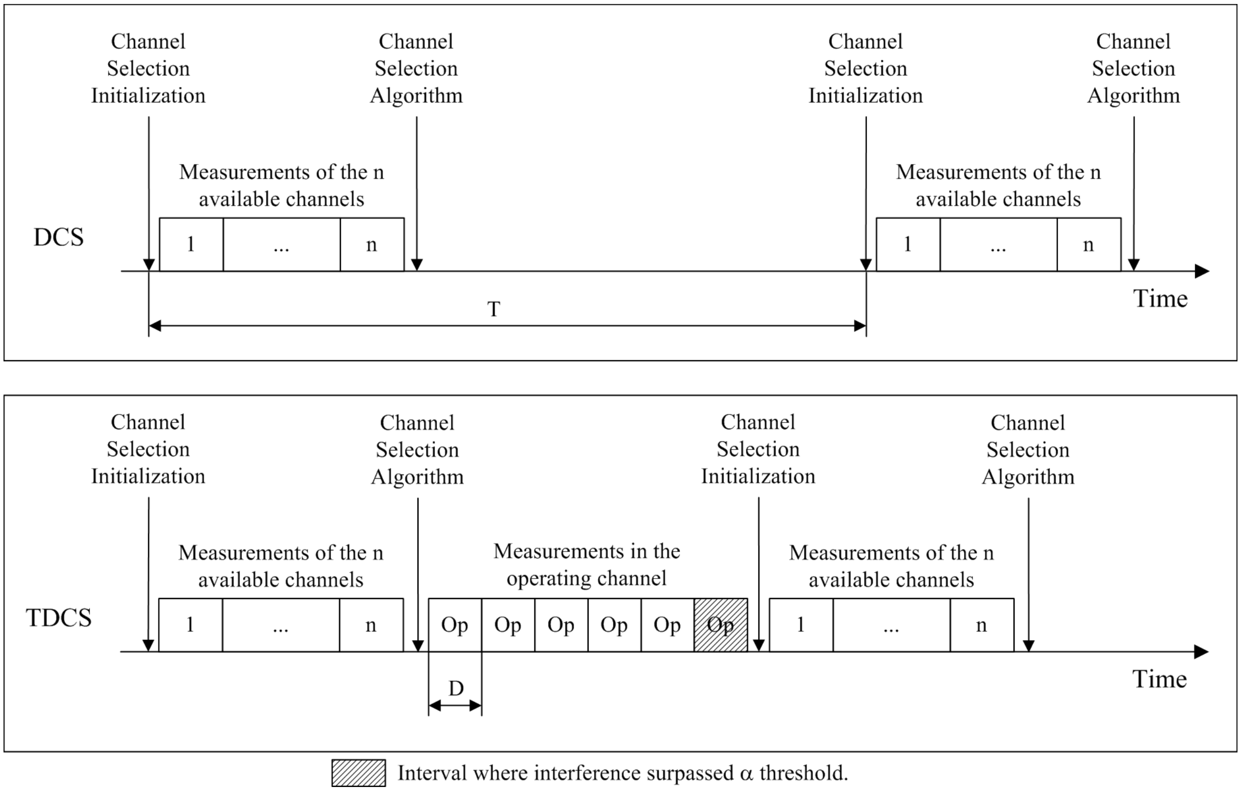

Fig. 2. Operation of the DCS and TDCS mechanisms

BSSs and variations in their traffic demand are frequent. In the case of DCS, these rapid changes can take time intervals in the order of minutes to be detected. Thus, a new proposal that allows faster responses to these interference problems is needed.

In the TDCS mechanism, the AP requests its client stations to generate reports in time intervals of $D$, in the order of seconds, about the occupation level in the BSS operating channel. These measurements do not prevent nodes from functioning normally. According to the 802.11k standard, it is not required that nodes stop sending and acknowledging packets to perform measurements on the operating channel [12]. Thus, the AP can verify by these periodic reports whether the mean occupation level in the operating channel surpassed the threshold of tolerance $\alpha$. When the threshold is exceeded, the process of looking for a new operation channel is started. So, the AP requests its client stations to perform measurements of the occupation and noise levels on all available channels for allocation. Once these data is gathered, the AP executes the channel selection algorithm, which now has only two steps: it selects the $n$ channels with the smallest mean occupation level; and then, among these $n$ channels, it selects the one with the smallest mean noise level.

