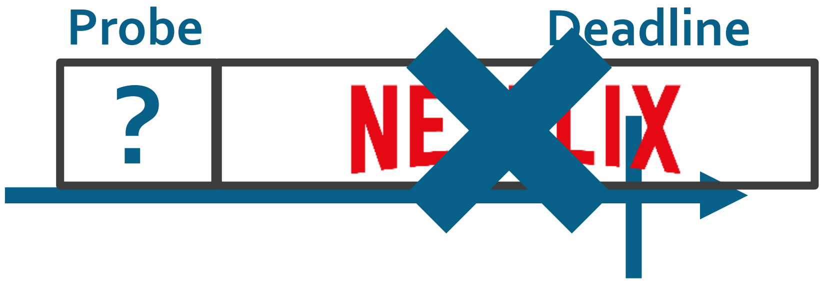
SERVICE CENTRIC SCHEDULING WITH STRICT DEADLINES

David Ramirez

Behnaam Aazhang

RICE

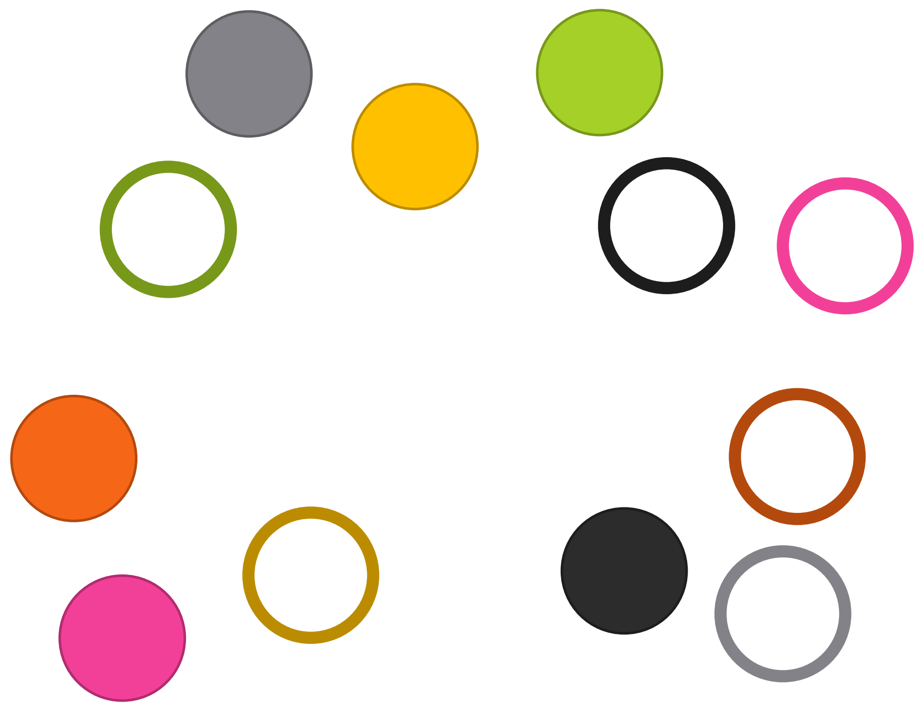
NETWORKS EXIST TO PROVIDE SERVICES



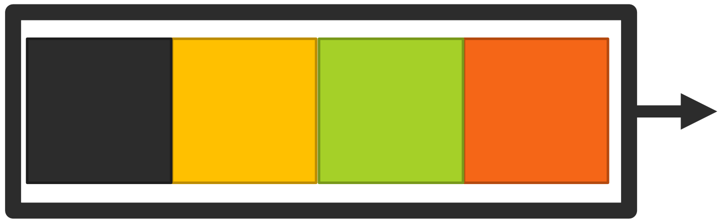
INELASTIC SERVICES

Kumar, Anurag, D. Manjunath, and Joy Kuri. *Communication networking: an analytical approach*. Elsevier, 2004

