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Robotic Message Ferrying for Wireless Networks using Coarse-Grained Backpressure Control

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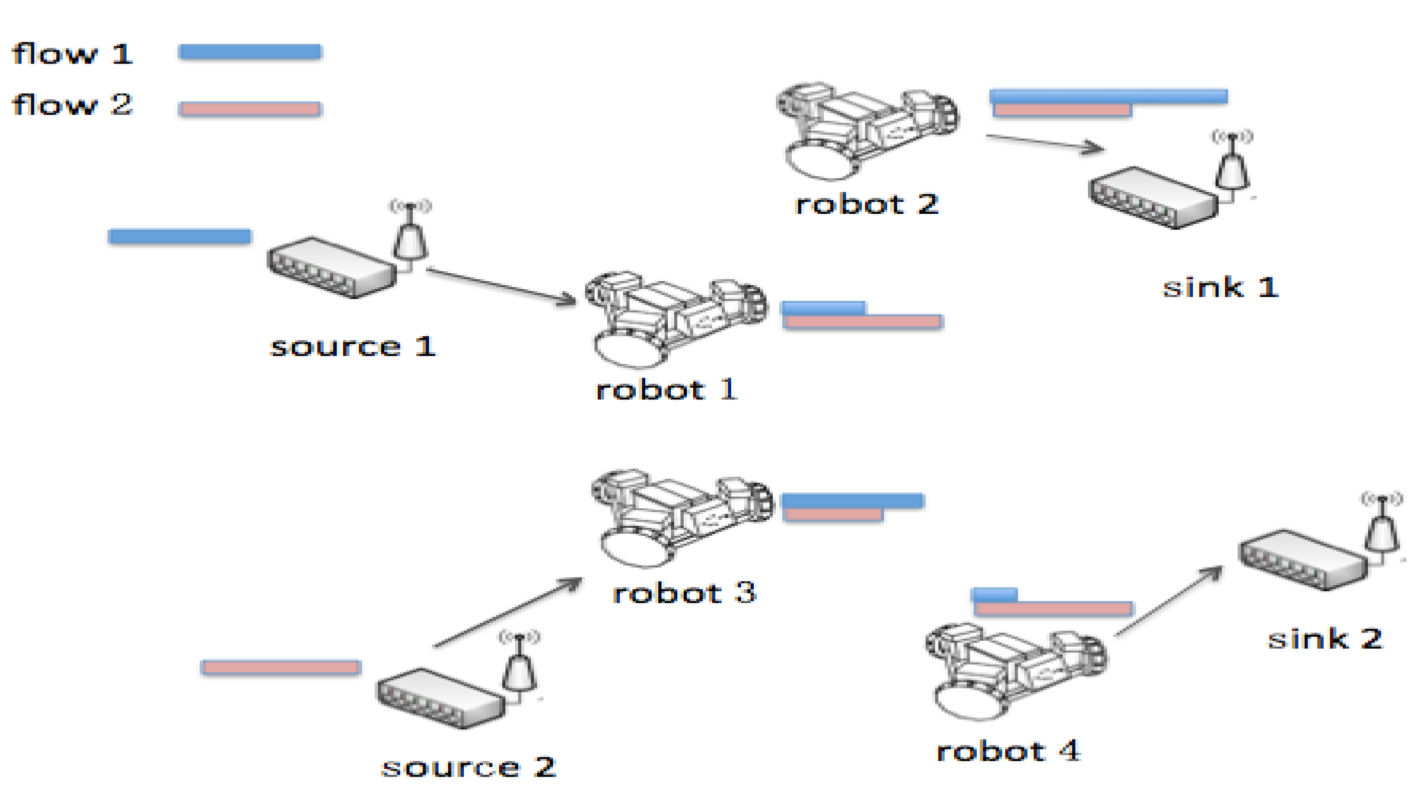
Introduction

- ***Goal***: Design an arrival-rate unaware scheduling algorithm for robotic message ferrying in wireless networks.
- ***Motivation***: Introducing robotic relays in the context of wireless networks provides a new design dimension, that of *controllable* (and *ipso facto*, *predictable*) mobility, which can be used to enhance data routing.
- ***Challenge***: Joint robotic control and transmission scheduling

Problem Formulation And Modeling

- K pairs of static sources and destinations, and they don't communicate directly with each other.
- N mobile robots, acting as message ferries, move around the network with a uniform velocity v to help transmit packets .
- Time is slotted. Every T slots form a new epoch.
- At the start of each epoch, a centralized scheduler uses the information of queue states in the network to match each robot to either a source or a sink. After the allocation, each robot communicates exclusively with its matched node in all time slots of this epoch. The communication rate is a function of the distance between the robot and its matched node. The maximum communication rate $R_{\max}$ achieved when the robot reaches its matched node.

