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Simple, adaptively-prioritised, spatially-reusable medium access control through the Dutch auction, with decentralised implementation for synchronised terminals

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***Abstract*—The Dutch auction (the price progressively falls until a buyer "takes" the object) is proposed as a foundation for decentralised medium-access control. Common auction formats are well-understood, relatively simple mechanism which have long been used for allocating an indivisible good to the party that values it the most, for such reasons as speed of allocation, discovery of the true "value" of the object, and fraud prevention. Various auction schemes have been proposed for the allocation of telecommunication resources, including medium access control (MAC). But previously proposals require a controller, and, to receive the bids, an alternate protocol which could waste resources, or miss important bids. For MAC, the Dutch auction has several major virtues: (i) a bid-processing protocol that automatically and simply prioritises the highest bid(s); (ii) possibility of distributive (auctioneer-free) implementation for synchronised terminals; (iii) confirmation of transmitter-receiver pairs at auction time, with smooth continuation if the pair is infeasible; (iv) exceptional signalling economy (the only strictly necessary signal is the winning bid). Secure software inside each terminal may record transactions for eventual payment collection, or the auction can be used as a prioritised-access algorithm, without real money exchange. Below we evaluate *qualitatively* the MAC potential of this auction, emphasising the distributed version, which can control access with spatial reuse in a wireless adhoc environment.**

Extended Abstract

General Motivation

Since time immemorial, auctions have been employed as a practical mechanism for the transfer of ownership of articles of value [1]. In the telecommunication domain, noteworthy relevant works include [2], [3], [4], [5], [6], [7], [8], [9], [10].

General reasons for choosing auctions include (i) speed of allocation, (ii) discovery of the true "value" of the offered object, and (iii) transaction "transparency" (fraud prevention)[1]. For medium-access control (MAC), auctions provide a form of "prioritised access" in that the channel is allocated to the terminal that most values access. A terminal's valuation of access could either (a) represent the "true" monetary "willingness to pay" of a (selfish) human user, or (b) be a "priority" index computed/adjusted by software inside the terminal using local information (e.g., [2], [6]). A terminal's priority may vary on such factors as its "importance", packet type, location, channel state, distance travelled, battery status, etc.

Sealed-bid auctions for MAC

A MAC auction should be relatively simple and rapidly produce a winner, since access must be granted quickly, and repetitively. Thus [2], [6], [8] propose the equivalent of a "sealed bid" auction; i.e., each bid is independently submitted in a "sealed envelope", the auctioneer "opens" all bids simultaneously, the highest bidder wins, and pays as pre-specified by the rules. A participant computes his bid considering his own valuation, what he may know (statistically) about the valuations of other participants, and the specific rules of the auction.

However, MAC sealed-bid actions do have disadvantages. They require an auctioneer (controller), as well as an alternate MAC protocol to receive the bids. This protocol may be problematic with a large, possibly variable number of bidders. If it is contention-free, it may be wasteful of resources; and if it is contention-based, the highest-value terminals may be unable to make a bid, and, consequently, a suboptimal allocation may result.

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The Dutch auction for MAC

In a Dutch auction, a public “clock” displays a progressively falling price. Each participant watches and waits until the price reaches a desired level. At some point, the participant that most values the object indicates its willingness to pay the current price [1].

For MAC purposes, the Dutch auction retains the relative simplicity and allocation speed of sealed-bid auctions, and add several fundamental advantages: (i) A built-in bid-processing protocol that automatically and simply prioritise the highest bid(s); (ii) the possibility of a distributive (auctioneer-free) implementation (start times, initial price, and rate of decrease can all be pre-specified, so that a terminal can determine from its own clock the current status of the auction); (iii) Confirmation of transmitter-receiver pairs at auction time, with smooth continuation if the pair is infeasible; (iv) exceptional signalling economy (only one bid signal (the winner’s) is strictly necessary in a single channel scenario).

Evidently, the distributed implementation requires tight synchronisation among terminals, i.e., a “common clock” (as would any “time slotted” or “spread spectrum” MAC scheme). However, unsynchronised terminals can be accommodated with the presence of an auctioneer, which can announce the beginning of the auction and its (possibly adaptable) initial price and time-rate of decrease. In fact, the auctioneer could broadcast the falling price, if the participating terminals lack an accurate clock.

Despite the above, [3] seems to be the only previous application of the Dutch auction in a telecommunication context (bandwidth allocation, *not* MAC).

Dutch auction with spatial reuse

Core protocol: For synchronised terminals, the distributed Dutch auction can provide medium access, with spatial reuse. At $t_0$the first auction starts with the pre-specified initial price, and time-rate of decrease, and lasts τ. At time $t_0+\tau$ the first winner(s) access the medium for a length of time T (even if a winner is selected in less than τ, channel access starts at $t_0+\tau$). At time $t_0+\tau+T$ another auction of length τ starts, with pre-specified parameters, followed by a period of channel usage of length T, and so on.