SERVICE QUEUES AND VALUES



Queue



Value

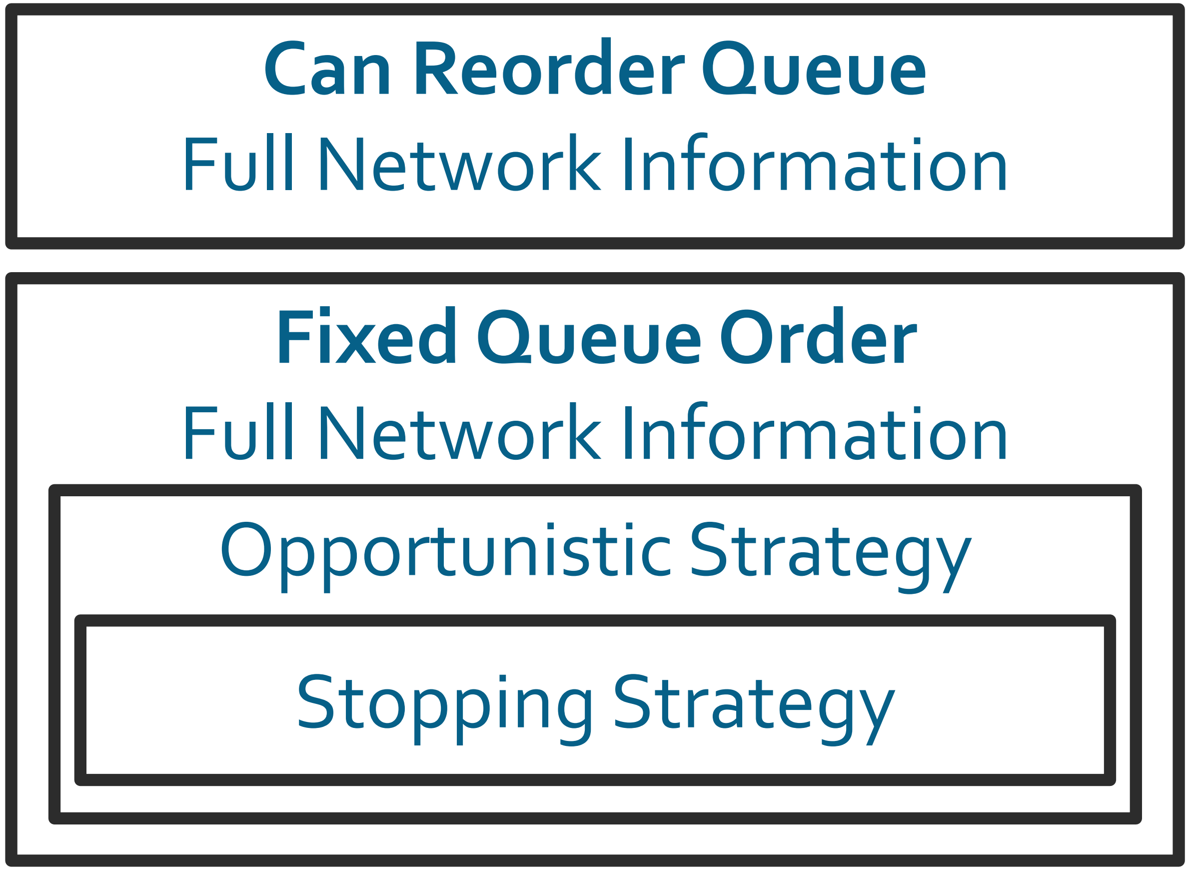
Schedule

Who should transmit?

NETFLIX | skype | E*TRADE | NETFLIX

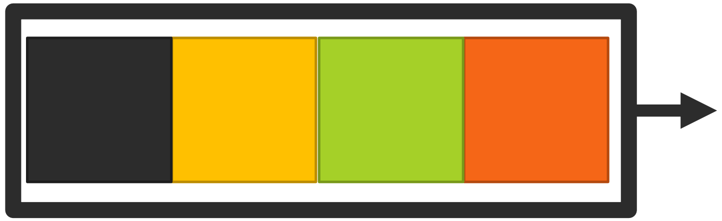
STATEMENT AND SOLUTION ROADMAP

How do we maximize the weighted sum value of completed service transmissions?



