On the effectiveness of IEEE802.11 broadcasts for soft real-time communication

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Abstract

Wireless communication became pervasive in many application domains, either to interconnect pieces of equipment, such as computer peripherals and mobile devices, or to facilitate the installation and operation of distributed systems in general, e.g., wireless LANs, or even to allow distributed systems to extend seamlessly over fixed or mobile hosts, such as industrial plants with mobile robots. In this paper we focus on the latter case, particularly on the communication system for a set of mobile robots that must cooperate in real-time to achieve a common goal. The communication is based on IEEE802.11, complemented with an overlay transmission control that reduces collisions among the robotic team. For efficiency in bandwidth usage, the protocol relies on broadcasts but these are known to be unreliable. Therefore, we carried out experiments to determine the effectiveness of using broadcasts instead of unicasts in the presence of spurious traffic. The results show that broadcasts are indeed more effective than unicasts even for relatively high spurious loads. However, this behavior was not verified when the spurious load had a very high level of burstiness, causing a noticeable degradation of broadcasts reliability.

1. Introduction

Wireless communication is receiving more and more attention from the industrial and research communities motivated by its inherent flexibility of deployment and thus, the facility to establish connections. Recent technical advances have been steadily reducing the cost of the respective network interfaces while increasing the reliability and throughput of the communication.

One application domain that benefits from this evolution in wireless communication is multi-robot systems, in which multiple autonomous mobile robots cooperate to achieve a common goal. This is the case of the CAMBADA robotic soccer team [2], developed at the University of Aveiro, to participate in RoboCup [7][8]. The team robots (autonomous agents) cooperate to beat the opponent in real soccer games and, for that purpose, communicate using a wireless IEEE802.11b network, in managed mode, sharing the same channel with the opponent team.

Therefore, it is important to use the medium efficiently to try maximizing the throughput and also the timeliness of the data exchanged among the team members. For that purpose, we presented in [9] a specific transmission control protocol to apply over IEEE802.11, namely an adaptive TDMA protocol, which uses the network bandwidth efficiently and reduces collisions among team members.

However, the wireless protocol IEEE802.11 relies on a CSMA/CA MAC technique that includes unicast and broadcast capabilities and, in principle, our protocol could be implemented using any of them. While unicast transmission already includes specific mechanisms to adapt to the channel conditions and resolve collisions and packet losses, broadcast transmission does not include, at the MAC level, any of these mechanisms and thus, this type of transmission is considered unreliable. In particular, there is no acknowledge or automatic retransmission of broadcasts.

On the other hand, broadcast messages are a very efficient way of distributing the same information to multiple nodes, allowing reducing the bandwidth used to disseminate data. This leaves more bandwidth available for other transmissions and it also improves the temporal coherency of the data since all receivers that receive it, do so at nearly the same time. This aspect is particularly relevant for real-time information.

This paper presents a comparison between the usage of broadcast and unicast transmissions to disseminate the state information among the CAMBADA robotic soccer team. We start in section 2 with a discussion of related work, then in section 3 we present the architecture of the robotic agents. Section 4 describes the wireless communication protocol used among robots and section 5 presents the experimental results. Finally section 6 concludes the paper.

2. Related work

There are several works in the literature comparing the two transmission schemes in IEEE802.11. For example, the work in [3], carried out within the Cortex project [1] shows that in robustness terms, multiple unicast transmission (one per each node) is preferable to a simple broadcast command, but on the other hand the second is more scalable and presents a better performance. In [4] several experiments are made on industrial environments, i.e., noisy per definition, concluding that the characteristics of the wireless links are variable over several time scales, even when looking over hours of tests. This variability is explained with the frequent changes in the environment conditions, i.e., moving people or moving parts of machines. In [10] the authors analyze the use of 802.11 to support producer/consumer protocols such as WorldFIP or FF-H1, over wireless links. They consider both broadcast and unicast transmissions to support the producer/consumer model as a function of the bit error rate in the channel.

Experiments made on WaveLAN [5] show the effect of packet size and the distance between communication nodes in the packet error ratio. In the two cases the error probability increases with the increase of size and distance.

