

Feasibility Study of Determinist Interconnection between Wired LAN and Wireless System, application to CAN and Bluetooth Technology

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Abstract: Wired industrial LAN are usually based on fixed position of the sensors/activators, constituting the first level of the CIM architecture (Computerized Architecture Manufacturing). However, necessity of mobile producers/consumers appears, and wireless LAN connections seem to be the right solution. Although the original functionality, applications field of the BT system (Bluetooth) are very different from an industrial LAN, we explore the possibility of interconnecting these two types of LAN. An application between a Bluetooth wireless network and a CAN wired network is explored in detail in the sense that we try to maintain in the BT_Network, the determinism supported by the CAN via its CSMA/CA arbitration access bus.

Keywords: wired LAN, wireless LAN, determinism, mobile, sensors, activators.

I Introduction:

Wireless LAN assumes short-range connectivity between several mobile devices, and this promising technology is assured of a great expansion in a short future. In an other hand, wired industrial LAN have their protocol established and stable. Most of those (Profibus, FIP and CAN) are field level in the CIM concept. Sensors/activators are supposed to be fixed elements.

Among existing wireless protocols, we can find Bluetooth technology, IEEE802.11, HomeRF, HIPERLAN/1, HIPERLAN/2... The two first seem to be the most adapted for an objective of interconnect a wired LAN. In this paper, we analyze the feasibility, based on a practical example, to interconnect BT mobile devices (i.e: mobile 2 axes robot) with a CAN network and maintain a determinist end-to-end point transmission delay.

The method to transmit or receiving data from or through a Bluetooth Access Point Node is yet commercially available but only in the sense that the wireless terminal (PC) is connected to an access point to visualize or supervising the CAN network. It uses all the layers of the BT specification and is not acting as a sensor/activator node.

The first problem is seen in terms of analyzing the compatibility of the different layers for each protocol (physical, MAC, LLC, application).

Secondly the approach is in terms of QoS (Quality of Service) where the wireless network has to give the same delays guarantees that the CAN network while the robot moves, and the problem of the loss of connection requests to configure several network configurations.

Finally the scenario of an application in development with a mobile robot is presented.

II Deterministic Feasibility Analysis

II-1 Layers Interconnections Equivalences

Note: Specifications of Bluetooth [1] and CAN network [2] may be easily found, also we do not further explicit the meaning of all terms encountered in this paper.

Like for CAN network, the physical and MAC layers are hard components made. Their transfer time is easy to evaluate and is upper bounded. The uppers level are software layers, the maximum transfer time is to be known for the determinist approach. The Link Manager Protocol (LMP) has the

same level as the L2CAP layer. It is an independent protocol and not connected to higher levels. It assumes the set-up of the node, the security and the control of the network. Its messages have a highest

this, the two considered networks must have a determinist configuration.

Only centralized networks with polling or token ring distribution assume fully this condition. The CAN network is a random

