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Station Assignment with Applications to Sensing

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[Developing the Science of Networks]

Motivation: Sample Scenarios

- Health monitoring system:
  - Patients with sensors of physiological data
  - Data periodically uploaded via one of a set of base stations
  - The set of base stations changes as the patient moves around
- Participatory sensing: Mobile users that periodically sense their environment and send the data

Model

- We model these systems as *dynamic clients* that transmit periodically via *base stations*
- Time is assumed to be slotted
- Each base station *s* has a **bandwidth** *B*
- A client *c* has
  - A **life interval** T_c (when the client is active)
  - A **stations group** S_c (the stations in range)
  - A **laxity** *w* (transmission periodicity)
  - A **bandwidth** b_c (requested to the station)

Station Assignment Problem

- The problem is how to assign to every client *c*
  - Slots in which *c* transmits
  - For each such slot, a station in S_c to which transmit
- Such that
  - Client *c* transmits at least once every *w* slots in T_c
  - No station is overloaded in any slot. I.e., for each *s* and every slot, the bandwidth of all the clients that send to *s* in the slot is at most *B*

Restricted Adversary

- Client churn is controlled by an adversary
- The problem has no solution unless restricted:
  - No client has bandwidth $b_c > B$
  - For every set *C'* of clients and all time intervals T, the bandwidth required by the clients in the interval is at most a fraction *ρ>0* of the capacity of the stations of *C'* (allowing some burstiness *β≥0*):

$$\sum_{c \in C'} b_c \frac{|T_c \cap T|}{w} \leq |T||S(C')|\rho B + \beta$$

  - We call this *(ρ,β)*-admisibility.

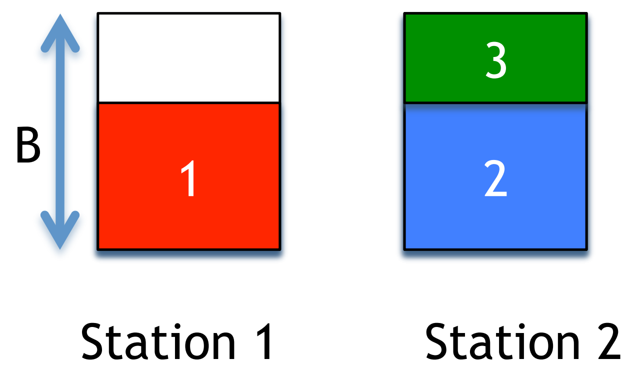
Admissibility

$$\sum_{c \in C'} b_c \frac{|T_c \cap T|}{w} \leq |T||S(C')|\rho B + \beta$$

- Permanent clients, $\beta=0$, $w=1$

$$\sum_{c \in C'} b_c \leq |S(C')|\rho B$$

Ex.: 3 clients, 2 stations, $b_1=b_2=2B/3$, $b_3=B/3$; and $S_1=\{1\}$, $S_2=S_3=\{1,2\}$, admissible if $\rho=1$



Admissibility and Solvability

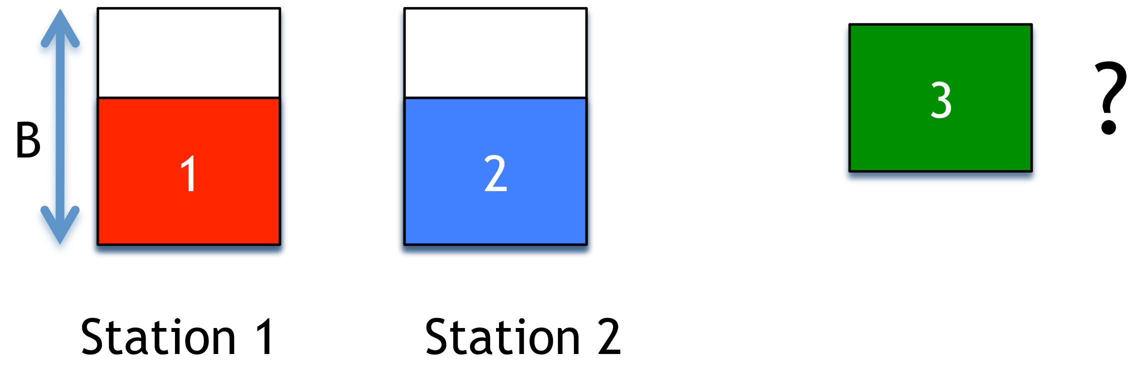
- Admissibility different from solvability!!

Permanent clients, *B=0*, *w=1*

$$\sum_{c \in C'} b_c \le |S(C')| \rho B$$

Ex.: 3 clients, 2 stations, $b_1=b_2=b_3=2B/3$; and $S_1=\{1\}$, $S_2=S_3=\{1,2\}$, admissible if $\rho=1$

But has no solution!!



