Cellular Network for Real-Time Mobile Auction*

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Abstract. Auctions are an ancient form of economic activity and, as such, have evolved with technology. However, some forms of traditional auction have survived unchanged, even in areas of great economic interest, until modern regulations imposed a change. We present the design of a specialized cellular network that has recently replaced traditional fish auctions in Galicia (Spain).

Keywords: Auction technology, mobile communications, wireless terminal, protocol engineering

1. Introduction

Galicia (Spain), like other Atlantic regions, obtains a large percentage of its income from sea industries: Inshore and deep-sea fishing, canning industries and shipyards. One of the main Galician cities, Vigo, is the most important fishing port in Europe. Inshore Galician fishermen are organized in guilds (*cofradías*), which sell captures in public auctions immediately after inshore boats are unloaded. These guilds have annual fish sales in the range of 100-200 million Euros (Xunta de Galicia, 1994).

A traditional fish auction takes place in a large hall where captures are displayed on the floor in boxes, classified by species, quality and weight. Authorized dealers and public walk around, listening to auction leaders who sing box prices in decreasing order. The first dealer who makes an indication to stop the countdown obtains the box.

European Union food handling regulations have recently interfered with tradition. It is compulsory to establish a physical barrier between displayed fish and dealers. In some places, such as Plymouth Fish Trade (UK) or Ostend Fish Auction (Belgium), dealers sit in desks with bid buttons, in dedicated auction rooms. Prices are displayed on a countdown electronic clock (Schelfhout, 2001).

In the case of Galicia, this solution is not desirable, for two reasons:

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Tradition: For centuries, dealers have been allowed to move around. Mobility is, therefore, a major concern.

Tourism: Inshore fish auctions are important tourist destinations at Galician sea ports. Any solution should have little impact on this secondary profit source, by introducing as few changes as possible in auction rooms.

As a result, the Galician government decided to fund a system in which dealers carry a mobile hand held computer to make their bids, and no major changes are introduced in the auction room. In addition:

A. The system must respect dealer privacy: dealers do not necessarily need to identify themselves at the control booth. Also, terminals must be operative when hidden.

B. Terminals must offer balance status and other messages when required by the user.

C. The system must be robust: all bids must arrive to their destination. At the same time, only authorized dealers and (more important) dealers with positive balance are allowed to bid.

D. Involuntary or hostile interference may disable the system, but must not cause a transition to an incoherent state.

E. Temporary terminal disconnection, either voluntary (leaving the auction room) or not (fading), must be transparent to users, unless they want to bid at the same time.

F. All dealers should be free to move to a different auction place (up to 64 possible guild facilities), without need of new registration.

This paper describes a cellular system that satisfies requirements A-F, which has been jointly developed by Universidad de Vigo and SAEC-DATA S.A. (Spain).

2. Background: Electronic Auctions

By electronic auction me mean any computer-related auction technology. For a review of most of these technologies, see (Schelfhout, 2001). We can make the following classification:

1. *Automated auctions*. Users are present at an auction room. Partially or totally, the auction process is replaced by electronic aids. This

is the case of the European fish auctions described in the previous section. Other examples are the Dutch flower industry (VanHeck and Ribbers, 1997) and the Nigerian coffee exchange (Schelfhout, 2001).

2. *Internet auctions*: Users are not located in an auction room. The auction is implemented as a client-server distributed system over the Internet. Users make their bids through a WWW browser (Ebay, 2001; Ubid, 2001).

3. *Artificial intelligence auctions*: For research purposes, real entities (such as users) are replaced by computer processes (Rodríguez-Aguilar et al, 2000).

Current systems for automated auction do not fulfil requirements A-F. As far as the authors know, no bidirectional mobile terminals for real-time auction were available in the market before this project. Existing terminals just transmit a code when a button is pressed, which is used to stop the auction. In some cases, such as infrared terminals, the underlying technology is intrinsically unidirectional[1]. Obviously, bidirectionality is required to transmit messages to the user. However, there are more subtle issues that depend on bidirectionality. For example, it is possible to implement advanced protocols for channel sharing that guarantee that all terminal transmissions will eventually reach their destination.

A bidirectional system also permits to establish different working modes. In our case, at least, there are two: terminal recognition, to let the system know which terminals are present (equivalent to GSM self-identification signalling phase), and auction (equivalent to GSM traffic exchange phase) (Mouly and Pautet, 1992).

3. A Mobile Network for Automated Auction

Our model is a particular case of automated auction. In order to satisfy constraint F above, our system is inspired by a GSM network. Each user owns a mobile terminal with a unique serial number. When the user enters a new auction room, the terminal initiates an automatic dialog with the base station placed there, and obtains a local working code. All cells are linked via the Internet, for administrative and roaming purposes.

Figure 1 shows the electronic entities that participate in the auction.

- *Cell*: A cell is an auction room. All active terminals entering a cell are assigned to it.