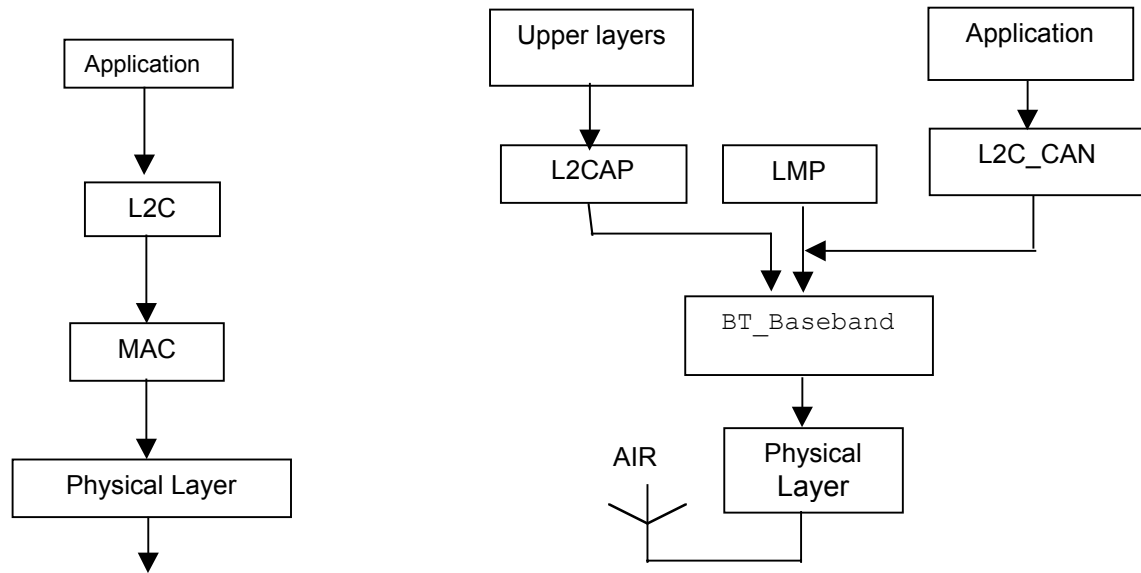


Fig. 1: Equivalence Layer Levels

priority then user data messages coming from L2CAP. LMP generates Protocol Data Unit's messages (PDU), and specific of them concern the Power System Control, i.e managing the emission-reception power level.

The Baseband layer supports Synchronous Connection Links (SCO) and Asynchronous Connection Link (ACL). The L2CAP layer is only defined for ACL messages with a "Best Effort" QoS level. As we are looking for a "guaranteed" QoS level, we need to implement a substitute level to L2CAP, which we call for the purpose L2C_CAN, linked to the local application. Because LMP and L2C_CAN are used for synchronous messages, the entry point is the same. We have inserted a soft switch giving priority to LMP messages.

II-2 Deterministic considerations

We are looking for an end-to-end determinist transmission of messages between two heterogeneous networks. For

access protocol with CSMA collision avoidance based on an identifier (Id) priority, giving a deterministic access to the network but not in respect with the equity access. In wireless protocols, a similar protocol is proposed: Resource Auction Multiple Access (RAMA) [Chandra 00]. RAMA is a random access protocol that achieves resource assignment using a deterministic access algorithm. Each node has a *bit Id*, and collision resolution is based on symbol-by-symbol transmission of this Id. In the contention phase, each node transmits its Id symbol-by-symbol. The wireless node station broadcasts the symbol heard to all the nodes. If this symbol does not match the symbol that the node transmitted, it drops out of contention. Like for CSMA/CD protocol, the RAMA protocol is unfair, as the node with the highest Id *always* wins the contention. Presently no commercial product uses this protocol.

Bluetooth offers a variety of type of messages in synchronous or asynchronous

mode. Some of them allow a periodic transmission and grants some guarantees on periodicity and latency delay. We analyse this possibility in § II-3.

II-3 Type of wireless messages

In CAN protocol, two standards frames coexist (2A and 2B), respectively with 11 bits and 29 bits identifiers. Although the implemented CAN controllers are both standard compatible, for the application presented later, we consider only CAN 2A

slots noted further T_{sco} as a multiple of 625 ms. The slot link is established by the master sending a SCO setup message via the LM protocol. This message will contain timing parameters such as the SCO interval noted T_{sco} and the offset delay transmission noted D_{sco} . These parameters are negotiated for the connexion with a particular slave and then are known in a deterministic approach as a maximum delay transmission.

