Tracking a large number of tokens: a customised prioritised medium-access protocol for target responses

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Scenario and problem description

- Objective: track many "targets" (things, animals and/or people), over known, limited area.
- Available resources:
  - Well-designed network of fixed "anchors" (with own reliable control/coordination channel);
  - Simple wireless device ("token") with each target
- Basic operation: Anchor sends "ranging request" (RR). If single target responds, it is "heard" by several anchors $\Longrightarrow$ system estimate its location.
- Problem: Many targets may hear the same RR $\Longrightarrow$ medium-access control (MAC) needed
- Complications:
  - Only small fraction of targets may be moving at given time $\Longrightarrow$ Simple time-division access not appropriate!
  - Priority needed when too many active targets "congregate" $\Longrightarrow$ simple ALOHA-style solution not appropriate
- Our approach: Use the Dutch auction!

Illustration of 1D tracking scenario

We focus on “corridor” model, but extension to 2D/3D is relatively simple

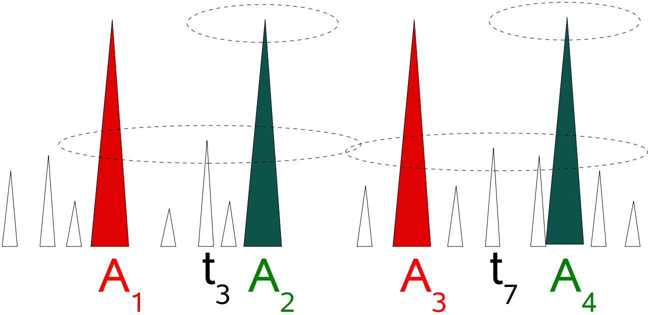


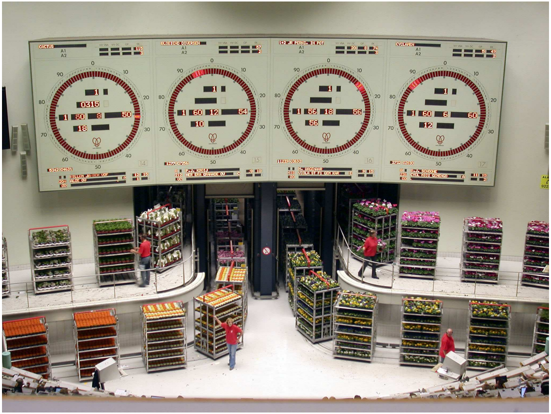
Figure: Large triangles: anchors; small ones: targets; target height: priority

Auctions for medium access: Why?

- allocate channel to those that most value it (“give priority”)[1]
- “incentive compatible”: “etiquette” or “altruism” not needed
- A terminal’s bid could come from
  - “true” “willingness to pay” of a user, or
  - “priority” computed/adapted by software according to
    - terminal, application and/or packet type
    - location
    - channel state
    - distance travelled
    - battery status, etc.

The Dutch auction

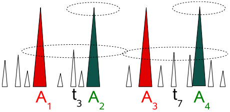
- Public "clock" displays a progressively falling price
- Participants silently watch and wait
- Eventually participant that most values object "takes it"



Dutch auction for general MAC: why?

- simple and fast
- own bid-making protocol that prioritises highest bid(s)
- exceptional signalling economy
- For synchronised ad-hoc networks[2]
    - distributive implementation (start times, initial price, and rate of decrease can be pre-specified; then a terminal can determine from own clock the auction status)
    - confirmation of transmitter-receiver pairs, with smooth continuation if the pair is infeasible
- Can also consider “higher layers”[3]

MAC for target responses: basic idea



- In “corridor”, *N* anchors take turns with spatial reuse sending RR (see green and red anchors in figure 1)
- After a RR, each target calculates its bid (explained below)
- Clock starts “ticking”. Price starts at highest possible bid, and decreases by fixed amount each tick
- 1st terminal whose bid matches current price responds
- If response is successful, anchor acknowledges it, and target records anchor’s ID
- If anchor period has not expired, clock ticking resumes until another target responds
- Process continues until this anchor period expires; then control is transferred to the other set of anchors (figure 1).