Related Work

- Similar work explores load balancing problem, minimizing largest station load:
  - [Alon et al, 1997] for offline problem: approximation
  - [Azar et al, 1994] for online problem: *competitive analysis*
- We are not aware of work the explores this problem with a restricted adversary
- Similar adversarial model used is scheduling in wired [Borodin et al, 2001] and wireless networks [Andrews Zhang, 2005] [Chlebus et al, 2006]

Contributions

- Definition of the Station Assignment Problem
- Threshold of β for solvability of offline versions
  - All clients have same bandwidth, station group and life interval:
    $$\beta \leq mwB\left(\frac{n/(mw)}{\lceil n/(mw)\rceil} - \rho\right)$$
  - All clients have same station group and life interval:
    - No $\quad \beta > mB(1/m + 1/2 - \rho)$
    - Yes $\quad \beta < mB(1/2 - \rho)$
  - General case:
    $$\beta \leq mwB(1/(mw) - \rho)$$

Contributions

- Threshold of β for solvability of online versions when client assignments are irrevocable
  - All clients permanent and same $b_c \geq \rho B$, and $w=1$

$$\rho \leq 1/(1+\sqrt{2m}) \wedge \beta < \rho B$$

  - Life interval of client is known upon arrival and $b_c=1$

$$\beta > mB(1/\ln m - \rho)$$

  - General case ($b_c=1$)
    - Deterministic $\beta > mB\left(1/\sqrt{2m} - \rho\right)$
    - Randomized $\beta > mB\left(3/\sqrt{2m} - \rho\right)$

(Bounds for β yield bounds for ρ)

Same Bandwidth, Stations, Life Interval

- Thm: If $\beta > mwB\left((n/(mw))/\lceil n/(mw)\rceil - \rho\right)$ for $n = \lceil (mwB\rho + \beta)/B \rceil$ no algorithm can solve the Station Assignment Problem
- Proof: Assume all clients have life interval *w*. Hence each must transmit once. Setting their bandwidth to *b=(mwBρ + β)/n*, the set of clients is admissible.

  By pigeonhole, some slot and station needs bandwidth $\lceil n/(mw)\rceil b > B$

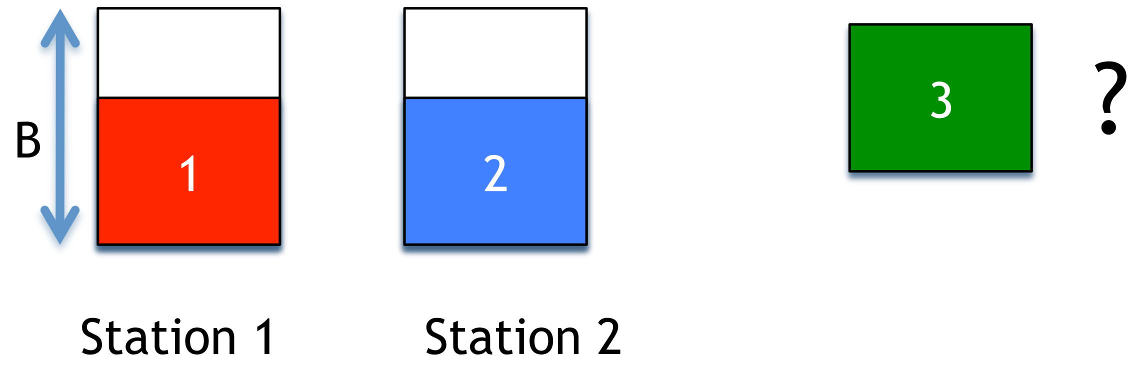
Example

- Let m=2, w=1, ρ=1, β=ε. Then

$$n = \lceil (mwB\rho + \beta)/B \rceil = 3$$

- The 3 clients have $b=(mwB\rho + \beta)/n = (2B+\varepsilon)/3$ and $S_c=\{1,2\}$
- Admissible: $\sum_{c \in C'} b \le |S(C')|\rho B + \beta = 2B + \varepsilon$

  But has no solution!!



Same Bandwidth, Stations, Life Interval

- Thm: If $\beta \leq mwB\left((n/(mw))/\lceil n/(mw)\rceil - \rho\right)$

  the algorithm that spreads clients evenly over stations in each interval of *w* slots solves the Station Assignment Problem

- Proof: The most loaded station in the most loaded slot requires bandwidth $\lceil n/(mw)\rceil b$

  By admissibility with |*T*|=*w*, we have *nb* ≤ *mwBρ* + *β*.

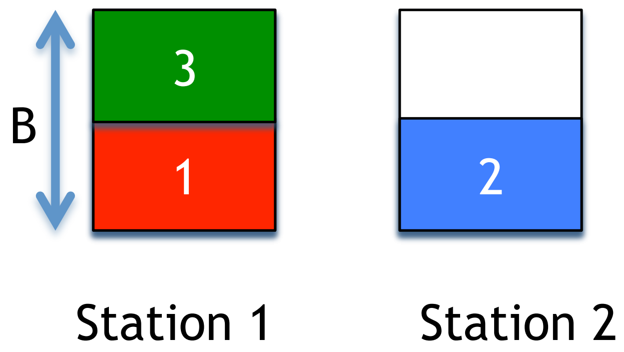
  Using this and the bound on *β*, the largest load is at most B

Example

- Let $m=2$, $w=1$, $n=3$. Then, to have

$$\beta \leq mwB\left((n/(mw))/\lceil n/(mw)\rceil - \rho\right)$$

  we must have $\rho \leq 3/4$ and, e.g., $\beta=0$
- The 3 clients can have $b=(mwB\rho + \beta)/n=B/2$ and $S_c=\{1,2\}$ and still be admissible
- Solvable



Conclusions

- The Station Assignment Problem is a new challenging problem
- Seems to be useful in environments where access to transmission wants to be guaranteed
- Some results for offline and online versions

Open Problems

- Many open problems!!
- Distributed protocols?
- Migration of clients?
- Handover?
- Room for generalization of the model (e.g., stations with different bandwidth, clients with different laxity)