- *Base station*: The core of the bid system. It is responsible of assigning TDM slots to user terminals, resolving conflicts, recognizing present terminals, transmitting messages to them, and deciding who wins an auction.

- *Terminal*: A terminal is a mobile hand held computer that sends bids to the base station and receives messages from it.

- *Clock computer*: During auctions, it displays a price countdown. A terminal bid stops the clock computer when a user is interested in the current price. Also, the clock computer:

  - Sets terminal recognition mode or auction mode in the base station.
  - Transmits a list or valid users and their balance to the base station.
  - Receives a list of present users from the base station.
  - Updates user balances.
  - Generates messages that are passed to the base station, to be transmitted to terminals.

4. A discussion on existing technologies

In this section, we discuss the advantages and drawbacks of three candidate wireless technologies to implement the modems of the base station and the terminals: Bluetooth, IEEE 802.11 Wireless LAN (WLAN) and 433Mhz band modems.

4.1. Bluetooth

Bluetooth (BT) (BTcore, 1999) is a short-range wireless technology. The typical separation between devices is 10 m (10meters, 2001). It has been designed for applications such as wireless headphones and computer-to-peripheral communications.

A BT network is composed of *piconets*. A piconet is a spontaneous network whose configuration changes when a BT device enters or leaves its range. A piconet has one master and up to seven *active* connected slaves (BTcore, 1999).

It is also possible to create *scatternets*. A scatternet is a net of piconets. In a scatternet, the master of a piconet could be a slave in another piconet. In this scheme, inter-piconet communication is allowed (García-Reinoso et al, 2001).

Drawbacks: due to project specifications, there will be up to 250 users in the auction place. This place is small enough to fit into a BT piconet. Obviously, the only way to achieve that number of users is by defining a scatternet. This means that many user terminals will be both masters and slaves. According to our experience (García-Reinoso et al, 2001), the resulting configuration would be too complex, and would require further study to determine feasibility.

Advantages: from our point of view, the main advantages of this technology are its low power consumption ($\sim$ 1 mA standby and $\sim$ 60 mA peak) (Lansford and Bahl, 2000), small modem size (1 cm^2) and future low cost (5-10 USD) (GSMbox, 2001; Journaldunet, 2001; Transfert, 2001; Security-Informer, 2001; Casira, 2001). However, at the time this paper was written, BT modems were still far from that price goal.

4.2. WLAN

IEEE 802.11 Wireless LAN architecture (IEEE, 1997; IEEE, 1999; Bromax, 2001; Tay and Chua, 2001) is composed of a number of base stations (access points) and up to 2,048 terminals per base station. Transfer rates vary from 1 Mbps to 11 Mbps.

This speed range allows extremely low response times for auction applications. Nevertheless, current implementations impose some limits:

- In order to guarantee DSSS 11 Mbps performance, there must be a separation of 25 MHz between channels (Ericsson, 2001; Colubris, 2001). The number of 5-MHz channels in the 2.4 GHz DSSS band varies from 13 (channels 1-13, ETSI) to a single one (channel 14, MKK) (IEEE, 1999). As intermediate cases, there are two contiguous channels in the Spanish regulatory domain and four contiguous channels in the French one (Spain and France have a joint population of 100,000,000 citizens, a considerable fraction of the EU market). As a result, there can be up to three overlapping cells in the same area with full performance.

- The typical number of terminals per access point in mass-market implementations is 64 (see table I).

- In some cases, the manufacturer recommends less than 15-20 simultaneous transmissions per access point, to ensure the quality and performance of data transmission (Nokia, 2001).

Drawbacks: using DSSS technology, a number of 250 modems per auction room requires cell planning. WLAN modems are too expensive

Table I. Survey of WLAN products

Company	AP	# users/AP	AP Price	WLAN cards	Card price
3COM	3CRWE74796B	63	825 USD	WLAN PC Card	179 USD
NOKIA	A032 AP	64	999 USD	C110	320 USD
Apple	AirPort Base Station	10	299 USD	AirPort Card	99 USD
Netgear	ME102	30 - 70	231 USD	MA401	84.95 USD
Xircom	APWE1120	64	298.99 USD	CWE1120	138.99 USD

for a simple bid terminal: according to table I, we would need four Netgear access points to handle 250 MA401 cards (note that this would not satisfy the channel separation recommendation in (Ericsson, 2001; Colubris, 2001)), with a total cost of 22,162 USD. Also, at a transfer rate of 1 Mbps, typical power consumption is $\sim$ 10 mA standby and $\sim$ 400 mA peak (Lansford and Bahl, 2000), which is much higher than the requirements of BT or 433 MHz band modems (see section 4.3).

Advantages: the theoretical number of users in the WLAN standard fulfils our project specifications. The transfer rates are very interesting for high-performance implementations.

4.3. 433 MHz band modems

The 433 MHz radiocontrol band is available in several EU countries for short-range[2] control purposes (DGTEL, 1991), and is equivalent to the 418 MHz UK band. Existing 433 MHz modems provide a transparent path for either narrowband modulations or square waves. As an example, the Radiometrix bidirectional RF unit, or BiM (Radiometrix, 2001) has a peak transmission rate of 40 Kbps.