## IV. SIMULATIONS

We realized experiments with network simulator ns-2 [13] to evaluate the performance of the proposed mechanism. To achieve this goal, several modifications in the original ns-2 simulator code were required. At first, we implemented the channel occupation and noise measuring mechanisms as specified in the 802.11k standard. Additionally, we implemented co-channel interference calculation and its corresponding impact on packet losses due to a reduced SINR. Other key feature implemented is the ability of APs and client stations to switch between channels during a simulation run. Moreover, in order to simulate infra-structured networks, we used the NOAH (*No Ad-Hoc Routing Agent*)[1] module to avoid ad hoc routing traffic. Finally, the *Hminmax* and TDCS mechanisms were implemented.

Besides to these implementations in the ns-2, a centralized tool for channel allocation was developed. This tool reads the positioning scenarios generated for the simulation experiments and provides a channel allocation, which gives an upper bound on the performance in terms of aggregated throughput for each simulated scenario. Thus, this centralized technique, which uses information on all existing BSSs in a certain area, can be used as a benchmark for comparison purposes.

### *A. Benchmark Tool*

Most of the proposals for channel allocation in centralized administration scenarios are based on the graph modeling of the interference among BSSs. From this model, a heuristic seeks for allocations that minimize a specific objective function. Based on this observation, a tool was developed that is

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[1] NOAH - http://icapeople.epfl.ch/widmer/uwb/ns-2/noah/

able to read node positioning scenarios used in ns-2 simulations and search for channel allocation that minimizes an objective function. Once the optimal solution is encountered, the channel allocation obtained can be used in ns-2 simulations for this scenario.

We would like to emphasize that the use of this tool is suitable only in cases where BSSs have a centralized administration since it depends on global information of nodes positioning in the area. Therefore, it could not be used in an environment with independent BSSs. The benchmark tool scans all possible channel allocations and calculates a cost for each configuration according to an objective function. For the interference graph construction, we use the model described in [7], where edges have weights based on the percentage of BSS clients that suffer that interference.

Some different objective functions that could be used with the benchmark tool had their performance evaluated through simulations. However, the one that presented the best results was the $Lsum$ objective function proposed in [7]. In the $Lsum$, the sum of edges weights is calculated for each possible channel assignment in a certain scenario and the allocation where the sum is minimum is chosen. This way, the benchmark tool seeks for a channel allocation that minimizes the total amount of interference that affects the BSS nodes of a certain scenario.

### *B. Simulation Environment and Methodology*

To evaluate channel selection mechanisms in scenarios with independent 802.11 networks in ns-2, we generated 100 deployment scenarios with 4, 6, 8, 10, 12 and 14 BSSs each. All results presented are mean values of 100 deployment scenarios with 95% confidence intervals.

Concerning nodes positioning, we created scenarios similar to that occur in practice in the case of independent networks. On those scenarios, each BSS was formed by one AP and five clients, and those nodes were positioned randomly inside a rectangular area of 1000 meters by 4000 meters respecting some constraints:

- **minimum distance among APs** - a minimum distance of 150 meters among APs as in practice it is unlikely that different APs owners are very close to each other;
- **maximum distance between AP and clients** - a maximum distance of 150 meters between clients and their AP, avoiding that clients are out of reception range of their AP. Besides, it avoids that clients be positioned close to the limits of the reception range of the AP, which in practice would cause instabilities due to variations of the signal level;
- **minimum distance among clients** - a distance of 5 meters among clients avoids that two clients are positioned very close to each other.

In all simulations, the *two-ray-ground* propagation model with standard ns-2 radio parameters was used, yielding 250 meters reception range and 550 meters carrier detection range. The data transmission rate of 802.11 interfaces was setup to 11 Mbps and the basic rate to 1 Mbps, and the background noise is of 10E-13 Watts. For channel allocation, only the 3 non-interfering channels were available, representing the channels 1, 6 and 11 of 802.11 b or g networks. We performed simulations with five different techniques for channel allocation: all BSSs in the same channel; a random channel allocation; the allocation provided by the benchmark tool; and the dynamic channel allocation provided by the Hminmax, DCS and TDCS mechanisms.

The measurement duration of each channel during scanning was 15 ms. This operation is only performed by the Hminmax, DCS and TDCS mechanisms. In the case of the Hminmax and DCS, the $T$ interval among executions of the channel selection algorithm was set to 1 minute in the average. In the case of TDCS, the $D$ interval among reports was set to 5 seconds. In DCS and TDCS, the tolerance threshold ($\alpha$) is set to 20% of occupation and the parameter $n$ is set to one channel. The choice of $n$ equal to 1 makes that DCS and TDCS only select the channel with the smallest occupation. Experiments were done with different values of $n$, and the best results were obtained with $n$ equal to 1. This indicates that, at least in these simulated scenarios, the interference caused by channel sharing is the one that generates the larger impairments in BSSs performance.