We note, that all messages will be limited to

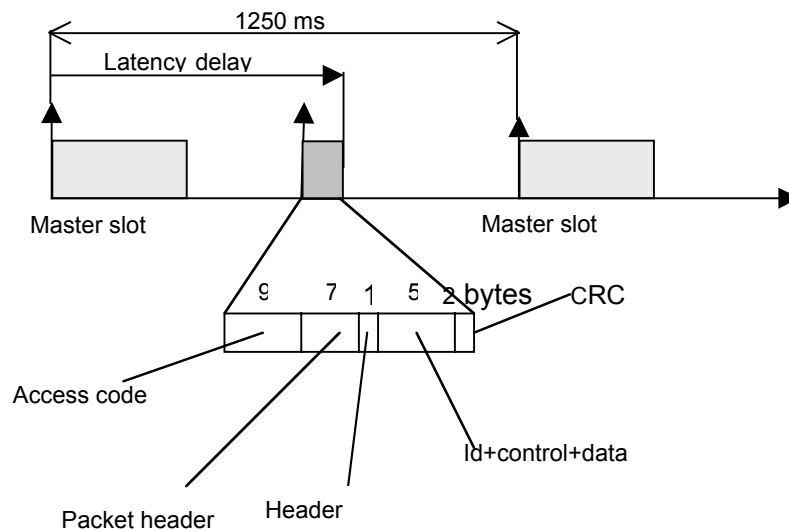


Fig. 2: Single Slot Latency Delay in a slave Payload Length

frames. The maximum number of data bytes per message is 2. The data payload length is limited to 5 bytes (2 for Id+1 for control+2 for datas).

Abbreviations: millisecond(Ms), microsecond (ms)

Payload: specific Bluetooth denomination relative to significant part of the message (voice and data). In Bluetooth, the transmission message ends, just after the CRC field, which limits the power consumption.

We will see in §II-4, that the convenient packet type transfer for this application is HV, which carries periodically voice data and is SCO compatible. The master will send packets at regular intervals counted in

one slot time (625 ms);

The packet message (master or slave response) is limited to a single slot as shown in fig 2.

Latency delay = $625 + 8 * (9 + 7 + 1 + 5 + 2) = 817$ ms (as 1 bit lasts 1 ms).

This value corresponds to the minimum round-trip (response delay) when the robot is in the Access Point reception area after the delay transmission. It is the simplest topology.

II-4 Other Bluetooth topologies configurations

We analyze here several possible wireless configurations induced by the mobility of the robot, when it is out of range from the Access Point; it has to be reconfigured in

another configuration. The restriction, we applied is that the area displacement is known, it means that the robot is not considered as a full mobile Bluetooth node, but intermediate nodes placed on the circuit have fixed positions and are acting as relays for the robot-Access Point communication.

First configuration: The robot is under the access point reception range. End-to-End delay has been discussed previously in §II-2.

Second configuration: A relay node is indispensable to link communication between the Access Point and the robot. Leaving the reception area of the original piconet, the robot has to disconnect itself and reconnect to another piconet. The two piconets form a scatternet configuration where a fixed node establishes a link between the access point and the robot. Therefore two configurations are possible:

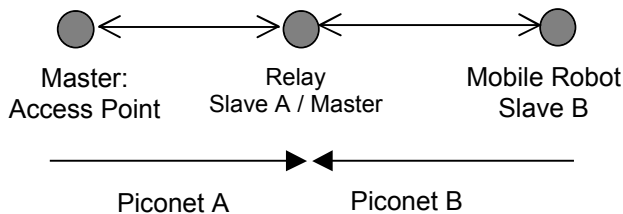


Fig. 4: Configuration A: Relay is Master in Piconet B and Slave in Piconet A.

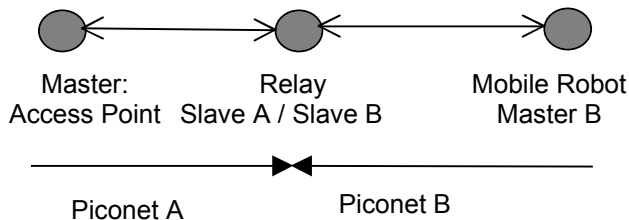


Fig. 5: Configuration B: Relay is slave in Piconet A and B, Robot is Master in Piconet B.

Assumptions:

a/ Connections are supposed established: the emission period T_{sco} is negotiated, and a minimum delay latency D_{sco} for the establishment is guaranteed.

b/ For LMP traffic, one must have possibility to transmit scan and inquiry pages, also $T_{sco} > 2$.

- With HV1 packet type, if $T_{sco}=2$, this situation is not suitable for the previous assumptions.
- With HV2 packet type, if $T_{sco}=4$.