Drawbacks: the transfer rate is 275 times slower than WLAN rate. It is necessary to develop application-specific MAC drivers (which are part of WLAN card distributions).

Advantages: bidirectional 433 MHz modems are cheap ($\sim$ 35 USD) and small (4 cm^2). In the 250-terminal example above, total cost would be 8,785 USD (including a single modem for the base station). Power consumption is extremely low $\sim$ 5 mA standby and $\sim$ 10 mA peak (Radiometrix, 2001).

4.4. Technology choice

We decided to discard Bluetooth, due to the complexity imposed by the seven-slave boundary (García-Reinoso et al, 2001).

Current WLAN hardware costs are too high for simple embedded systems. System cost is a major concern, because the auction environment is extremely aggressive, and it is necessary to replace mobile terminals and base stations quite often. Also, WLAN may require cell planning, as the number of users grow.

Finally, due to the previous reasons, we decided to implement an auction protocol using 433 MHz modems. In the following sections, we demonstrate that it is possible to implement an efficient auction system on that platform, while keeping costs at the same level as previous unidirectional systems (Schelfhout, 2001).

4.5. Control

We implemented system control on a Motorola MC68HC11 microcontroller (Miller, 1993), which executes the automated auction protocol. The MC68HC11 comprises an 8-bit CPU and timing and serial port peripherals. Byte-level auction protocol is supported by the Serial Communications Interface (SCI), via exceptions. An underlying NRZ source coding (with one start bit and one stop bit per byte) is injected in the RF module.

Figures 2 and 3 show an internal view of the base station and the mobile terminal, respectively, as implemented with a BiM modem and a MC68HC11 microcontroller. The mobile terminal has a LCD display for user messages (see figure 1), and four buttons for bidding, user message interfacing and set-up. The terminal has an approximate autonomy of one month with a DC 9V battery, in normal operating conditions.

5. Automated Auction Protocol

Figure 4 shows the basic unit of the auction protocol Time Domain Multiplex (TDM). It has a $B \to T$ channel, which is transmitted from the base station to the terminals, and one smaller channel per auction in the opposite sense, $T \to B_1$ and $T \to B_2$[3]. We chose this structure due to the simplicity of our RF module. Other mobile systems with a complex RF interface, such as GSM, have a different TDM per transmission sense, in separate carriers (ETSI, 1997).

All auction protocol frames have the same structure: a 3-msec. synchronization burst (10101...), an idle byte, a frame start byte, and a data load (2 bytes for $T \to B$ and 17 bytes for $B \to T$). Here, a "byte" is a source-level byte (10 bits), including start and stop bits. A $T \to B$ frame is any frame placed in channel $T \to B$ (a $B \to T$ frame is defined accordingly). Overall frame length is 10.4 msec for $B \to T$ and 5.6 sec for $T \to B$[4], at 31250 Kbps. Note that a large percentage of transmission time is consumed by synchronization, which is imposed by the BiM RF module. All terminals in the same auction compete for the same $T \to B$ channel, in a slotted ALOHA fashion (Bertsekas and Gallagher, and references therein, 1992). Collisions are detected as serial transmission error exceptions. In order to locate the correct $T \to B$ channel for an auction, terminals use $B \to T$ frame starting time as a reference (the base station injects a new $B \to T$ frame immediately after the last $T \to B$ channel).

Depending on frame type, there are two different data loads:

a) A $T \to B$ user frame has a two-byte data load. The first byte is the user local code. The second one is a checksum, for robustness.

b) A $B \to T$ base station frame has a 17-byte data load, which is shown in figure 5.

$B \to T$ $MODE$ bits control auction working mode:

- Let $a = 1$ or 2. $I_a = 0$, $L_a = 0$ sets terminal recognition mode for auction a. In this mode, The set V of valid terminals[5] is scanned by placing their serial number in the 16-bit SN field. A temporary local code is proposed for terminal SN in field LC. If terminal SN is present, it must acknowledge with a $T \to B_a$ frame containing LC. User terminals are disabled until they receive their (SN, LC) pair. As a result of terminal recognition, up to 250 terminals may participate in auctions that take place in the same cell. $E_a = 1$ activates auction a. Let R be the set of enabled terminals, $R \subset V$. If a user in R pushes bid button a, the terminal sends a bid by placing its LC in a $T \to B_a$ frame.

- $I_a = 1$, $L_a = 0$ and $SN - H = 0xFF$ sets winner identification mode in case of bid collision, for auction a. In this mode, the base station sends an upper bound UC_a for LC[6]. All potential winners such that $LC < UC_a$ must answer by placing their LC in a $T \to B_a$ frame. In case of a new collision, the process is repeated until a unique winner results. To achieve this goal, the base station varies UC_a in a logarithmic search (Bertsekas and Gallagher, and references therein, 1992) within R, starting from $\lceil \frac{size(R)}{2} \rceil$.