Key step: priorities and bids calculation

- Choose coordinates so that anchor *i* is at (*i*,0).
- Anchor includes its ID in ranging request (RR).
- Target "remembers" the anchor to which it last responded
- After a RR, each target calculates its bid as follows:
    - the target's priority is $p = 1 + d$, with d the distance between the present anchor, and one in memory (e.g., if target last "spoke" to A_5 and now hears A_2, $d = 5 - 2 = 3$.
    - bid equals $p + r$ with r randomly chosen with as many significant digits as possible in (-1/2,1/2) (e.g. if previous target draws -0,2450, its bid is 4-0,2450= 3,7550)
- Outcome: if a target receives a RR
    - from the same anchor it last responded to, it gives itself lowest possible priority: 1.
    - from A_N and it last spoke to A_1 its priority is the highest (b/c it is very far from its last location known to the system)

Implementation issues/challenges

- Scheme works more easily if targets have a “common clock”. This may or may not be a major challenge
- If targets are not synchronised, anchor can possibly broadcast the new price at every “tick”, but a target may spend non-negligible energy receiving the price message
- System parameters (tick duration, rate of decrease, etc) should be “optimised”. Processing and signal travel time, and clock “drift” should be considered
- Possibility of simultaneous responses need to be addressed

Possibility of “colliding” responses

- In order for a “collision” to occur, several targets must:
  - have the same priority, **AND**
  - draw the same random number, **AND**
  - respond to the same anchor
- Thus, probability of response collision seems negligible
- Anyhow, if a response collision does occur:
  - Anchor will not acknowledge responses
  - Targets involved will not put this anchor in memory
  - Targets will follow the “rules” (e.g. recalculate a bid, or just wait for next anchor period)
  - Auction will continue

Recapitulation

- The Dutch auction is great for general MAC, b/c it
  - automatically and simply prioritises higher bids through its own bidding protocol
  - can be implemented without a controller (if terminals are synchronised)
  - has exceptional signalling economy (in simplest case, only one bid signal is necessary: the winner's)
- For tracking many targets with widely varying mobility and activity patterns, time-division and "Aloha" schemes fail
- A Dutch-auction-based MAC protocol has been proposed
- It gives priority to targets that are presently far from their last location known to the system
- Analysis is entirely *qualitative*. Numerical performance experiments are desirable.

Real-life Dutch flower auction in Aalsmeer (NL)

- Price clock starts at a “high” price, and progressively falls
- A bidder wishing to buy at current price, pushes a button to stop the clock, and uses microphone to indicate desired quantity
- Then the price clock moves to a slightly higher price, before resuming decreasing movement
- The next bidder who stops the price clock buys at current price, and so on until the complete lot of flowers is sold
- The auction then starts to sell another lot
- Prices form about once every 4 seconds on a clock

Facts and figures about Aalsmeer auction

According to www.vba-aalsmeer.nl, in 2006 :

- Daily number of growers delivering products: ≈5.300
- Daily number of traders purchasing: ≈1.050
- Daily number of transactions: ≈44.000
- Transactions per clock per hour: ≈1.100
- Average daily turnover (auctioning): EUR 4,8 million
- Annual turnover: EUR 1,75 billion
- Size of auction complex: 1 million m^2 or 200 football fields (World's largest commercial building per Guinness)

Dutch auction in progress

For Further Reading I

- E. Wolfstetter, "Auctions: An introduction," *Journal of Economic Surveys*, vol. 10, pp. 367–420, Dec 1996.
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- C. Lima and G. de Abreu, "Game-theoretical relay selection strategy for geographic routing in multi-hop wsns," in *Positioning, Navigation and Communication, 5th Workshop on*, pp. 277–283, Mar 2008.