

Energy-Optimal Scheduling with Dynamic Channel Acquisition in Wireless Downlinks

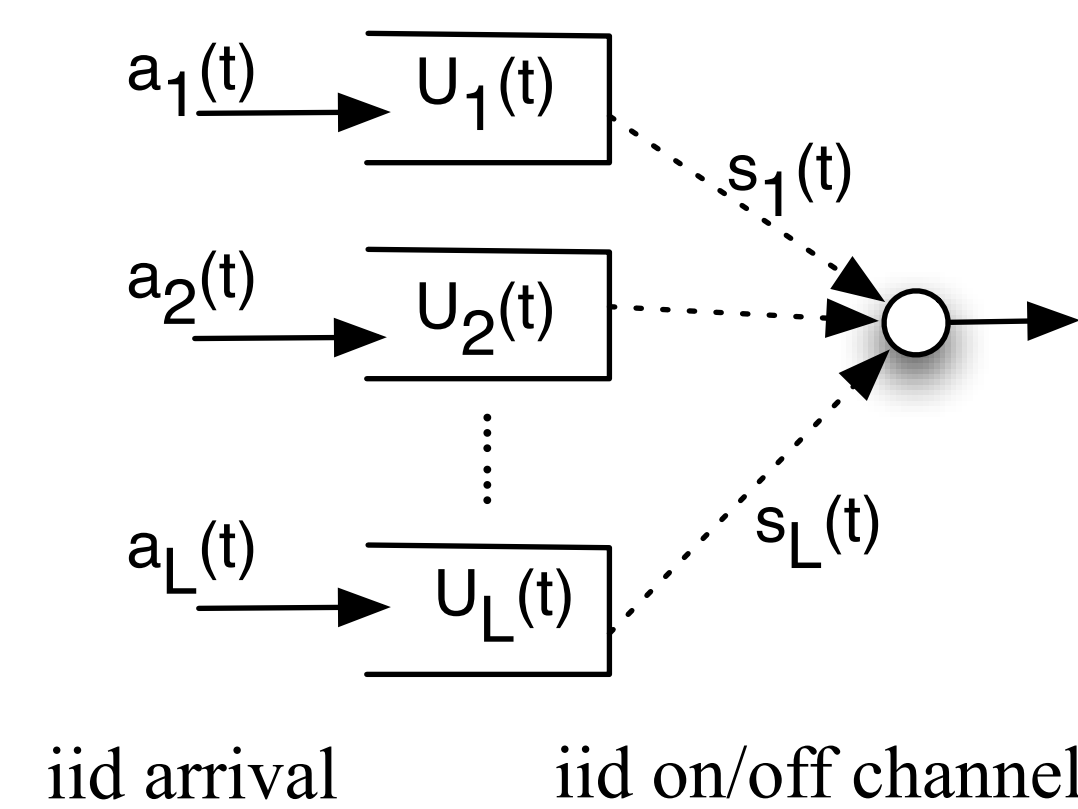
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Abstract

Channel acquisition is central to opportunistic scheduling for transmission over wireless channels. Practically it comes with probing power overhead. In low traffic regime, disregarding the channel and transmitting packets *blindly* may suffice to stabilize the network, and it wastes no probing power. Under the additional probing power cost assumption, we explore when is *appropriate* to probe the channel so that the network capacity can be achieved with minimum power consumption.

1. Network Model



- A time-slotted L -user wireless downlink with iid arrivals $a_i(t)$ (with rate λ_i) and iid ON/OFF channels $s_i(t) \in \{0, 1\}$.
- $s_i(t)$ represents the maximum transmission rate on channel i in slot t . Transmission consumes constant power P_t in every slot.
- On every slot either all channels are probed (with power P_m) or none is probed.
- In every slot at most one user is selected to serve.
- **Goal:** Design joint channel probing and rate allocation algorithms that are **power** and **throughput optimal**.