- $I_a = 1$, $L_a = 1$ and $SN - H = 0xFF$ sets winner acknowledgement mode for auction a. In this mode, the base station sends the winner LC in UC_a.

- $I_a = 0$, $L_a = 1$ sets purchase mode for auction a. By repeatedly pressing his bid button, the winner requests as many boxes as $T \rightarrow B_a$ frames. Each request must be acknowledged by a $B \rightarrow T$ purchase acknowledgement frame ($C_a = 1$).

The auction protocol includes the possibility of sending ASCII messages to the terminals, to be shown on their LCD displays. Typical messages are current account balance and the total amount of boxes purchased. Any $B \rightarrow T$ frame can be used to send a 12-byte message (see fig. 5) to any terminal, by setting $MC = LC$. $MC = 0xFF$ sets broadcast mode.

6. Protocol Discussion

Bidirectional handshake ensures that all bids arrive to their destination (constraint C). It could be argued that a unidirectional system can achieve this objective, by means of repeated trials. However, our system has a *guaranteed* finite bid time for a given size of set R, which is a basic characteristic of real-time systems. Also, although a unidirectional system may filter users with negative balance or unregistered ones, a bidirectional system blocks RF transmission from them, which yields a better spectrum utilization.

Concerning constraint A, RF technology (as opposed to infrared) allows terminals to be operative when hidden. Dealers do not need to identify themselves at the control booth: the registration process is automatically handled by the terminal recognition procedure.

Our digital protocol design is more expensive than trivial solutions based on dumb terminals that simply send "pure" carriers. However, these systems can be easily fooled by interference, and an incoherent state may result violating constraint D. This is specially dangerous in the case of the 433 MHz band, which is widely used, for example, by construction cranes.

Constraint E has been considered for those cases in which users leave temporarily the auction room, or move to a place with high attenuation (behind a column, for example). As a design parameter, a terminal considers that its LC is no longer valid if it does not receive a $B \rightarrow T$ frame for 2 minutes. Consequently, the base station enters terminal recognition mode periodically. In order to satisfy constraint F, this mode is complemented with a roaming system, which keeps coherence of sets V across the cellular network. The system uses Internet for this purpose (see figure 1).

Finally, constraint B is supported by the messaging system.

7. Protocol Performance

Human perception is an essential consideration to evaluate protocol performance. Ideally:

- Elapsed time T_s between any winner bid and auction stop should be zero.
- Different bid times should be discriminated with arbitrary precision.
- Elapsed time T_w between auction stop and winner determination should be zero.

These goals are technologically impossible. However, it is possible to take advantage of the following subjective facts:

- An average human can hardly distinguish two manipulations separated by 0.1 sec. This fact is used to set price persistence time, 0.25 sec.
- Once auction stop is signaled, winner determination can be delayed an extra 1 sec. (this delay can be longer, if the stop alarm includes a "slow" message display on the auction screen).

With these facts in mind, protocol performance can be evaluated, as follows:

- Even in the case of collision, the system detects a bid within a basic protocol unit timeframe (figure 4). Therefore, $T_s \cong 20$ msec. For the same reason, non-simultaneous bid times can be discriminated with 20-msec precision.
- Elapsed time between auction stop and winner determination is variable, because it depends on the existence of collisions. In the best case there is only one winner, and $T_w = 0$ msec. In the worst case[7], and assuming $size(R) = 256$, $T_w \cong 20 \times log_2 \lceil size(R) \rceil \cong 160$ msec.

Therefore, in this situation, $T_s + T_w \cong 180$ msec, which is much less than the initial objective of 1 sec for T_w alone.

In normal operating conditions some collisions will take place. In order to estimate real performance, the following assumptions were made: for a current price start time, some users try to stop the auction with response times that follow an exponential distribution with 100-msec mean. Potential winner LC identifiers are uniformly distributed in R. A collision takes place if there are at least two bids in the 20-msec window that includes the first bid (or, in other words, if two or more terminals try to use the same $T \rightarrow B$ channel). Then, a logarithmic search starts to find the winner, and T_w is equal to the number of 20-msec steps.

50,000 runs were made to calculate each point in figures 6 and 7. For different R sizes, a different number of simultaneous bids take place (shown as percentages of R size). Figures 6 and 7 show average and standard deviation of $T_s + T_w$, respectively (again, note that *100 msec was a goal for T_s alone*, which has a fixed length of 20 msec). In all cases, it was concluded that protocol performance was acceptable from a subjective point of view.

Alternatively, a cheaper unidirectional system was evaluated. In it, the terminals just send a $T \rightarrow B$ frame when the user presses the bid button, and the base station is a simple receiver. To be more precise, the terminals send a frame as soon as the bid button is pressed, and a second one with an uniformly distributed delay in [0,180] sec (the upper bound was chosen to let this system be as competitive as possible compared to ours). Again, some users try to stop the auction with response times that follow an exponential distribution with 100-msec mean. Figures 8 and 9 show average and standard deviation of T_s, respectively, across 50,000 runs. In this case, T_s is the elapsed time between the first user bid and the reception of the first correct $T \rightarrow B$ frame. Therefore, $T_w = T_s$. Note that the first user bid is not necessarily the winner one, since this system can not solve interference situations. An interference takes place if two user bid frames overlap.

