Randomized Channel Selection in Multichannel Access Point Networks

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***Abstract*—Multi-channel system are becoming more and more available and require new techniques to speed up the channel access, especially when the mobile device is equipped only with a single antenna.**

In this paper, we introduce some techniques and selection policies which allow a mobile device to speed up the acquisition time for finding out a channel with satisfactory conditions. The 3 policies we introduce all speed up the scanning phase significantly while achieving near optimal throughput.

We assess analytically and numerically the performance of the policies and show an acquisition time divided by a factor two to five, while the achieved throughput stays comparable to an exhaustive search .

I. INTRODUCTION

The next generation of wireless systems will offer to the mobile device the opportunity to choose a channel based on the conditions of the channel. Already some system are equipped with an antenna which can be tuned to different frequencies, or with the capability to switch the code they are using.

One typical such system is that of 802.11 [1]: current access points and 802.11 cards come with a choice of 11 channels to choose from. This is typically pre-set at configuration for the access point, so that the mobile node's selection of the channel is decided by the network manager at configuration time.

3GPP2 [2] has been working on the standardization of MC-CDMA, namely multi-carrier CDMA. More generally, OFDM (orthogonal frequency division multiplexing) allows a mobile node to choose through a set of different frequencies for transmission.

An issue with the multi-access channel for mobile devices equipped with a single antenna is the time to switch to a different channel: this time involves a switching time to get to the new frequency, and involves a scanning time as well to assess whether the new channel satisfies some desired properties.

Seamless handoffs between access points are made difficult by the time it takes to assess the quality of the next channel to hand-off to. Prior work [3] attempts to facilitate the switch to a new channel by pro-actively evaluating the performance of the new channel. However, there is little work to find out reactively (or break before make) what is the best new link to perform a handover to, despite the fact that, quite often, proactive handoff is not practical.

In this study, we consider ways to speed up the time to access a new channel by limiting the scanning phase to only a few randomly picked channel instead of scanning the exhaustive list of all available channels. We see that the performance degradation of such a scheme is more than compensated by the speed to access the new channel.

In this abstract, we will highlight the properties of the model which we consider, than state the main results, and present some numerical evaluation results.

II. SYSTEM MODEL

We consider a system where M nodes contend for N channel in a multi-access channel. We assume that the system is time slotted, that is indexed by $t \in \int$. The channel condition for each of the N channel varies over time according to some stochastic process with a correlation time such that the channel state is constant over every time slot t.

We consider a switching cost c_s and a scanning delay cost c_d. We also consider a performance variable for the channel, for instance the available rate due to fading conditions of the channel, or due to contention for the channel. For the sake of simplicity, we consider the channel rate in the remainder of this document. However, different performance metrics can be substituted. We denote by r the available channel rate. We assume that for any slot t, the channel performance r follows a probability distribution f_r,

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which we assume to be independent from time slot to time slot.

III. TWO CHANNEL SELECTION POLICIES

We present two selection algorithms for multi-channel selection.

A. FkS

The first one is a variation of the classical ”hiring problem.” The problem is stated as follows: one wishes to hire someone for a position, and interviews the N candidates sequentially. Each interview i produces an assessment of the candidate which accurately predicts the performance p_i of the candidate, which is a random variable picked independently from some identical distribution. At the end of the interview, a decision must be made to hire the candidate, or to keep interviewing more candidates. The optimal algorithm to select the candidate is to interview k candidates to calibrate the candidate pool, and then hire the next candidate i amongst the $N-k$ remaining for which $p_i > max_{j=1,2,\ldots,k} p_j$.

In our multi-channel access, this means the mobile device first scans k channels amongst the N available, and the keep on scanning until one channel offers a better performance than the k first ones. If none does, unlike the hiring problem, the maximum over all N is chosen. We denote this selection algorithm as the First-k Selection, FkS.

This algorithm reduces the scanning time, as it does not scan all the channel, unless none of the $N-k$ remaining channels outperforms the first k. We will see in the next section the gain in terms of reduction of the scanning time.

B. BkS

The second selection algorithm is a randomized selection algorithm. The selection goes as follows: the mobile device first picks k channels out of the N available channels randomly. It then scans the performance of these k channels and eventually settles for the one with the better performance.