2. Motivating Example

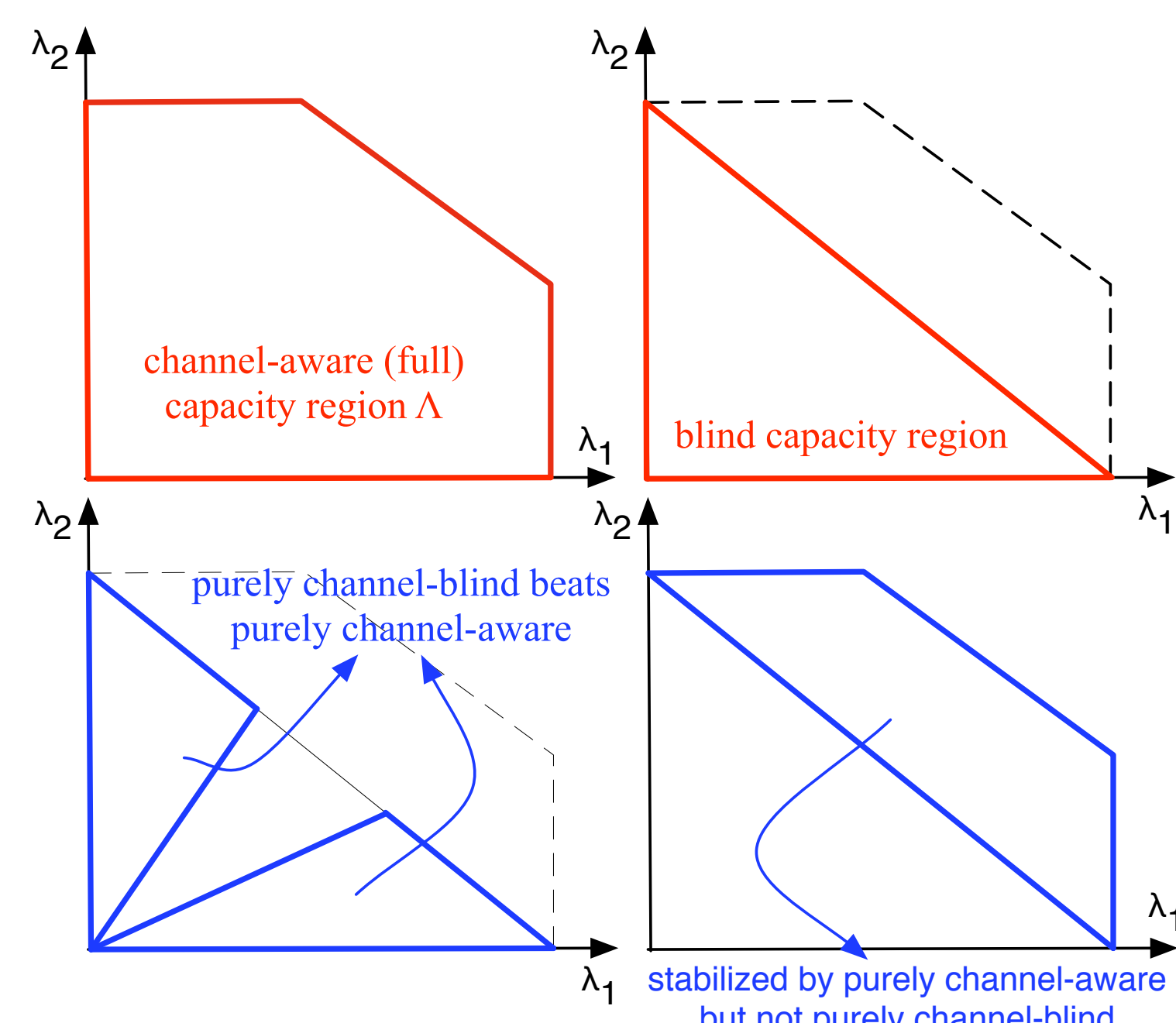
Consider two-user downlink $L = 2$.