PROBLEM FORMULATION

Queue



$$\max_{\mathbf{x}} \sum_{i=1}^{N} x_i w_i$$

$$s.t. \quad \sum_{i=1}^{z_l} x_i t_i + \beta(z_l) c \leq T_l \ \forall\ l$$

$$\beta(z_l) = \max\{i : x_i = 1, i \leq z_l\}$$

$$z_{Skype} = 2$$

$$\sum_{i=1}^{z_l} x_i \leq \beta(z_l) \leq N$$

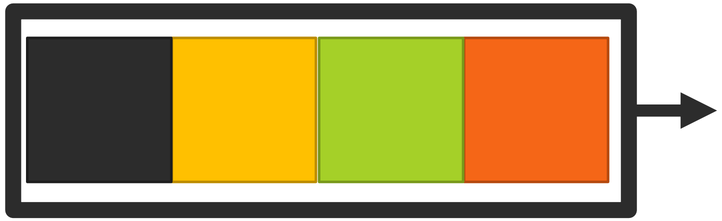
$$\mathbf{x} = \{1,1,0,1\}$$

$$z_{E*TRADE} = 3$$

$$z_{Netflix} = 4$$

PROBLEM FORMULATION

Queue



$$\max_{\mathbf{x}} \sum_{i=1}^{N} x_i w_i$$

$$s.t. \quad \sum_{i=1}^{z_l} x_i t_i + \beta(z_l)c \le T_l \;\forall\; l$$

Solve via Dynamic Approach

FULL NETWORK INFORMATION

Fixed Queue Order

- Solve dual <u>without</u> penalty
- Add probing penalty to all feasible solutions
- Select *best* solution among remaining feasible solutions

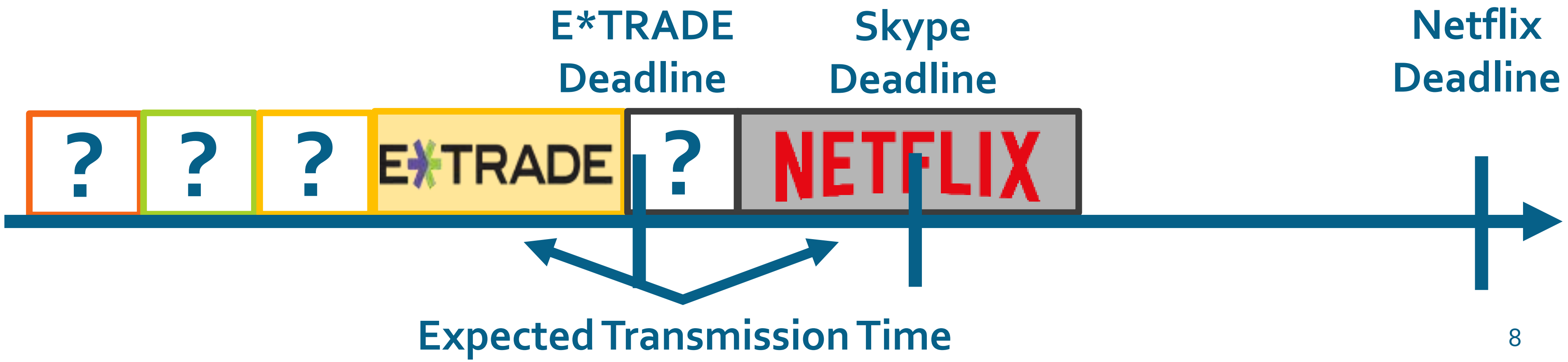
Can Reorder Queue

- Solve dual <u>without</u> penalty
- Reorder by minimum time first **if** transmitting
- Add probing penalty to all feasible solutions
- Select *best* solution among remaining feasible solutions

OPPORTUNISTIC STRATEGY

- if service in queue (*Netflix*) transmits

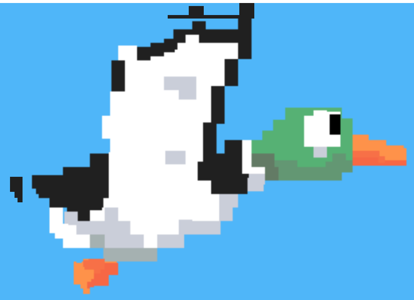
- if service in queue (*Netflix*) **does not** transmit



PRACTICAL STOPPING STRATEGY

Optimal Stopping Problems

Series of random variables are viewed and a decision to stop must be made to minimize an associated function



Chow, Yuan Shih, Herbert Robbins, and David Siegmund. "*Great expectations: The theory of optimal stopping*". Boston Houghton Mifflin, 1971

Ferguson, Thomas S. "*Optimal Stopping and Applications*." *UCLA* 2012

PRACTICAL STOPPING STRATEGY

Stopping Problems

Series of random variables are viewed and a decision to stop must be made to minimize an associated function

In our case…

- Series = Probing order
- Random variables = Transmission times
- Stop = Transmit
- Function $\min_i E[i\delta + t_i]$ $\quad Transmit\ if\ t_i \le V^*$