When a terminal wishes to “take it”, up to 3 short messages may be sent: (1) the winner sends its ID and that of the desired receiver (2) the receiver, if available, sends a short confirmation message (3) the winner sends a 2nd short message confirming the successful pairing. These 3 messages are reminiscent of the RTS/CTS messages in DCF[11]. If the transmitter-receiver pairing is not successful, the auction continues. Evidently, for *each* price value, the “tick” of the auction “clock” must allow sufficient time for the possible exchange of these 3 messages before moving on to the next lower price. The example below explains the process further.

Specific example: Figure 1 shows a situation in which 7 terminals wish access to a single communication channel. A row in table I shows the index of a transmitter, its desired receiver, and valuation. Conceivably, a terminal could have a buffer with several possible messages each with its own valuation (see rows 2 and 3).

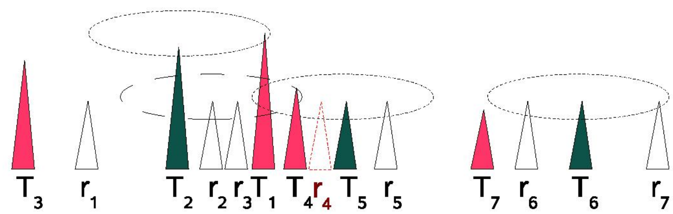

Figure 1. The distributed Dutch auction as a MAC protocol with spatial reuse

Table I
POTENTIAL TRANSMITTERS, RECEIVERS AND VALUATIONS

T_i	r_j	v
1	1	10
1	4	9
2	2	7
3	1	6
4	3	5
5	5	4
6	7	3
7	6	2

At t_0, each terminal (regardless of the physical location) knows that the (distributed) Dutch auction starts, at a pre-specified price, say 11, which will fall at a rate of 0.1 every ε. $\varepsilon \ll \tau$ is long enough to allow the 3 messages mentioned above. After a length of time of 9ε the price is 10.1, which is too high for everyone. After one more ε, the price becomes 10. Terminal 1 immediately sends its “I take it” message but r_1 is out of range, and does not respond. Thus, the clock continues to“tick” without a winner. 10ε later, the price drops to 9, and T_1 sends another “I take it” message this time with intended partner r_4. r_4 is in range, but in sleeping mode (indicated by a dotted red outline in fig. 1). Again, the pairing fails, and the clocks continues to tick (T_1 has no additional potential partners, and “drops out”

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of this auction). Eventually the price reaches 7, which triggers an "I take it" from T_2 (heard by T_1 , r_1, r_2 and r_3); r_2 confirms (heard by T_1, T_2, T_4 and r_3), and T_2 confirms the successful pairing (heard by T_1 , r_1, r_2 and r_3). Notice that T_3 has not heard any of the previous messages, and continues to behave as if there has been no winners. Thus, 10ε later, T_3 'thinks' that the price is 6, and sends its "I take it" (heard only by r_1). But $r_1$declines, because it knows about the $T_2 \rightarrow r_2$ pairing (notice that r_1 would *not* have known this without the second message from T_2). The process continues similarly with T_5 and T_6 setting successful pairings, but *not* T_7. Notice that, similar to T_3 before, T_7 has not heard *any* of the preceding messages, and 'thinks' it has won when its clock indicates that the price is 2, but r_6 declines because it knows of the successful $T_6 \rightarrow r_7$ pairing (without T_6's 2nd message r_6 would *not* have known it).

Main implementation challenges

The importance of tight synchronisation in a distributed implementation has already been discussed. Also, the parameters of the protocol (initial price, rate of decrease, τ, T, and ε) should be chosen optimally. Furthermore, the possibility of simultaneous winners needs to be dealt with.

If 2 simultaneous "I take it" messages are sent, the potential receivers will be unable to decode them, and hence will not respond. Each winner will 'think' that its desired receiver is unavailable, and the auction would continue. Thus, if ties are infrequent, they would cause no significant damage.

If the possible valuations can be idealised as continuous random variables, then the probability that 2 terminals have the same valuation is negligible. On the other hand, if the valuations ("priorities") are members of a relatively small discrete set, then the probability of tied winners can be high. In this case, some some randomisation can help. For instance, suppose the valuations are integers between 1 and M. Then, at the start of the auction, each terminal may draw a random number between $-1/2$ and $1/2$, with as many significant digits as possible (considering ε above), and add it to its "true" valuation. Thus, the terminals whose "true" valuations were equal to 2, would have new valuations in the range 1,5 to 2,5. The probability that two terminals remain tied after the randomisation is negligible.

Conclusion

Previous work has shown the feasibility and effectiveness of auctions for simple, adaptively-prioritised medium-access allocation. But previous proposals require an auctioneer (controller), and an alternate MAC protocol to handle bids, which could either waste resources, or miss important bids. We have analysed *qualitatively* the potential of the Dutch auction for medium access allocation, and conclude that it retains the favourable features of previously proposals, while remedying their most serious limitations, and expanding the set of scenarios where MAC auctions can be used.

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