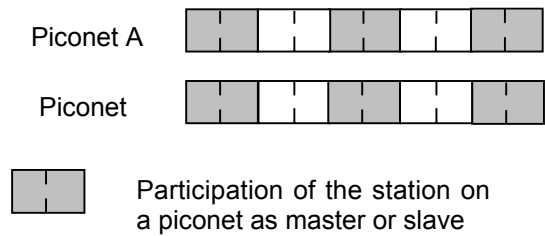


Fig. 6: Synchronisation for HV2 packet type

The two piconets should have their own clocks synchronized, that is only possible if the relay node is Master in the two piconets.

- With HV3 packet type, if $T_{sco}=6$,

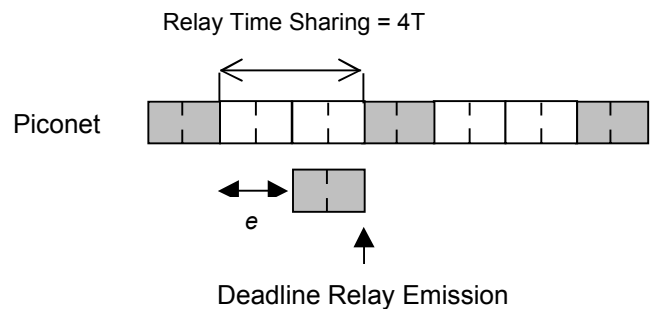


Fig. 7: Synchronization for HV3 packet type

Message and its retransmission on Piconet B imply $0 \leq e \leq 2T$, where T is the length of a slot.

This solution is the most robust and is recommended in the BT specifications. Also we have retained HV3 packet types.

Third configuration: Generalization of the situation, several relay-nodes link the

transmission between the access point and the robot.

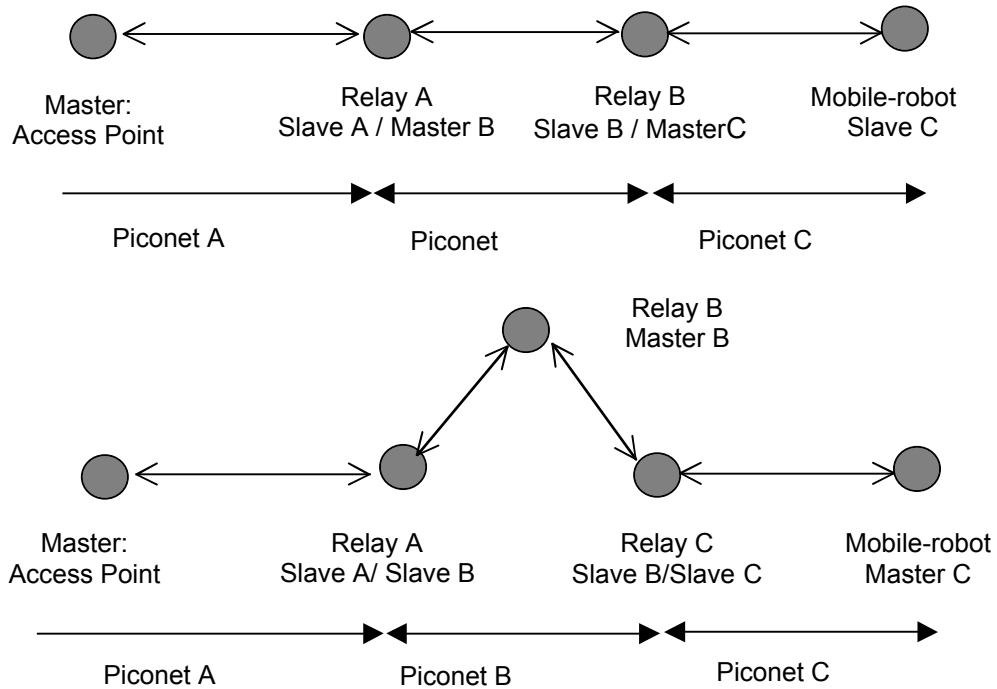


Fig. 8 : Possible topologies

communication between access-point and robot. We limit our approach with a scatternet based on 3 piconets PA, PB and PC with 3 relays-nodes, which looks realistic for an industrial process. Two possible topologies emerge, and then we try to define a generalized relation of the delay

Transmission Delay T_d is:

$$T_d = 2T + e_1 + 2T + e_2 + 2T + d_b.T + d_c.T,$$

where $d_b.T$ and $d_c.T$ are establishment times of the SCO link between a master and his attached slave on piconet B and C.