Chow, Yuan Shih, Herbert Robbins, and David Siegmund. "*Great expectations: The theory of optimal stopping*". Boston Houghton Mifflin, 1971

Ferguson, Thomas S. "*Optimal Stopping and Applications*." *UCLA* 2012

ALTERNATIVES FROM LITERATURE

Shortest Time First

- Allowed to reorder by min E[t] first
- Follow new order and transmit

Weighted Proportionally Fair

- Share resources depending on weighted average of bits
- No penalty for skipping once share is finished

$$\frac{\text{value of service } i \bullet \text{bits of service } i}{\sum_{\text{all values}} \text{value of service } j \bullet \text{bits of service } j} \bullet \text{Time}$$

Kumar, Anurag, D. Manjunath, and Joy Kuri. *Communication networking: an analytical approach*. Elsevier, 2004

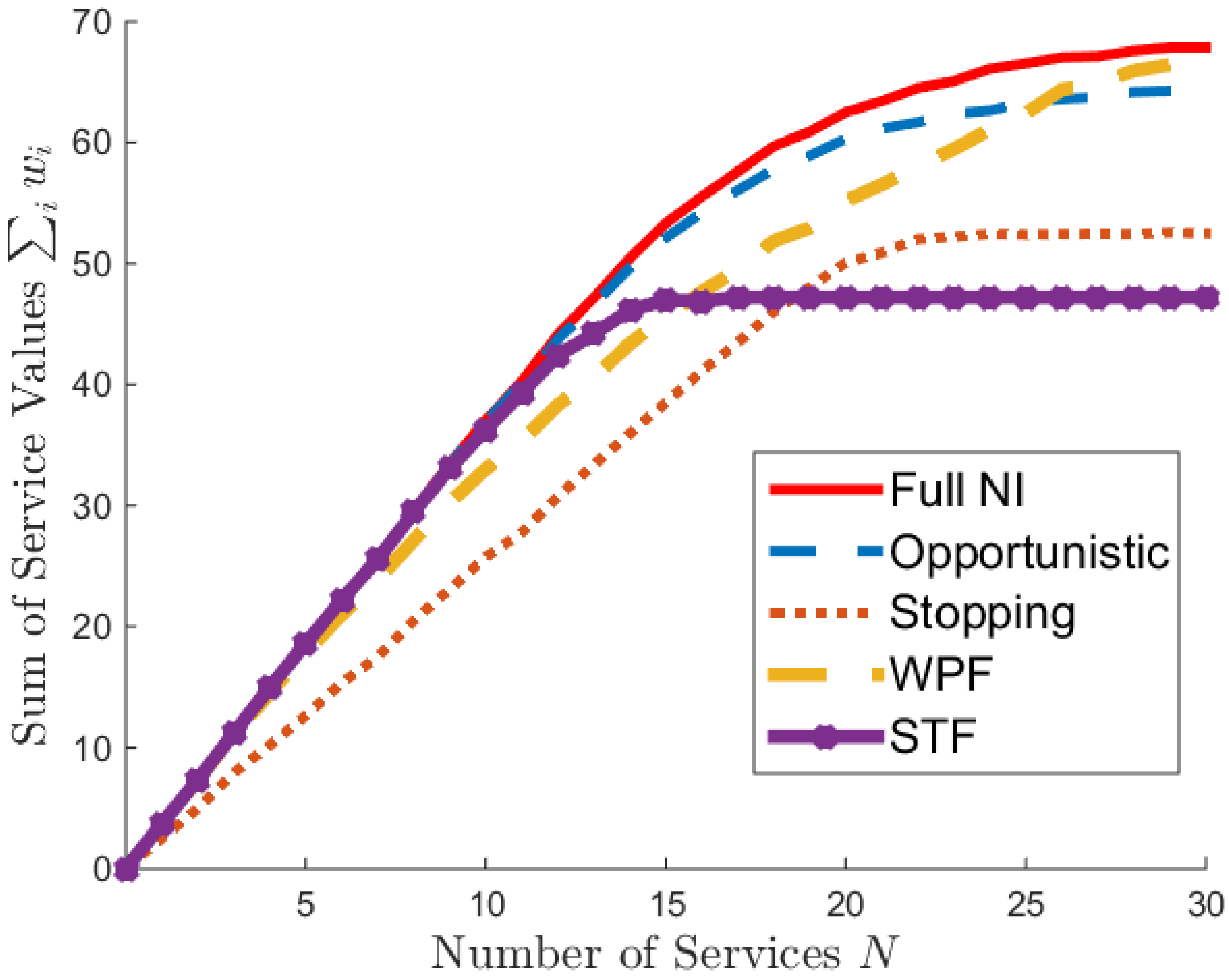
SIMULATION SETUP

- Fixed transmit power
- Gaussian channels
- Rate = log(1+SNR)
- Service values {1,2,4,8}
- Common deadline of 1 millisecond