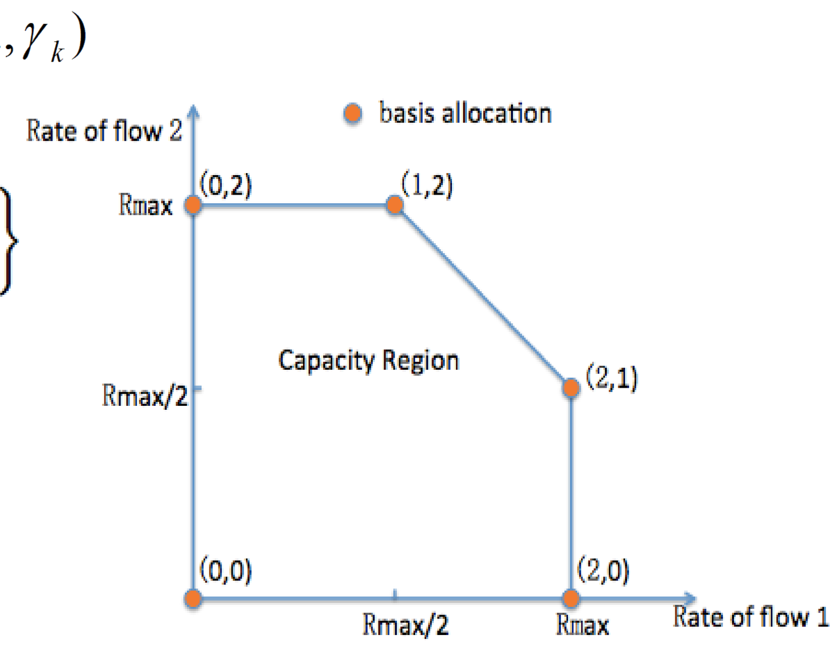


Algorithm for Known Arrival Rates

- Given a rate vector $\gamma = (\gamma_1, \ldots, \gamma_k)$ in the capacity region

$$\Lambda = \left\{ \lambda | 0 \le \lambda_i < R_{\max}, \quad \forall\, i, \ \sum_{i=1}^{K} \lambda_i < \frac{R_{\max} N}{2} \right\}$$

we can find a convex combination of basis allocations with coefficients $\alpha = (\alpha_1, \ldots, \alpha_m)$ to achieve γ.



- The given rate vector γ can be scheduled by allocating n_i epochs ($n_i / \sum_i n_i = \alpha_i$) each for the two parts of the i^th basis allocation. And after a total of $\sum_i 2n_i$ epochs, the whole schedule is repeated.

CBMF Algorithm for Unknown Arrival Rates

At the beginning of each epoch:

- Compute the weights $w_{src(i),j} = (Q_{src(i)} - Q_j^i)$ and $w_{\sin k(i),j} = Q_j^i$.
- If the allocation $A(i,j) = 1$, denote $w_{i,j} = w_{src(i),j}$. If $A(i,j) = -1$, denote $w_{i,j} = w_{\sin k(i),j}$. Else, if $A(i,j) = 0$, $w_{i,j} = 0$.
- Find the allocation matrix A that maximizes $\sum_{i,j} | A(i,j) | w_{i,j}(A(i,j))$ subject to the following three constraints:

(1) $\sum_i | A(i,j) | = 1$

(2) $\sum_j I\{A(i,j) = 1\} \le 1$

(3) $\sum_j I\{A(i,j) = -1\} \le 1$

The first constraint ensures that each robot is allocated to exactly one source or sink. The second constraint ($I\{\}$ represents the indicator function) ensures that no source is allocated more than one robot, while the third constraint ensures that no sink is allocated more than one robot.