Apparently, in figures 8 and 9, T_s seems to be lower than the ideal goal of 0.1 sec. However, as the percentage of simultaneous bids grow, all bids are potentially lost. To illustrate this problem, figure 10 shows the region in which 95% of the runs finish with a winner (*95%-customer satisfaction* region). Note that, for 50 users, which is a common number in fish auctions, the system becomes useless if more than 5 users make a simultaneous bid. The points in figures 8 and 9 that lie outside the 95%-customer satisfaction region are meaningless.

8. Concluding Remarks

This paper describes a specialized cellular network for mobile auction, which is fully operational in the inshore guild system of Galicia, Spain. It has been demonstrated that this system respects current regulations, economic considerations and tradition. At the time this article was written, several cells were already connected to the network, with more than one thousand users. Figures 11-13 shows the current layout of the Bayona auction (note that the customers in figure 13 hide their terminals, as assumed in section 1, constraint A).

Future research is oriented in two directions:

- Protocol upgrade: Future modifications, which are unknown at this moment, will be supported by the message field in $B \rightarrow T$ frames.
- We are currently working in extensions for on-line and off-line Internet and WAP auctions.

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Notes

[1] One of the Galician auctions, Portonovo, used this kind of terminal. Portonovo has recently adopted our system.

[2] $\sim$ 30 m indoors, $\sim$ 100 m outdoors.

[3] Different fish auctions may take place in the same auction room. In the system described there are two auctions, but the generalization is straightforward.

[4] There exists an additional 1-msec guard before each channel.

[5] A cell can handle up to $size(V)$ terminals, $size(V) < N$, where N is the number of users in the network. V is actualized either by roaming or at the administration computer (see figures 1 and 12). In our case, $size(V) = 1000$ and $N = 65280$.

[6] In this mode, $SN - L$ and LC are UC_2 and UC_1, respectively.

[7] A full logarithmic search is required. For example, in case of simultaneous bids from $LC = 0$ and $LC = 1$.

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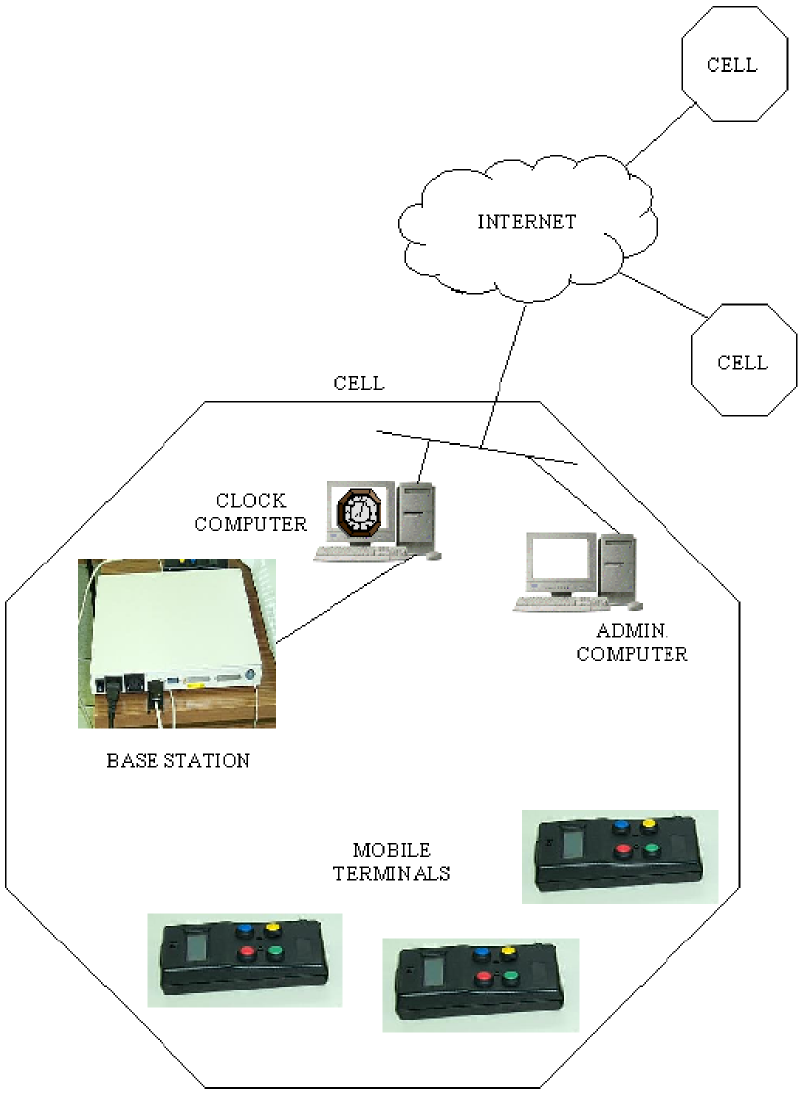