Another work [6] attempted to improve reliability of broadcast transmissions by adapting the RTS/CTS mechanism optionally used with unicasts to minimize the hidden node problem and reserve channel bandwidth.

To achieve a sufficient degree of reliability/real-time guarantees in wireless communications, [11] proposes a protocol that takes advantage of the contention-free MAC coordinated mode. However, this mode is not supported by the majority, or all, of the COTS wireless cards or access points and thus it is not applicable to our case.

In this paper we analyze the effectiveness of using broadcasts, with respect to the alternative use of unicasts, to disseminate real-time state information among a set of mobile robots. While most of the previous works addresses the relative performance of broadcasts and unicasts considering a dedicated channel with errors, we will address the situation in which the communication channel is shared with other uncontrolled sources of data, namely the opponent team and possibly other wireless-enabled devices in the vicinity of the soccer field. The only work that considers a similar experimental scenario is that of [3] but it differs from ours in the protocol used and the dependable nature of their application.

We also believe that the results in [5] may be relevant for our work in the sense that the probability of collision is established as a function of the data payload of the transferred packets. In fact, we used a fixed data size of 660Bytes in the experiments but our system is intended to transmit only relevant data at each TDMA round, according to predefined update requirements. This means that the average packet size will be lower than the one used in the experiments reported in this paper. According to [5] we expect that the probability of collisions will also be lower and thus, the performance of the protocol will improve.

3. Architecture of the CAMBADA team

The software architecture of the robots is developed around a distributed real-time database (RTDB) implemented on a PC running Linux/RTAI [2], which holds the state data of the robot together with local images of the state data of the other team members. Then, several Linux and RTAI tasks work over the RTDB updating its contents and defining the robot behavior at each instant (Figure 1). The replication of the state data of each robot in the RTDBs of the others supports an easy access to remote sensing, favoring cooperative behaviors. Moreover, the access to remote sensing information is carried out locally with fast non-blocking functions. The communication system manages the refreshing of the data in an automatic way, in the background, by triggering the update transactions at an adequate rate.

In what concerns the wireless communication, it is handled within Linux by a high-priority task, with SCHED_FIFO scheduler, due to unavailability of RTAI device drivers for certain wireless cards. Nevertheless, this task is also synchronized by RTAI. The periodicity of these transmissions is in the order of 100ms, a value that establishes a compromise between the bandwidth used by the system and the temporal coherency of the remote data inside the RTDB. Notice, however, that the temporal coherency requirement of the remote data is not stringent since it is not used within high-speed closed-loop control.

An important feature is that the communication follows the producer-consumer co-operation model, according to which each robot regularly transmits, i.e. produces, its own data while the remaining ones receive, i.e. consume, such data and update their local structures (Figure 2).

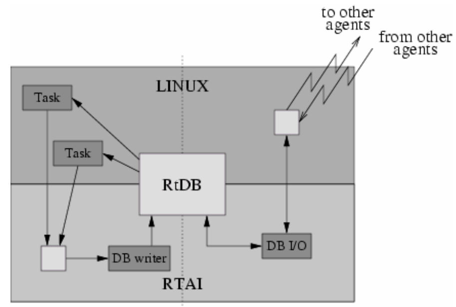

Figure 1. The main processor software architecture

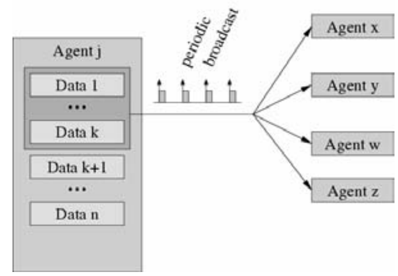

Figure 2. Each robot (agent) broadcasts periodically its subset of state data that might be required by other robots

4. Communication protocol among robots

Robots communicate using an IEEE 802.11b network, sharing a single channel with the opposing team and using managed communication (through an access point). This raises several difficulties because the access to the channel cannot be controlled and the available bandwidth is roughly divided by 2. Therefore, the only alternative left for each team is to adapt to the current channel conditions and reduce access collisions among team members. This is achieved using an adaptive TDMA transmission control that uses the frames reception instants to setup and maintain the slot and round synchronization. The round has a predefined period called *team update period (Ttup)* that sets the responsiveness of the global communication. Within such round, there is one single slot allocated to each team member so that all slots in the round are separated as much as possible (Figure 3).