The performance of the selection algorithm depends on the value of k and N. However, we will show that for Rayleigh fading channel, one can pick k small enough yet attain a performance close from the optimal pick. We denote this selection algorithm as the Best k Selection, BkS.

IV. ANALYTICAL RESULTS

In this section, we present the main results for both the FkS and the BkS policies.

Theorem IV.1: The optimal value of k for the FkS policy is equal to 36 % of N.

Proof: The proof is omitted, as it is a direct consequence of the classical candidate interview problem. ∎

Theorem IV.2: The BkS selection algorithm ensures a reduction in the switching and scanning delay of k/N.

Proof: This is an immediate consequence of the definition of the BkS selection algorithm. ∎

To build some intuition as to the gain of the BkS policy, we consider the case where the N rates are distributed uniformly over $[0, R_{max}]$. Without loss of generality, we can set $R_{max} = 1$.

Theorem IV.3: The gain of BkS in this situation is equal to

$$\frac{k}{k+1} \tag{1}$$

and for any fixed ratio $\epsilon = k/N$, one can achieve a gain for the BkS policy arbitrarily close to the optimal.

Proof: For independent and uniformly distributed random variable R_i over $[0,1]$ the BkS picks the maximum over k samples, which is distributed as $U_k = \max(R_1, \ldots, R_k)$. $P[U_k < x] = x^k$, which yields that $E[U_k] = k/k+1$.

For the second statement of the theorem, it suffices to see that the optimal average throughput is $N/N+1$, which is sandwiched between 1 and $k/k+1$. Thus, as $k/k+1$ converges to 1, it becomes arbitrarily close to $N/N+1$. ∎ .

The previous results shows that one can be almost optimal, despite considering only a fraction of the available channels. However, one need to consider a more realistic scenario as the uniformly distributed rates we considered earlier. We now turn our focus to Rayleigh distributed channel, as is traditionally assumed in the literature.

Definition IV.1: Define $\alpha(k)$ to be equal to:

$$\alpha(k) = \Sigma_{i=1}^{k} \frac{1}{i} \tag{2}$$

Theorem IV.4: In Rayleigh fading channels, the BkS algorithm attains an average throughput gain

$\alpha(k)$ over the mean channel throughput. The gain is asymptotically equal to that of the optimal channel $\alpha(N)$ if the ratio k/N is kept constant.

This theorem states that if we set the ratio of the probed channel number k over the total number of channels N to a constant, say 1/2, then the time to find the best channel is divided in half with asymptotically no loss on the throughput.

Proof: The normalized gain achieved by selecting the best of k channel in Rayleigh fading environment is given by:

$$\alpha(k) = 1 + \frac{1}{2} + \ldots + \frac{1}{k} \qquad (3)$$

A proof of this can be found for instance in [4], equation (9). As $\alpha(k)$ is asymptotically equal to $\ln(k)$, if $k = \epsilon N$, then the gain $\alpha(N)$ is also asymptotically equal to $\ln(k)$. Thus BkS achieves the same gain as the policy which picks the optimal channel. ∎

A. Improvement of FkS

We return now to the FkS policy. Recall that it scanned through the first k channel to establish a benchmark and assess a raw statistics of the channel. Based on the information gathered during the scanning of the first k channels, it then picked a channel subsequently scanned.

While this allowed to reduce the number of scanned channels (we will see in the next section that it requires to scan only three quarters of the channels on average), it is possible to reduce the training sequence as follows:

The node scans the channels as in FkSS. Define the threshold rate R_δ to be at the first iteration, δ times the maximal rate observed so far, where δ is a fixed number between 0 and 1.

During the next scanning epoch τ, instead of bench-marking against the first k rate, the node picks the first channel which offers a rate greater than R_δ. If no channel does, then it picks the larger rate $R_{max}(\tau)$, and reset the value of R_δ to be $\delta R_{max}(\tau)$.