Figure 1. System architecture

Figure 2. Base station prototype

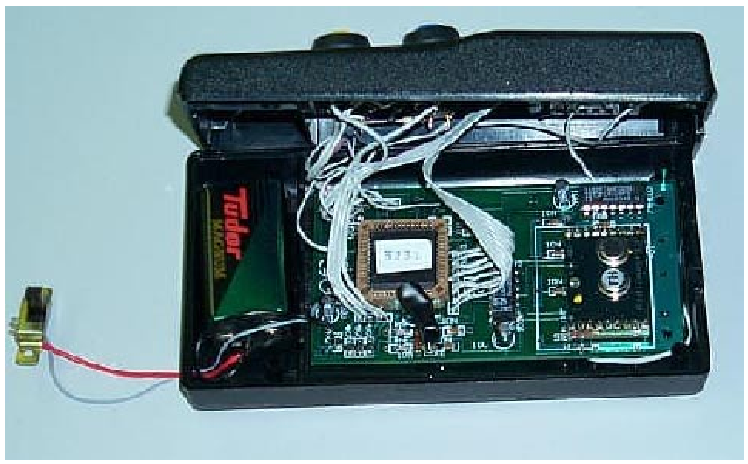

Figure 3. Mobile terminal prototype

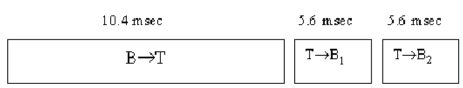

Figure 4. Basic protocol unit

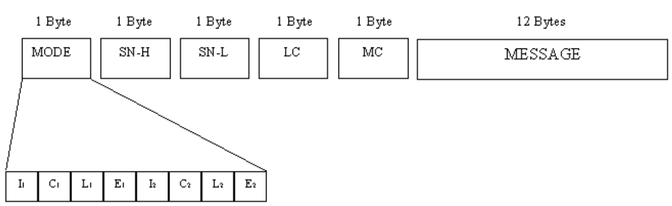

Figure 5. $B \rightarrow T$ data load

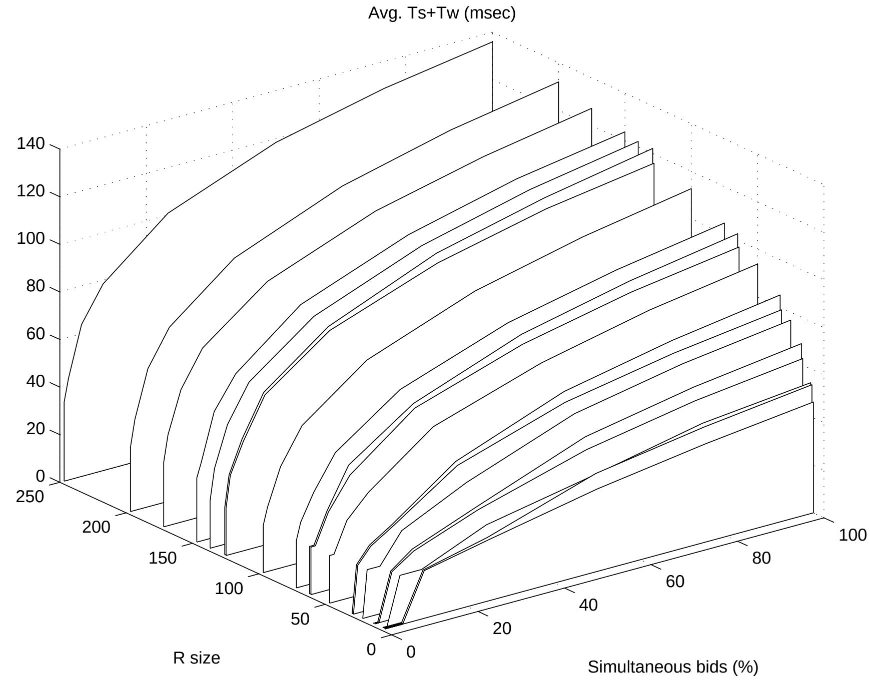