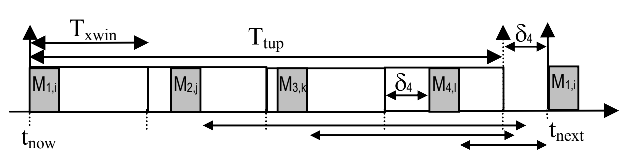

Figure 3. Adaptive TDMA synchronized on frame reception

When a robot transmits at time t_{now} it sets its own next transmission instant $t_{next} = t_{now}+Ttup$, i.e. one round after. However, it continues monitoring the arrival of the frames from the other robots. When the frame from robot *k* arrives, the delay δ_k of the effective reception instant with respect to the expected instant is calculated. If this delay is within a validity window *[0, Δ]*, with *Δ* being a global configuration parameter, the next transmission instant is delayed according to the longest such delay among the frames received in one round (Figure 3), i.e.,

$$t_{next} = t_{now} + Ttup + max_k\,(\delta_k)$$

As referred before, each robot must distribute its own state information to the other robots of the team. This is a natural scenario for using broadcasts but, given the lack of reception guarantees, it could be advantageous to use unicast transmissions. Unfortunately, in this case we increase substantially the bandwidth occupation with a total data submitted to the network given by:

Unicast_traffic = *Broadcast_traffic* * (# *of robots* – 1)

5. Experimental results

To evaluate the effectiveness of each transmission type (broadcast or unicast) for the dissemination of each robot state data, several experiments were conducted in different scenarios of uncontrolled traffic load.

The experimental setup comprised 4 robots that use the TDMA round, a station to generate the additional traffic and a dedicated silent station, configured in monitor mode, to time-stamp and log all traffic in the medium. The round length was set to T_{tup}=100ms corresponding to a minimal inter-slot period T_{xwin}=25ms. The frames sent by the robots were all carrying 660B of data payload and were transmitted in raw mode, bypassing the IP stack. The network was configured for a fixed rate of 11Mbit/s. On the other hand, the additional traffic load was IP based and it was generated using the *ping* command addressed to the access point (AP) with 1000B, 2000B and 3000B of payload and programmed to transmit in intervals of 5, 10 e 15ms, respectively. Additionally, a large file was also transferred to an external node using the *scp* command. Large transfers were fragmented in 1500B data packets.

In order to detect losses, all robot packets were numbered at the sender and time-stamped upon reception. Figure 4 shows the results concerning the distributions of consecutive lost packets for each load scenario and for transmissions from robot 1. For practical convenience, the loss of packets was logged at the monitoring station for broadcasts and at node 0 for unicasts, only. Due to space constraints, we omit the data concerning the transmissions and losses from the other robots but they were similar to the results shown. The load distribution is also shown, exhibiting its temporal characteristics.

The results show that the number of consecutive packets lost was roughly identical but slightly worst in broadcast than unicast. Using the *ping* command the loss ratios are always lower than 2.3% for broadcast and 1.1% for unicast. This command generates packets relatively separated in time, thus presenting a high permeability to the team transmissions. In this case, there seems to be no reason to use unicasts, as broadcasts save bandwidth, improve the temporal coherency of the transmitted data and present as good reliability. On the other hand, the transfer with the *scp* command presented a very high bursty behavior thus frequently colliding with the robots transmissions. The *scp* packets always takes the maximum of 1500B of pay load, which means that the network is largely occupied. For this type of load, the higher reliability of the unicasts was noticeable with respect to the degradation suffered by the broadcasts.

6. Conclusion

Wireless networks are being extensively used to provide communication for teams of mobile robots, in certain cases subject to temporal constraints. However, it will not be normally possible to control the traffic in the medium and thus, the only possible way to improve the timeliness of the team transactions is to adapt to the current load and prevent collisions within the team. This was the motivation for the development of an adaptive TDMA protocol that we carried out in previous work. In this paper we analyzed the protocol performance using broadcasts and unicasts, under different uncontrolled load scenarios. It was observed that, as long as the additional traffic is not highly bursty, the broadcasts supersede the unicasts. We believe this is the case in the RoboCup application scenario, where the opponent team is not expected to produce bursty traffic.