- Let **purely channel-aware** policies be those that serve packets only if channels are probed.
- Let **purely channel-blind** policies be those that never probe the channels.
- Minimum average power for **purely channel-aware**:

$$\left(\sum_{i=1}^L \lambda_i \right) P_t + \theta^* P_m, \quad \theta^* \triangleq \inf \{ \theta \in (0, 1) \mid (\lambda_1, \dots, \lambda_L) \in \theta \Lambda \}.$$

- Minimum average power for **purely channel-blind**:

$$\left(\sum_{i=1}^L \frac{\lambda_i}{\mathbb{E}[s_i(t)]} \right) P_t.$$



- Typically, mixing strategies are better than purely channel-aware and purely channel-blind. Need a unified treatment.

3. Dynamic Channel Acquisition (DCA) Algorithm

Let $V > 0$ is a predefined control parameter. In slot t ,

- **Rate allocation:**
 - If channels are probed, among users with ON channel state, serve the one with the largest positive $(2U_i(t) - VP_t)$. If no such user, serve no one.
 - If channels are not probed, serve the user with the largest positive $(2U_i(t)\mathbb{E}[s_i(t)] - VP_t)$. If no such user, serve no one.

- **Channel probing:**
 - Compute a **metric** for channel probing

$$-VP_m + \sum_{i=1}^L \left[(2U_i(t) - VP_t) 1_{[2U_i(t) > VP_t]} \right] \Pr \left\{ s_i(t) = 1, s_j(t) < \frac{U_j(t)}{U_i(t)}, \forall j < i, s_k(t) \leq \frac{U_k(t)}{U_i(t)}, \forall k > i \right\} \quad (1)$$

- Compute a **metric** for blind transmission

$$\max \left\{ 0, \max_{i \in \{1, \dots, L\}} \{2U_i(t)\mathbb{E}[s_i(t)] - VP_t\} \right\} \quad (2)$$

- If (1) > (2), probe the channels.
- DCA algorithm relies only on **channel statistics** and **current queue backlog**.

4. Origin of DCA Algorithm

- DCA comes naturally from the underlying **Lyapunov drift analysis**.
- DCA generates **enough negative drifts** that decrease queue backlogs whenever they are sufficiently large, so that network stability is guaranteed.
- By blending power terms into the drift analysis, we can generate such negative drifts with minimum power.

5. Performance of DCA

- Let $P_{opt}(\lambda)$ denote the minimum power to stabilize rate vector λ . Let $V > 0$ is a control parameter. Then DCA algorithm yields