Strategies

- Full Network Information (NI)
- Opportunistic
- Stopping
- Weighted Proportionally Fair (WPF)
- Shortest Time First (STF)

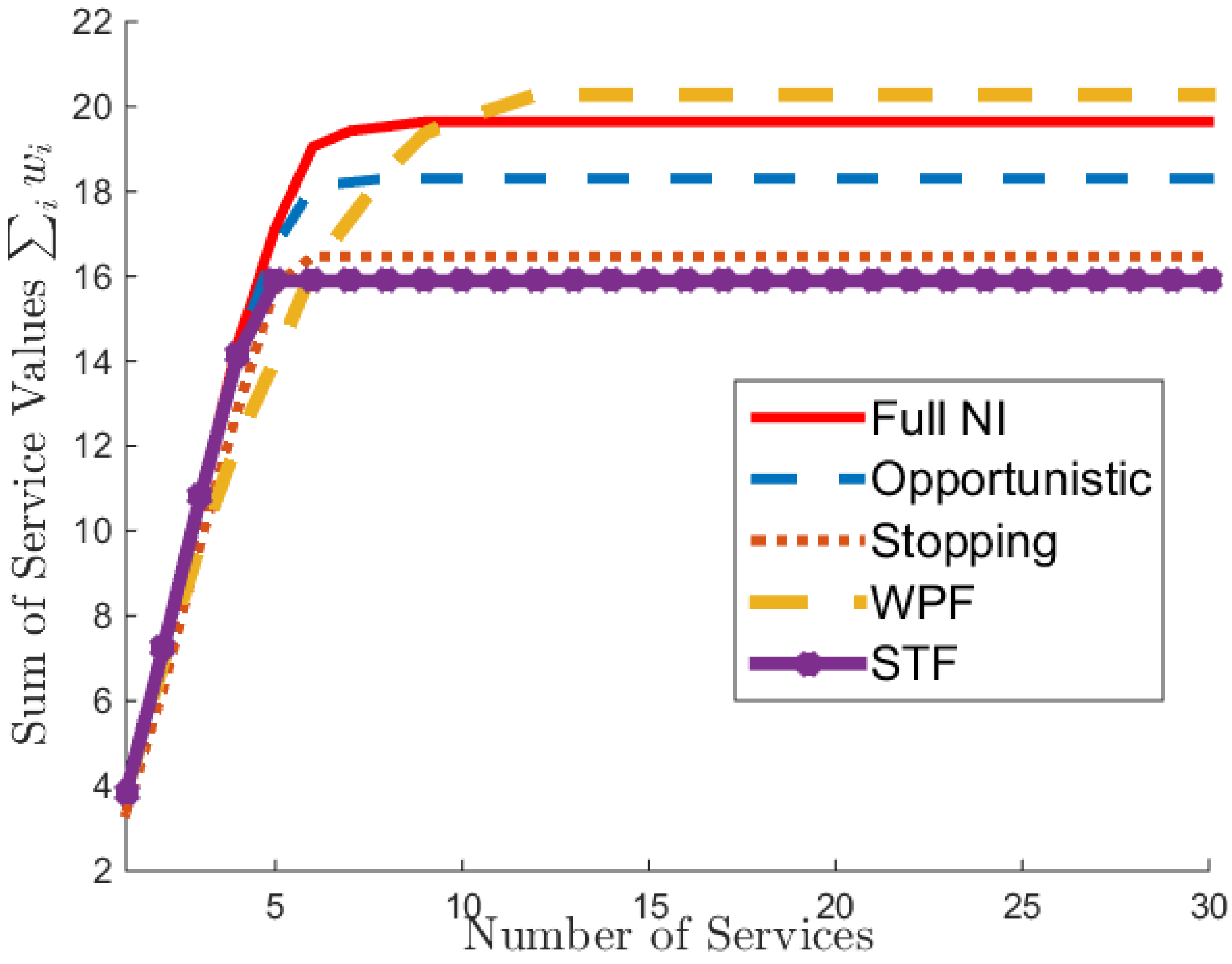
- Packet length 1kb
- 20 microsecond probing time (e.g. 802.11 RTS/CTS)