If a channel is allocated, then the threshold is updated using a sliding window moving average. The new threshold is thus, where i is the chosen channel and r_i the rate on the channel during the epoch τ:

$$R_\delta = (1-\beta)R_\delta + \beta r_i \qquad (4)$$

Since we have seen that in average, the first k channels of a Rayleigh channel system will have a gain over the mean of $\alpha(k)$, setting $\delta = \alpha(k)$ would yield a better performance than BkS and reduce the number of scanned channels even more.

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For epoch $\tau$
Scan channel 1 for rate $r_1$.
While $r_i < R_\delta$
Repeat: Scan channel $i$ for rate $r_i$
Go to channel $i+1$
End while
If $r_i > R_\delta$
$R_\delta = (1-\beta)R_\delta + \beta r_i$
Else
$R_\delta = \delta \max(r_i)$
End If
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TABLE I

SELECTION ALGORITHM

We denote this policy the δTS for δ threshold selection.

V. PERFORMANCE EVALUATION

The trade-off in selecting the channel is between the eventual performance of the channel versus the delay to switch and scan the different channels. We conduct simulations of the performance gain as well as the delay in the case of an 11 channel 802.11 system.

A. FkS

We first consider the FkS selection algorithm. In figure 1 we display the rate achieved by the FkS algorithm. The optimal rate is the curve consistently at the top of the graph. The FkS selection algorithm achieves a rate which is on average 94.5% of the optimal rate. However, the mean cost is reduced further, and is equal to 74% of the scanning cost for the optimal case. For 11 channels, the optimal k is equal to 4 by Theorem IV.1.

B. BkS

In Figure 2 we present the rate achieved by the BkS policy for two values of k: 2 and 3. The three curves on Figure 2 are by construction: the lowest one is the Best of 2 Selection, the middle one is the Best of 3, and the top one is the optimal selection.

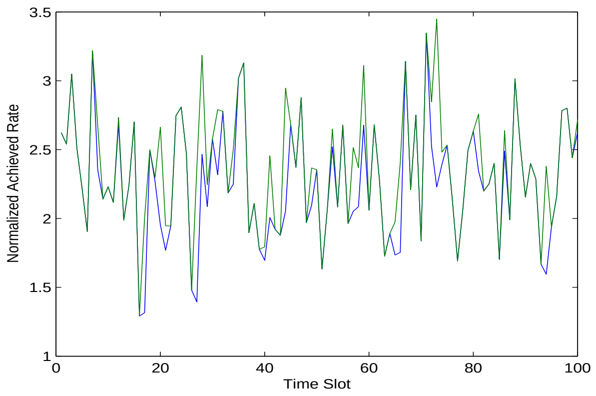

Fig. 1. Achieved Rate for Optimal Rate Selection and FkS policy

We see that the B2S achieves 77% of the optimal throughput, yet requires only 18% of the delay. This means that a reduction of 82% in the channel selection cost still achieves a reduction of only 23% in the achieved rates. For the B3S policy, the achieved rate is on average 84% of the optimal, yet the channel acquisition cost in only 27% of the optimal channel selection.

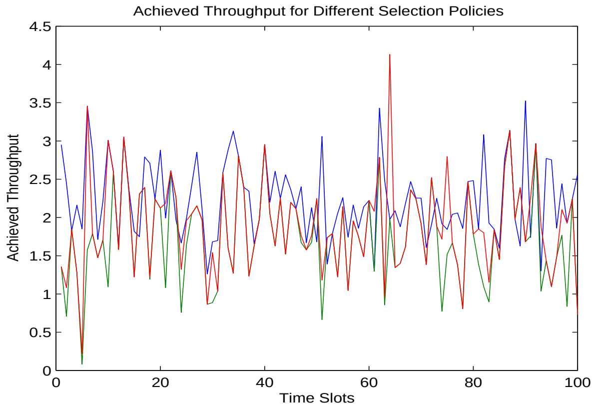

Fig. 2. Achieved Rate for Optimal Rate Selection, and B3S and B2S policies

C. δTS

We chose some heuristical value for the different parameters. To achieve good performance in terms of throughput, δ should be high enough. In the performance evaluation, we arbitrarily pick $\delta = 0.9$, a value which gives us good performance. To insure that the threshold stays reactive to the rate variations, we chose the parameter of the moving average $\beta = 0.2$.