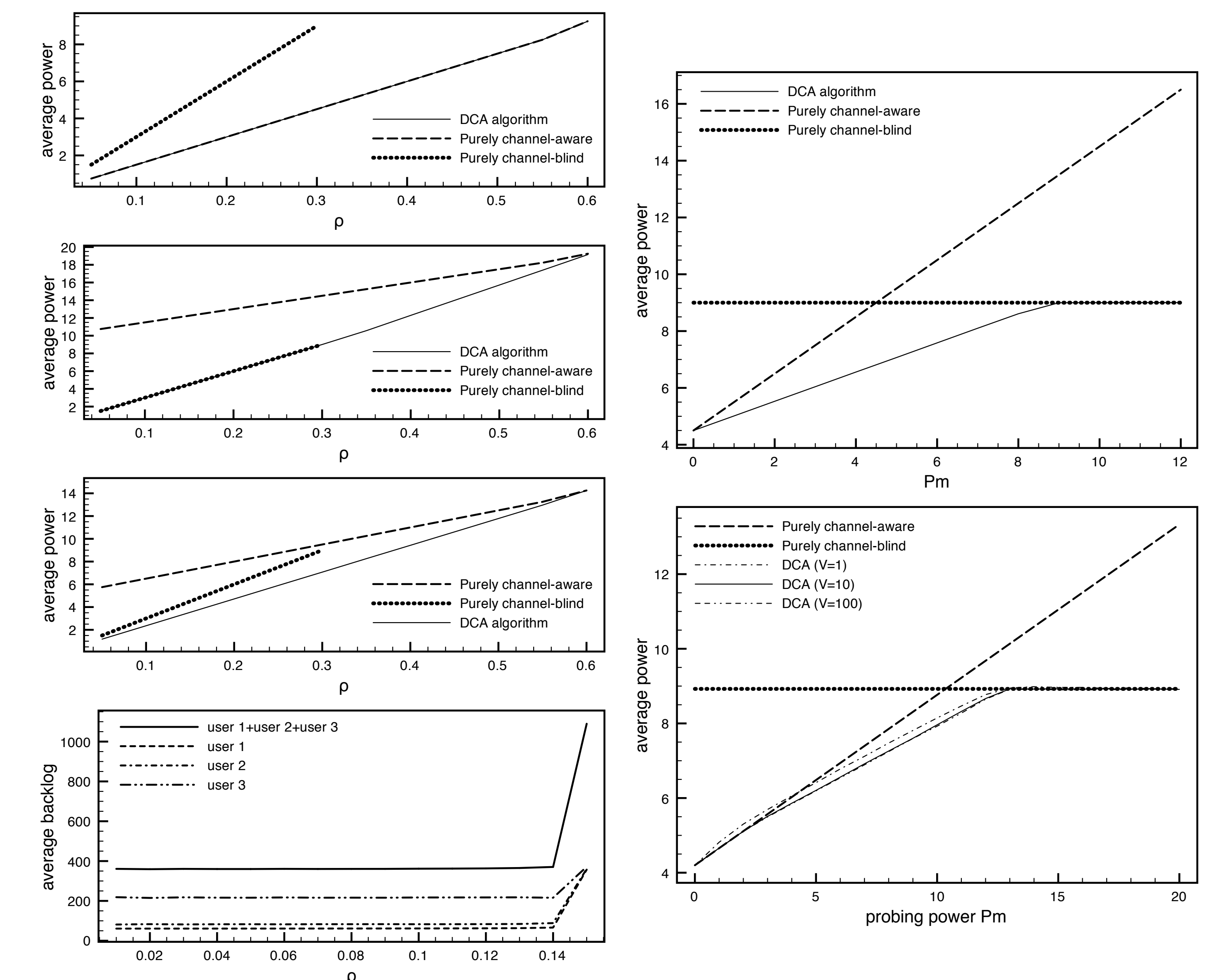
$$\limsup_{t \rightarrow \infty} \frac{1}{t} \sum_{\tau=0}^{t-1} \sum_{i=1}^L \mathbb{E}[U_i(\tau)] \leq \frac{B + V(P_m + LP_t)}{2\epsilon_{max}}$$

$$\limsup_{t \rightarrow \infty} \frac{1}{t} \sum_{\tau=0}^{t-1} \sum_{i=1}^L \mathbb{E}[P_i(\tau)] \leq \frac{B}{V} + P_{opt}(\lambda)$$

where $B > 0$ and $\epsilon_{max} > 0$ are finite constants.

- By increasing V , power consumption of DCA can be made arbitrarily close to $P_{opt}(\lambda)$, at the expense of increasing network delays.