Strategies saturate at different points

- Packet length 2kb
- 100 microsecond probing time (e.g. 4x4 MIMO)
- Full NI does **not** reorder

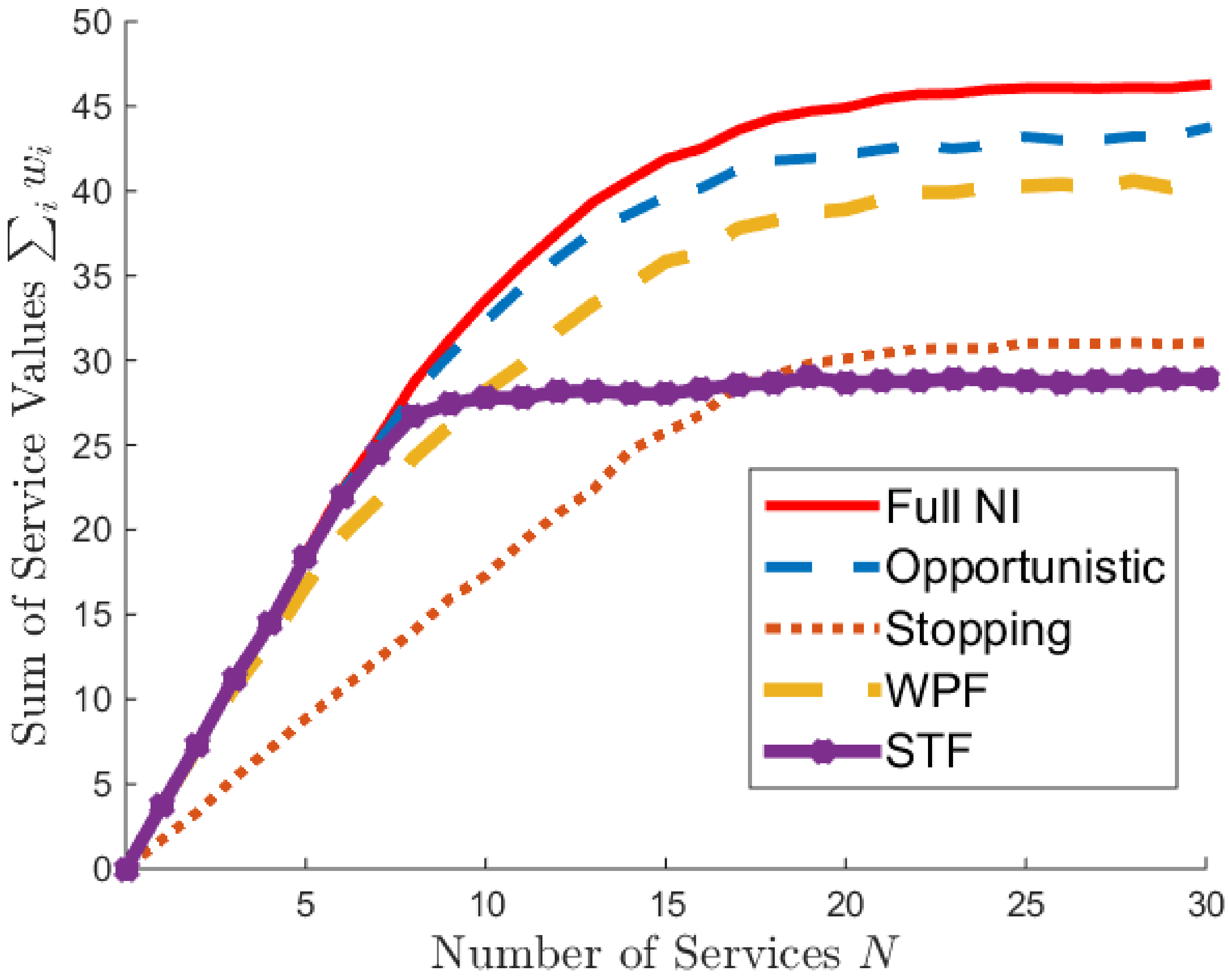
WPF benefits from skipping in order



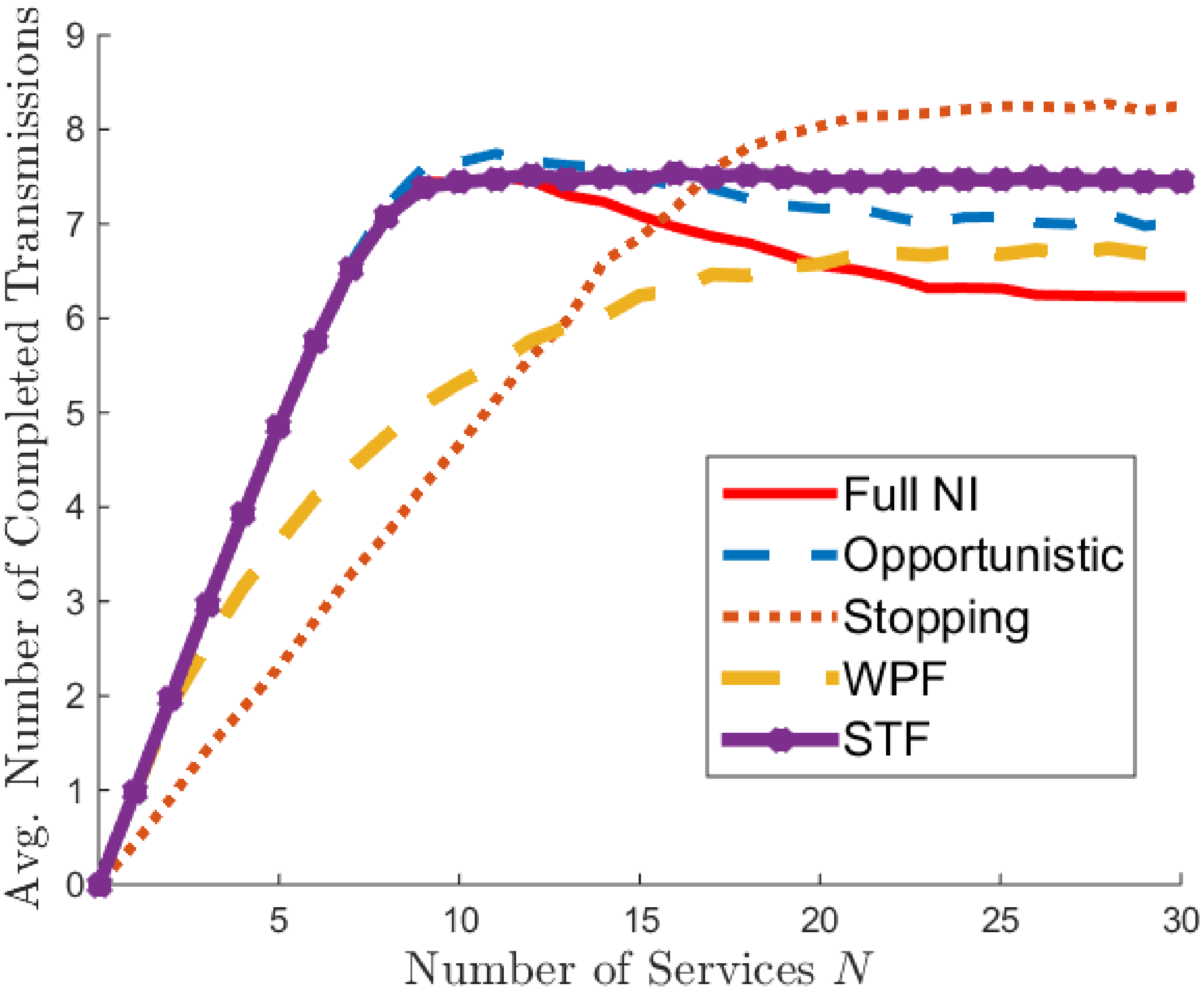
Bejarano, Oscar, et al. "Mute: Sounding Inhibition for MU-MIMO WLANs." *IEEE SECON 2014*

- Packet length 2kb
- 20 microsecond probing time

Cost of computations can payoff



- Packet length 2kb
- 20 microsecond probing time
- Stopping (eventually) transmits more
- Full NI transmits less, but more valuable



More value for less transmissions

TAKEAWAY MESSAGE

- Quantitative value of service with strict deadlines and non-negligible probing time
- Overhead in transmissions and probing influences strategy selection

To consider…

What *is* the value of a service?