Figure 6. Average $T_s + T_w$ (msec), bidirectional system

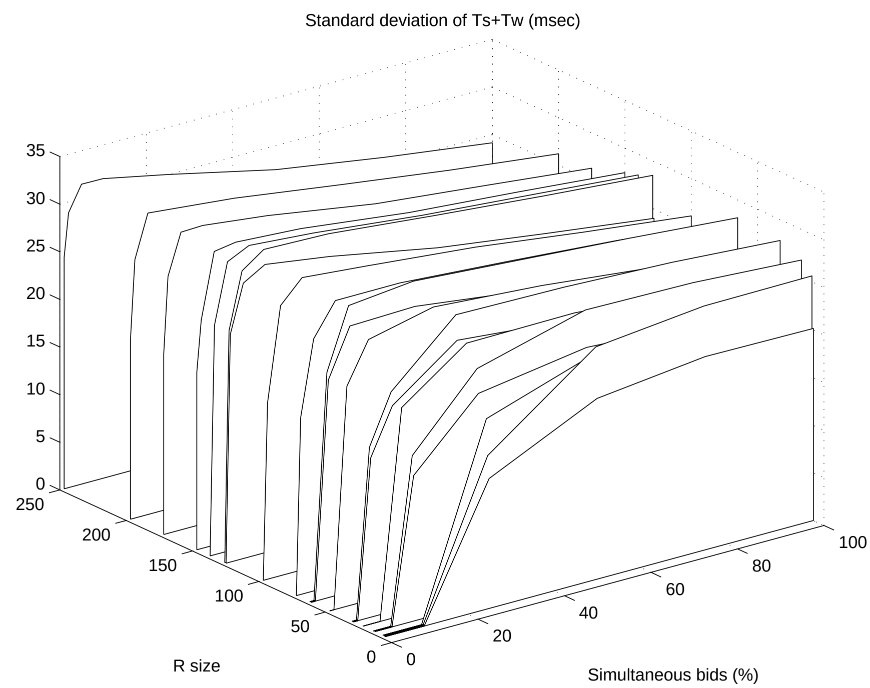

Figure 7. Standard deviation of $T_s + T_w$ (msec), bidirectional system

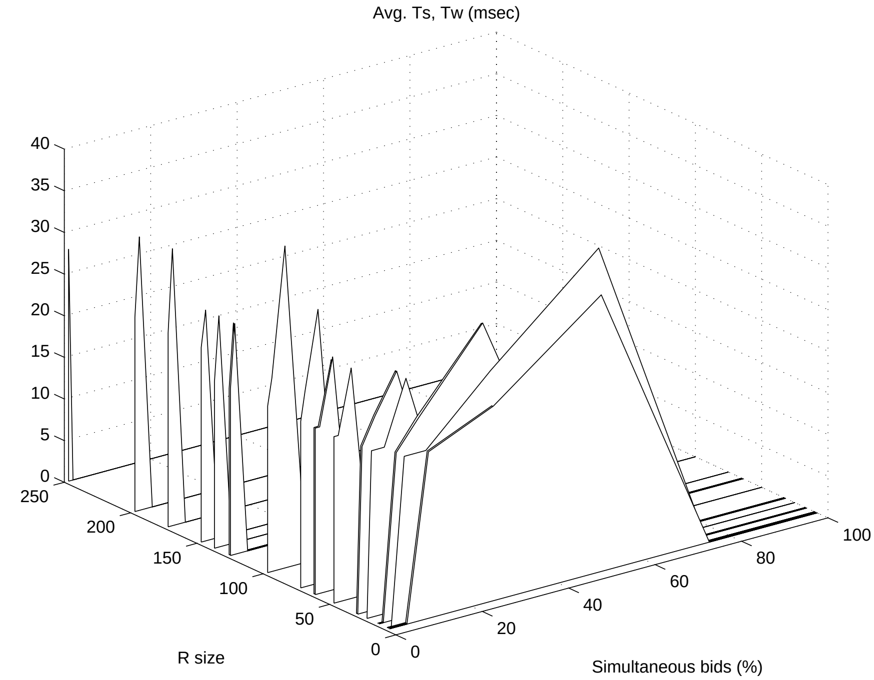

Figure 8. Average T_s, T_w (msec), unidirectional system

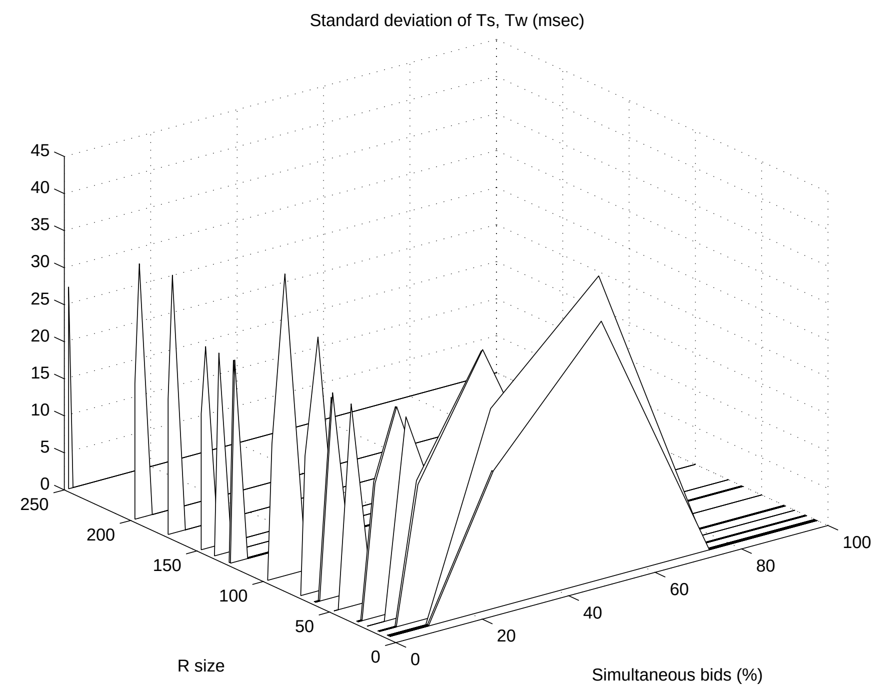

Figure 9. Standard deviation of T_s, T_w (msec), unidirectional system