6. Simulation Results

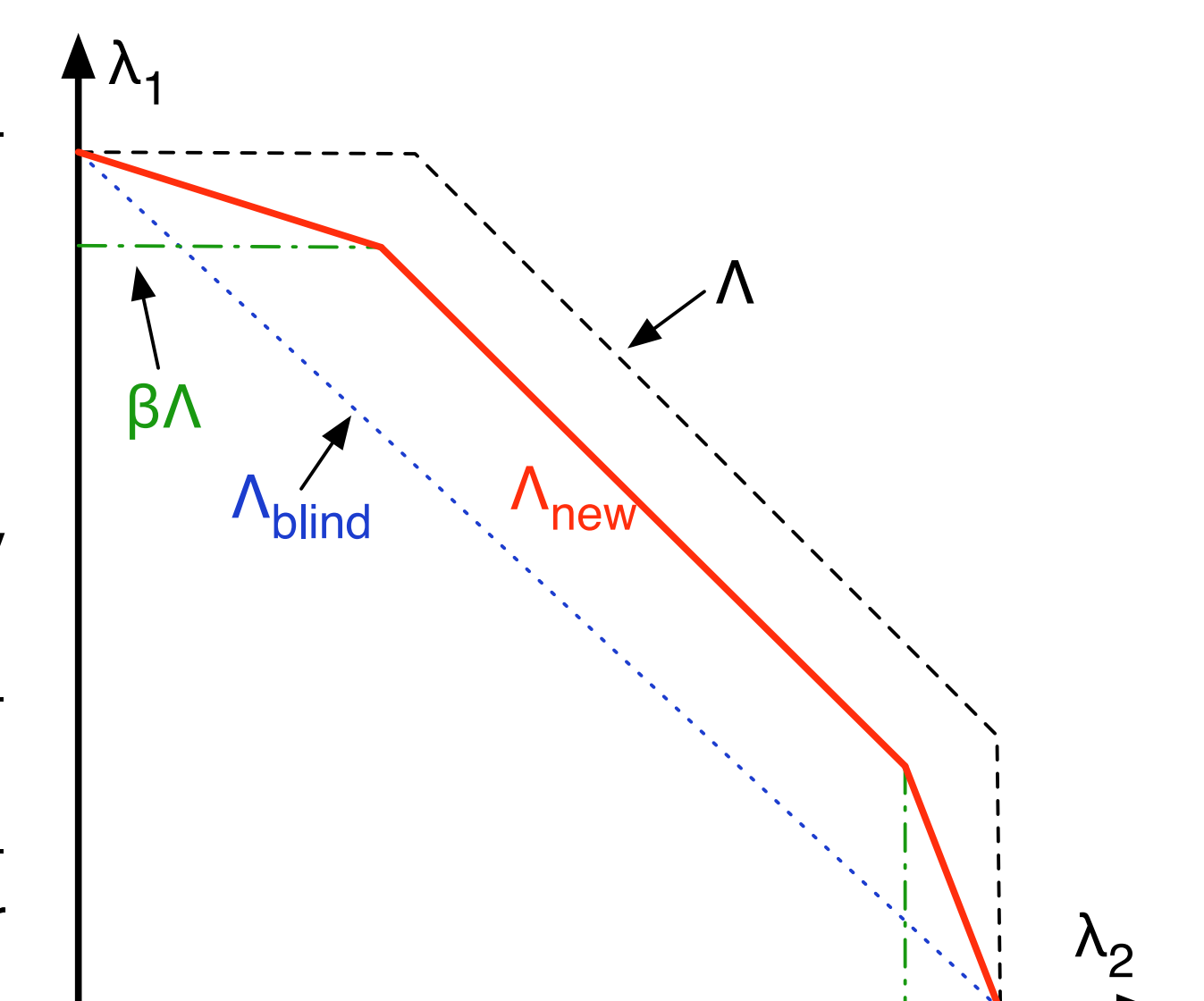


From simulations we observe:

- DCA spends a fair amount of time blindly serving a good channel.
- DCA almost always probes channels before serving a bad channel.
- Purely channel-aware policies do not guess on good channels.
- Purely channel-blind policies do not use multiuser diversity gain.
- DCA blends the two aspects well.

7. Extension and Future Work

- The model can be naturally extended to
 - General rate allocation problem with multi-rate channels.
 - Partial channel acquisition
 - Timing overhead due to channel probing
- Generalize to Markov channel
 - Wireless channels can be adequately modeled as finite-state Markov chains.
 - Not a simple extension, completely different problem.
 - Channel memory provides partial information of future channel states. It helps for better channel probing decisions.



References

- [1] C.-P. Li and M. J. Neely, "Energy-optimal scheduling with dynamic channel acquisition in wireless downlinks," to be published.
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- [3] L. Georgiadis, M. J. Neely, and L. Tassiulas, "Resource allocation and cross-layer control in wireless networks," *Foundations and Trends in Networking*, vol. 1, no. 1, 2006.