Distributed Fair Scheduling for Information Exchange in Multi-Agent Systems

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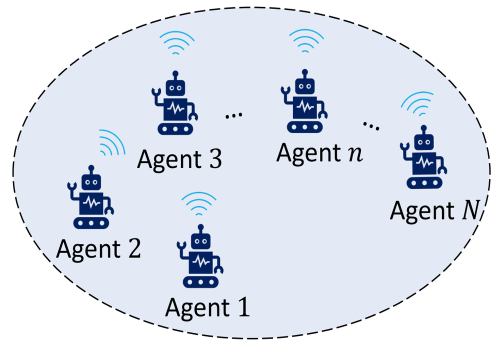
Introduction

Communication between the agents involves two major challenges:

- Limited bandwidth $\Longrightarrow$ limits the transmission rates
- Shared communication medium between the agents $\Longrightarrow$ restricts the number of agents that can simultaneously exchange information



A distributed algorithm is required for scheduling the agents' transmissions

Fairness

A key metric in scheduling algorithms

- Some agents might hog the communication medium for a long period of time and therefore, lead to starvation of other agents
- The agents' messages might have different importance or different latency requirements

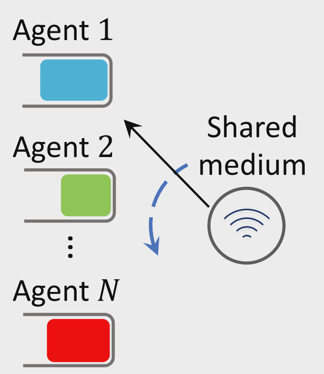
Weighted Fairness

Idealized definition of fairness (fluid traffic model)

Generalized Processor Sharing (GPS)

- Bandwidth must be allocated in proportion to the weights associated with the agents, i.e.,

$$\frac{W_i(t_1,t_2)}{\phi_i} = \frac{W_j(t_1,t_2)}{\phi_j}, \qquad i,j \in \mathcal{B}(t_1,t_2)$$



Fair packet scheduling

- Weighted Fair Queueing (WFQ),
- Self-Clocked Fair Queueing (SCFQ),
- Start-time Fair Queuing (SFQ),
- …

$$\left|\frac{W_i(t_1,t_2)}{\phi_i} - \frac{W_j(t_1,t_2)}{\phi_j}\right| < \varepsilon, \quad i,j \in \mathcal{B}(t_1,t_2)$$

Goal: Designing a *distributed* fair scheduling algorithm for providing weighted fairness in single-hop wireless networks

DSCFQ Algorithm

- **Class I (high priority):** The set of agents that need to retransmit their messages because of their unsuccessful last attempts
- **Class II (low priority):** Agents with new information to share

Class II

- **Scaling factor (α):** a parameter for suitable scaling of the backoff intervals to reach a high throughput
- **Compensation factor (ϵ_k^i):** a parameter that compensates the fairness deviations caused by the discrete backoff intervals.

1- When message i reaches the front of agent k's transmitter queue, it is tagged with backoff tag B_k^i, where:

$$B_k^i = \left\lfloor \alpha\left(\frac{L_k^i}{\phi_k} - \epsilon_k^i\right)\right\rfloor \qquad \epsilon_k^1 = 0, \qquad \epsilon_k^i = \epsilon_k^{i-1} + \left(\frac{B_k^{i-1}}{\alpha} - \frac{L_k^{i-1}}{\phi_k}\right)$$

2- Class II agents can start decrementing their backoff counters only after sensing the medium idle for one time slot. The backoff counter is decremented by one after each idle slot and is frozen during the busy periods.

3- Whenever an agent's backoff reaches zero, the agent can transmit

4- If a transmitting class II agent detects a collision, it stops the transmission, increments its collision counter by 1 and starts following the procedure for class I agent

Class I

Collision counter (q): keeps track of the number of collisions of an agent since its last successful transmission

1- Class I agents can access the medium as soon as it becomes idle

2- **Splitting Algorithm for Collision Resolution**:

- Agent k chooses a uniformly distributed integer c_k in $[(q_k-1)m+1, q_k m]$.
- Once the medium becomes idle, agent k transmits a pulse for a duration of c_k slots and then starts sensing the medium.
- If the following slot is busy, it defers its transmission and repeats this step
- Otherwise, the agent starts its transmission.

3- If a collision happens, agents involved in the collision increase their collision counters and repeat the previous step.

4- Each time an agent transmits successfully, it resets its collision counter to 0 and follows the procedure for the class II agents.