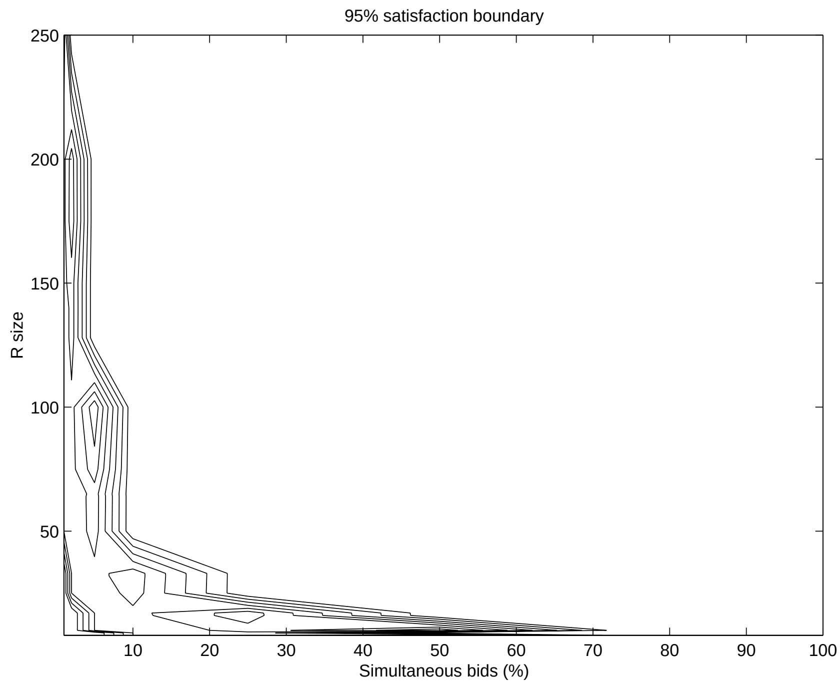

Figure 10. 95%-satisfaction boundary, unidirectional system

Figure 11. Barnacle auction at Bayona, Spain

Figure 12. Base station & admin. computer at the Bayona auction

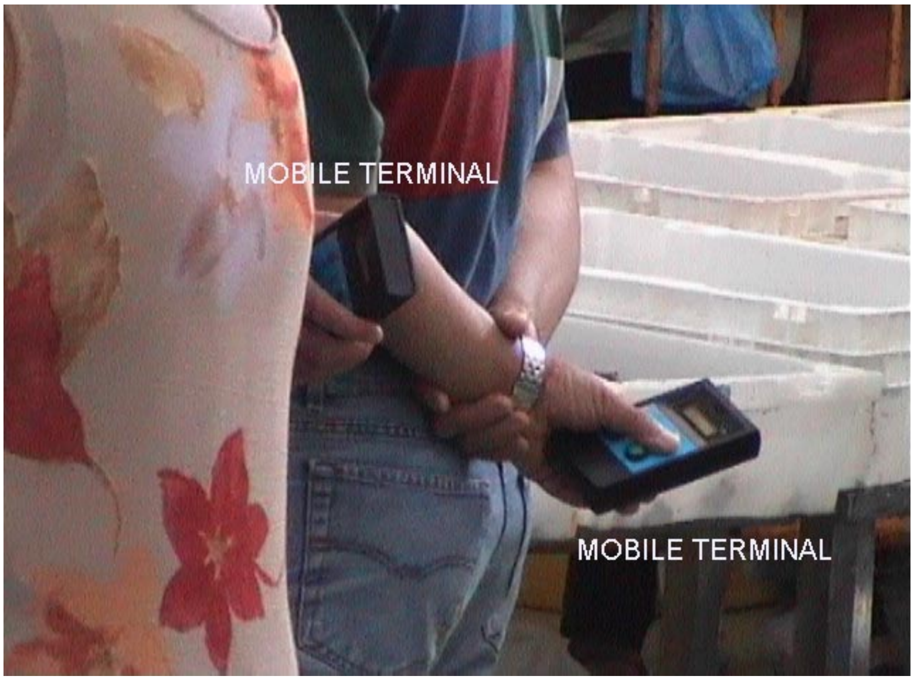

Figure 13. Mobile user terminals at the Bayona auction, close view