Two different types of traffic were used in the experiments: FTP and HTTP. In the case of FTP traffic, each client station downloads a large file during all the experiment. The objective of using this type of traffic is to reach the maximum of the capacity of the network in each BSS. This way, it is possible to maximize the effects of mutual interference among BSSs, making possible the evaluation of the utilization level of available channels. The experiments with FTP traffic had a duration of 300 seconds each.

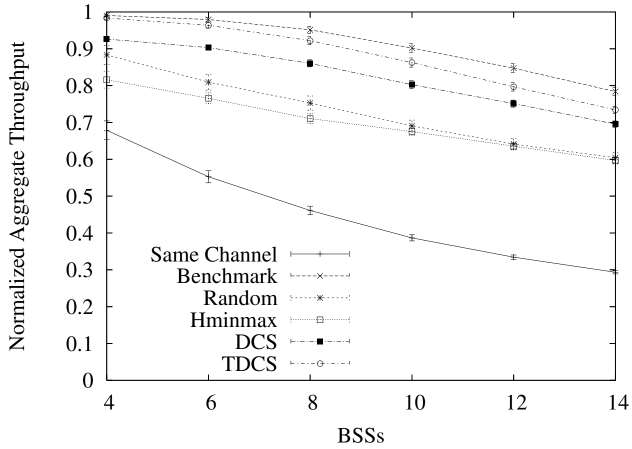
In the case of the HTTP traffic, the web cache traffic generator from ns-2 was used. The module was configured with values obtained in [14] and presented in Table I. The simulations using the HTTP traffic consisted of only one session per client station lasting for the entire experiment. Besides, in each BSS, one of the client stations performs a download of a file during all the experiment with the aim of generating background traffic. The experiments with HTTP traffic had a duration of 600 seconds each.

### *C. Channel Allocation Mechanisms with FTP Traffic*

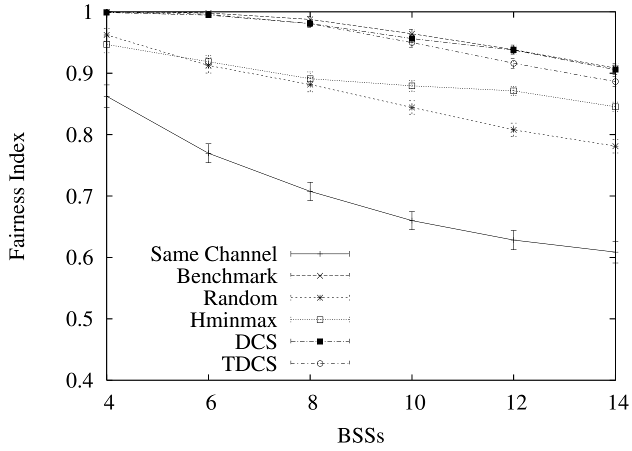
Figure 3(a) shows the normalized aggregated throughput as function of the number of BSSs when using FTP traffic. The aggregated throughput is the sum of throughputs from all traffic flows and it represents the utilization level of channels available for allocation. For the normalization, the equation 1 is used, where: $n$ is the number of BSSs in the scenario; $V_{BSSi}$ is the individual aggregated throughput of BSS $i$; and $V_{BSSisolated}$ is the value of the aggregated throughput obtained by an isolated BSS. This way, the normalized aggregated throughput provides values between zero and one, where the closer to one indicates that the performance approximates the one of an isolated BSS without any interference.

| **HTTP Traffic Configuration** | | |
|---|---|---|
| **Parameter** | **Distribution** | **Configuration** |
| Size of the Objects | Truncated Lognormal | Average = 7758 bytes<br>Deviation = 126168 bytes<br>Minimum = 50 bytes<br>Maximum = 2 Mbytes |
| Objects per Page | Truncated Pareto | Average = 5,64<br>Maximum = 53 |
| Page Reading | Exponential | Average = 30 seconds |
| Page Processing | Exponential | Average = 0,13 seconds |

TABLE I
HTTP TRAFFIC CONFIGURATION.



(a) Normalized Aggregated Throughput



(b) Fairness Index

Fig. 3. Performance comparison of different types of channel allocation with FTP traffic.

$$\textit{Normalized Aggreg. Throughput} = \frac{\sum_{i=1}^{n} V_{BSSi}}{n \times V_{BSSisolated}} \quad (1)$$

As can be seen in Figure 3(a), the TDCS mechanism has a performance close to the one obtained by the optimal channel allocation provided by the centralized benchmark tool. In the best cases, the TDCS outperforms by 8% the DCS, by 18% the Hminmax and by 48% the Same Channel allocation. The gains in comparison to the other mechanisms occur because TDCS responds faster to detected interference. Besides, the Hminmax has the limitation of not capturing all interference in the construction of its localized interference graph. So, it presents performance inferior to DCS and TDCS and similar to the simple random channel allocation.