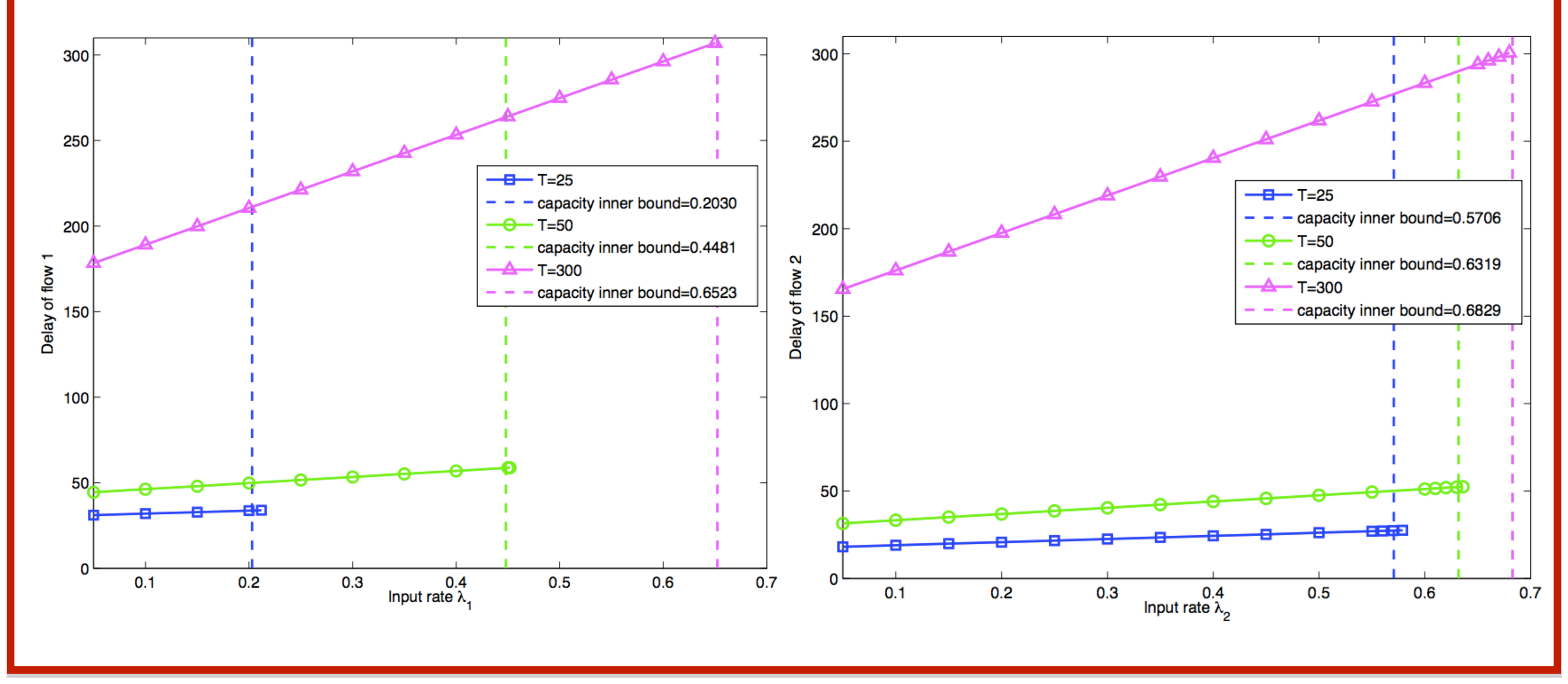
Capacity Analysis

Theorem: For any arrival that is strictly within

$$\Lambda_{IB}(v,T) = \{\lambda \,|\, 0 \le \lambda_i < R_{\max}(1 - \frac{d}{vT}), \forall i, \sum_{i=1}^{K} \lambda_i < \frac{R_{\max}(1 - \frac{d}{vT})N}{2}\},$$

the CBMF algorithm ensures that all source and robot queues are stable.

Simulation Results



Conclusions And Future Work

- ***Conclusions:*** We addressed two fundamental questions:
  - what is the throughput capacity region of such systems?
  - How can they be scheduled to ensure stable operation, even without prior knowledge of arrival rates?
- ***Future Work***:
  - Improve the CBFM algorithm to support the entire capacity region.
  - Design an adaptive algorithm by adapting epoch length to satisfy any unknown arrival rates and maintain minimum delay.

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