If $d.T$ is the maximum establishment time of a SCO link and n the number of piconets constituting the scatternet required between the Access Point and the farthest position of the robot ($n \geq 1$), then:

$$\begin{aligned} \text{Delay}_{\max} &= 2n \cdot T + 2(n-1) \cdot T + d \cdot (n-1) \cdot T \\ &= T \cdot (n \cdot (4+d) - d - 2) \end{aligned}$$

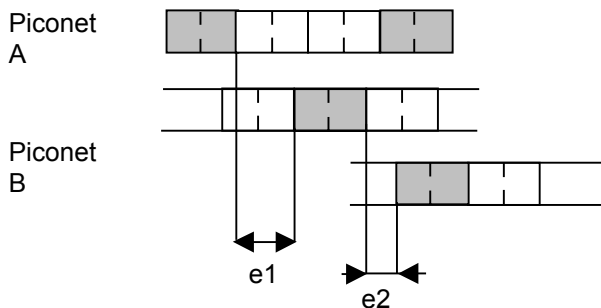


Fig. 9: Synchronisation in a multi-piconet topology

III Application

Fig. 10 is the synoptic of the general application implemented in development with the 2 LAN systems.

Node A is the network analyzer, nodes B and C are standard activators/sensors nodes. Node D is the CAN monitoring point (creating Id, visualization) and also the Bluetooth access point. Node E is BT node, supposed semi-fixed. Node F is the mobile-robot node.

Software programs CAN and BT sides are

Communication between the Application_Task, IT_Task E (Emission ISR) and IT_Task R (Reception ISR) routines are asynchronously realized by a mailing system. Incoming and outgoing messages from, or through, the CAN network are deposited in their respective buffers.

Incoming and outgoing messages from, or through, BT_network are linked synchronously with a "Rendez-vous" system via a common buffer memory. Isr_BT_Task assumes the L2C_CAN layer as discussed in § II.

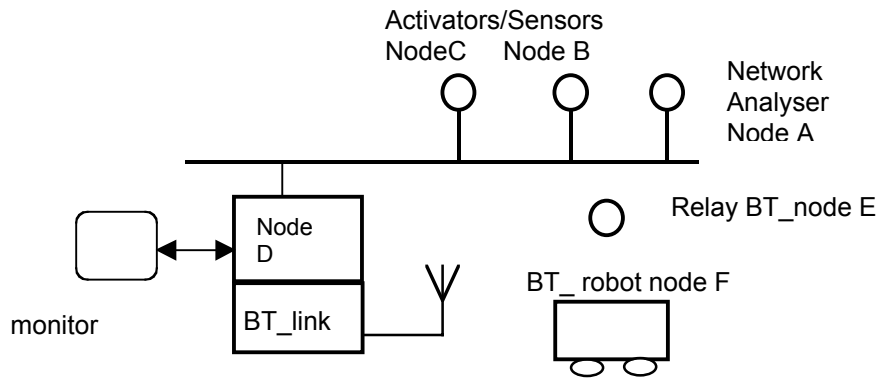


Fig. 10: Basic System Application

synchronized by an RT_Linux kernel with a 3 level Interrupt Service Routine (Isr) as shown in Fig. 11.