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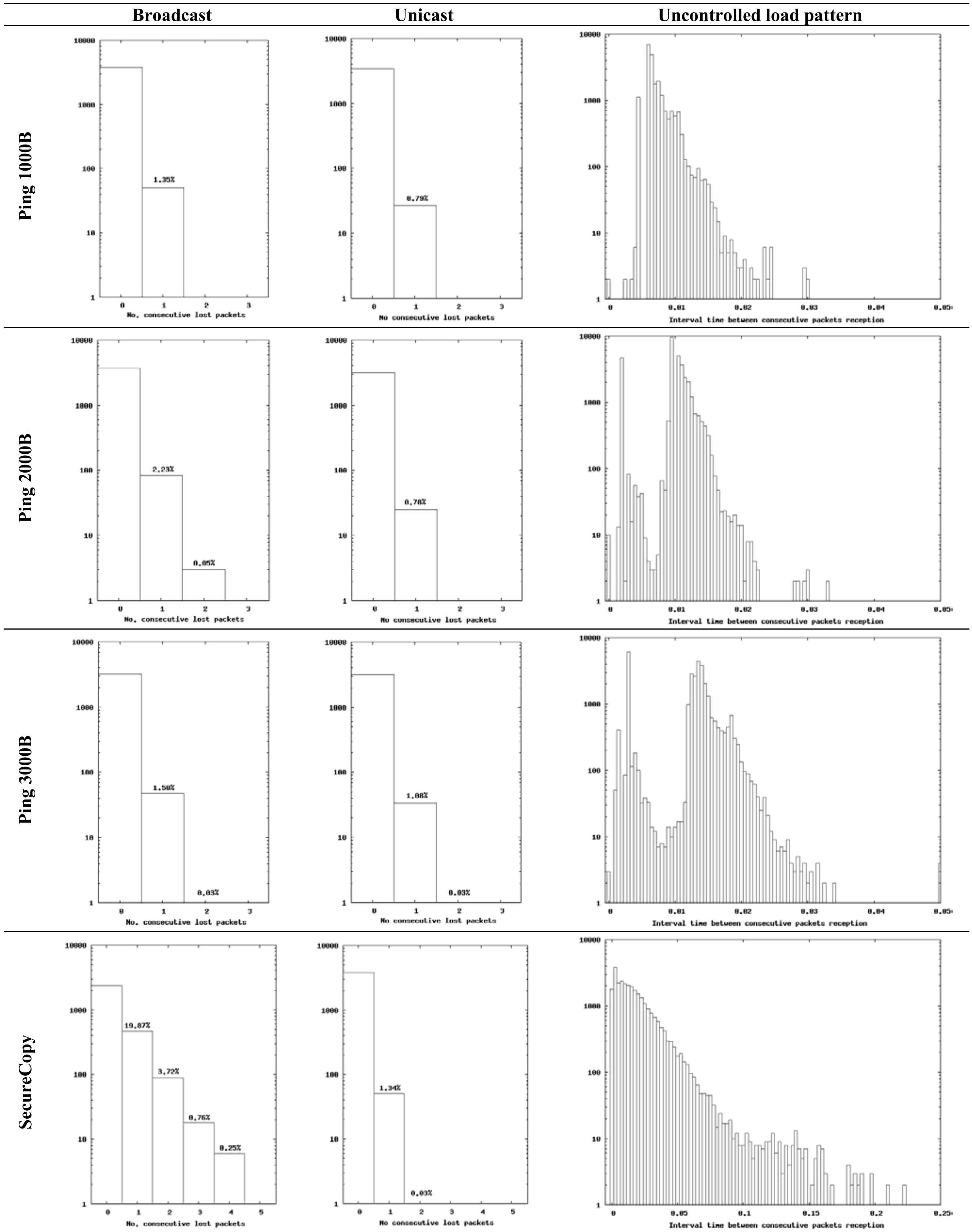

Figure 4. Histograms of consecutive lost packets when using broadcast and unicast transmissions in different medium occupation