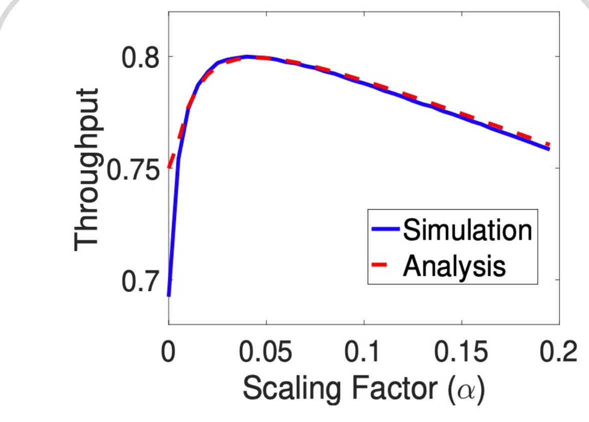
DSCFQ Properties

- **Theorem:** For any two agents $k,j \in \mathcal{B}(t_1,t_2)$, DSCFQ guarantees that:

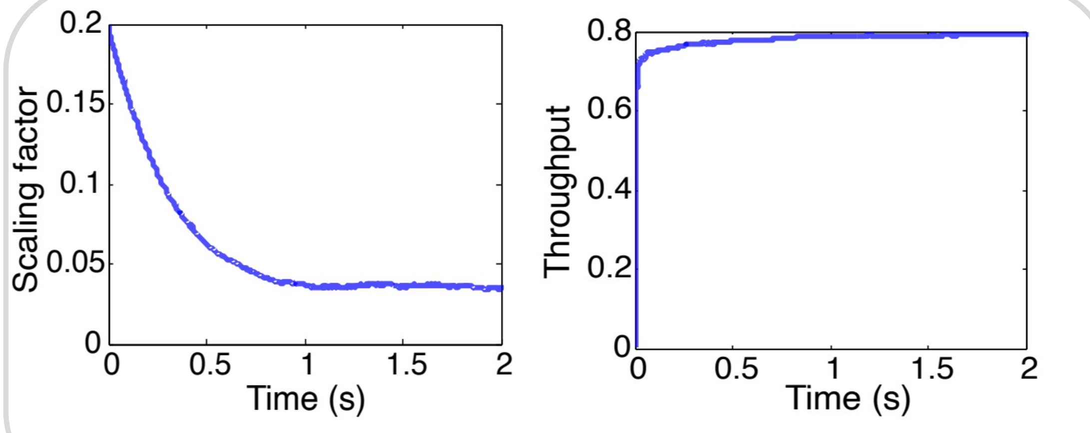
$$|w_k(t_1,t_2) - w_j(t_1,t_2)| \le \frac{L_k^{max}}{\phi_k} + \frac{L_j^{max}}{\phi_j} + \frac{2}{\alpha}$$

- Our algorithm uses an adaptive mechanism to obtain the optimal scaling factor (α) that maximizes the saturation throughput

Numerical Results

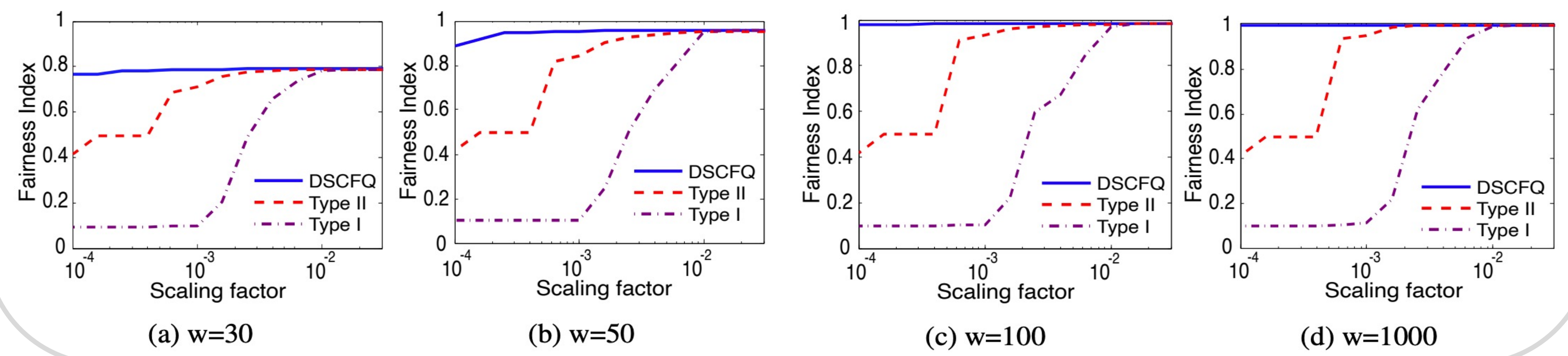


$\alpha^* \cong 0.04, T^* \cong 0.8$



Convergence to the optimal operating point

Features	Type I algorithms	Type II algorithms	DSCFQ (Ours)
Considering priority in collision resolution	✗	✓	✓
Using Compensation factor to address the effect of discrete backoffs	✗	✗	✓



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