The other metric evaluated in the experiments was the fairness in the capacity sharing among the BSSs. The fairness index, proposed in [15], was used to this purpose and it indicates how close to each other is a group of values. It is given by $\frac{\left(\sum x_i\right)^2}{n\sum\left(x_i^2\right)}$, which provides the fairness among $n$ $x_i$ values (aggregated throughput of each BSS). This calculation gives values between zero and one, where the closer to one is the value the better is fairness.

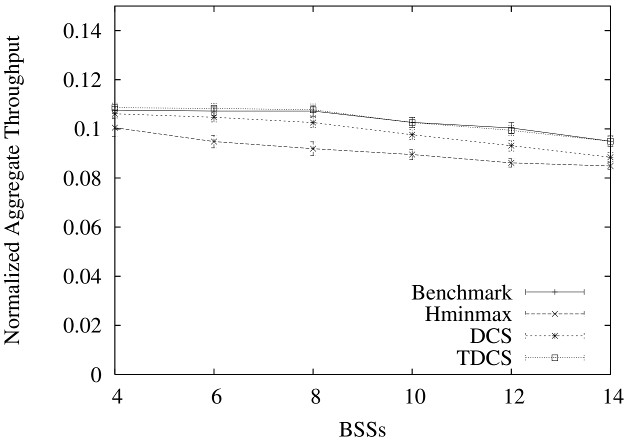
Figure 3(b) shows the fairness index results. For this metric, we can notice that the DCS and TDCS mechanisms presented the best results, close to the performance of the benchmark tool. Therefore, at the same time that it provides a good aggregated performance, the new TDCS mechanism is able to guarantee fairness in the capacity sharing of available channels among BSSs. Meanwhile, the Hminmax presents inferior performance for not being able to detect all interference types. Hence, some BSSs suffer from interference that is not detected, leading to an unfair resource sharing.

### *D. Channel Allocation Mechanisms with HTTP Traffic*

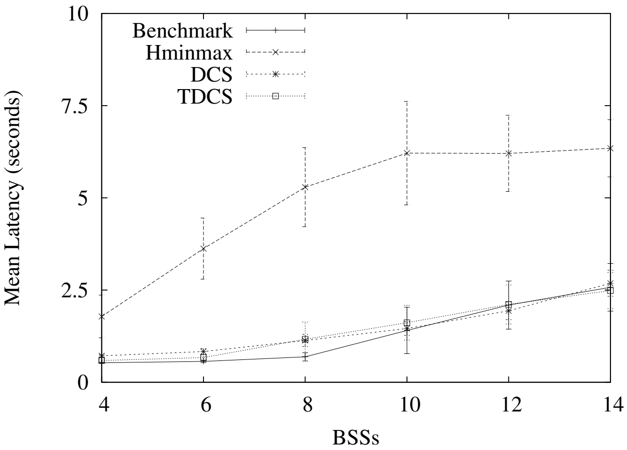
Figures 4(a) and 4(b) present the normalized aggregated throughput and the mean latency of downloaded pages from the HTTP traffic sessions generated. In this case, automatic channel allocation mechanisms presented similar performance, in both metrics, to the one obtained in the simulations with FTP traffic. The DCS and TDCS mechanisms were the ones that obtained closer results to the benchmark, with a small advantage, in the aggregated throughput, for the TDCS mechanism. Meanwhile, Hminmax mechanism presented the worst performance due to its inefficiency in capturing the interference suffered by the BSS nodes.

## V. CONCLUSION

The channel allocation in independent scenarios is an important problem for infra-structured 802.11 networks since



(a) Normalized Aggregated Throughput



(b) Mean Latency

Fig. 4. Performance comparison of different types of channel allocation with HTTP traffic.

the lack of planning of BSSs channel assignment can harm the performance of them. Some proposals in the literature try to solve the problem of channel allocation in independent scenarios through automatic channel selection mechanisms for these networks. However, these mechanisms still present limitations that could reduce their performance. For this purpose, the TDCS mechanism was proposed. It is an evolution of a previous proposal of ours, called DCS. The new mechanism is more efficient on identifying interference variations that affect the BSS performance, triggering the search of a better operating channel when harmful interference is detected in the current one.

The evaluation of the TDCS mechanism and the comparison of its performance with the previous proposals, such as DCS and Hminmax, showed that it obtains a superior performance for aggregated throughput in most of the cases. Concerning fairness and HTTP pages latency, TDCS presents superior performance to the Hminmax mechanism and similar to the DCS.

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