In terms of scanning delay, the δTS policy scans only 53% of the channels, a further reduction over FkS. In terms of actual throughput, which we plotted in figure 3, the achieved throughput is equal to 95% of the optimal, that is the loss in throughput is very small, especially compared to the gain in delay to acquire the channel.

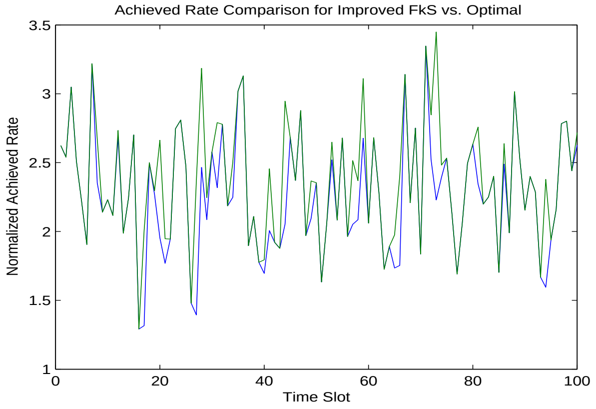

Fig. 3. Achieved Rate for Optimal Rate Selection, and δTS policies

We plot in figure 4 the achieved rate of δTS compared with the optimal achievable rate for different values of δ varying between 0.75 and 1. One can see that the achieved throughput increases with the value of δ, at the expense of a longer acquisition delay. The corresponding acquisition delay increases from 41% to 55% of an exhaustive search, that is a reduction by a factor 2. Meanwhile, the achieved throughput stays between 89% of the maximal for $\delta = 3/4$ and 94% of the maximal achievable rate for $\delta = 1$. In the worst case, the reduction of throughput with respect to the maximum is only 11%.

VI. CONCLUSION

In this paper, we have considered different policies for a single radio system which speed up the time required to scan the channel to find a channel with satisfying performance. We have introduced three different policies which offer different throughput/delay characteristics, but all significantly improve in terms of delay vs. an exhaustive policy, while suffering only a limited degradation in throughput compared with the maximum achievable throughput.

We have derived some analytical properties of the selection policies and have assessed the performance of all the policies through some numerical evaluation.

Further research would involve implementing the selection algorithm in an actual single radio system,

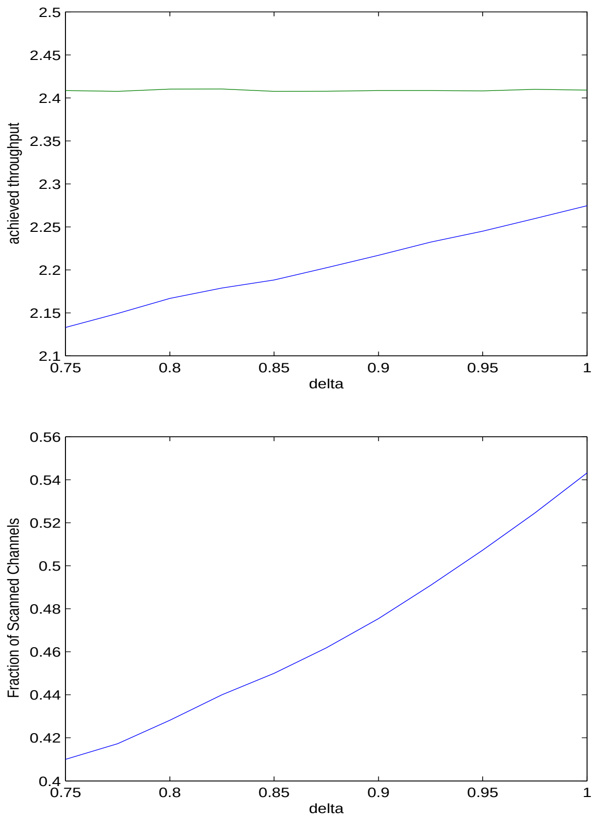

Fig. 4. Achieved Rate And Delay for δTS policies for different values of δ vs. Optimal

such as an 802.11 card able to connect via multiple access points on different channels.

REFERENCES

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