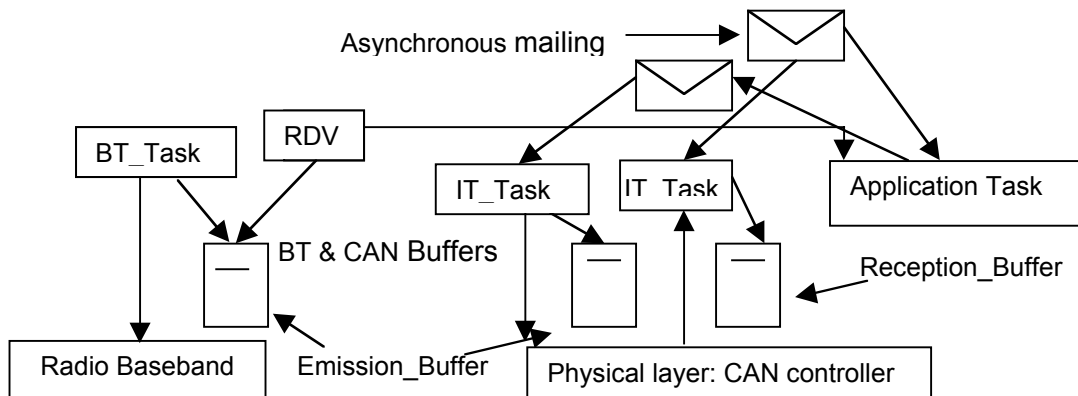


Fig. 11: Software Organization of Node D

III-2 Mobile-robot BT_application

Application implemented onto the mobile-robot is very simple. 3 identifiers are necessary:

1st: 2 bytes X, Y displacement position order, 8-bit resolution

2nd: 2 bytes X, Y robot active position order, 8 bit resolution

3rd: 2 bytes for control and maintenance information.

The position order is referenced to a fixed origin of the piece where the robot has to move. The frame is transmitted when the position order has changed. Acknowledgment of the reception message is not mandatory because there is sufficient control on the radio base band, and the traffic of frame is not important.

The X, Y Active position referenced in the plane as above is determined locally in an embedded computer and ultra-sonic sensors.

III-3 Resume of the application

The active position X-Y of the robot is transmitted synchronously every T_{sco} negotiated, unless a change of the position order is received, or a maintenance message is received. When the LMP layer has to send message, he has the highest priority.

The displacement position order send through the access point is emitted in a similar manner. The access-point delay is upper-bounded in the wireless network and can be also bounded in the CAN Network, depending of the Id priority given to this application.

To guarantee the determinism of the situation all the delays participating to the messages transmission are to be upper bounded [Cottet 99]. Fig. 12 explicits these nodes delays.

d_1 delay is the delay transfer of the L2C_CAN layer that can be estimated between 10 and 20 ms; d_2 is a hard delay of 100 to 200ns. These two last delays are negligible values comparing to the previous latency delays.

A minimum CAN 2A frame length with 2 data bytes is 64 ms (interframe included and

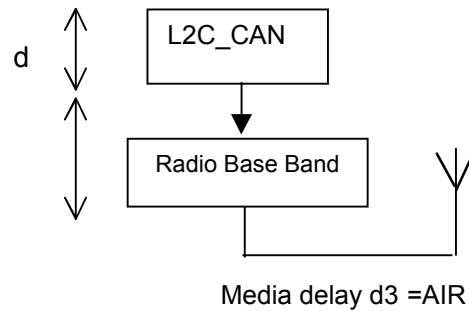


Fig. 12: Transmission Delays

no stuffing bits). Compared to the maximum latency delay, the ratio is 33. That means that 33 CAN 2A frames may be transmit on the wired CAN network before the response of the active position robot is received in the reception buffer CAN side of the Node D. And to guarantee this maximum delay emission on the CAN network has not to be delayed once more by the CSMA/CA arbitration. This is easy to solve in giving the highest priority to the robot-mobile identifier.

III.4 Connecting and disconnecting from the piconet

The robot needs to be informed that the maximum distance of reception is reached, and a procedure of disconnection has to be started. Although an internal measurement system may be implemented in the mobile, we suppose there is no one and it is not so easy to realize.

We have seen in §II.1 that the LMP send in priority PDU's messages from a slave or a master. A power control system is implemented in the Radio Base Band hard layer, and is linked to the LMP by PDU's messages of the form: notification-indication. Also the LMP is informed of the quality of the reception level. It may sends specific primitives requests. The master LMP transmit a LMP_incr_power_req to the robot slave; If the robot is till at its maximum power transmission, that means that shortly the connection will be over. The robot may reply by a LMP_not_accepted message, or a LMP_error_message, but in BT specification, the response is not mandatory.

III.5 Relaying data

committee in formation.

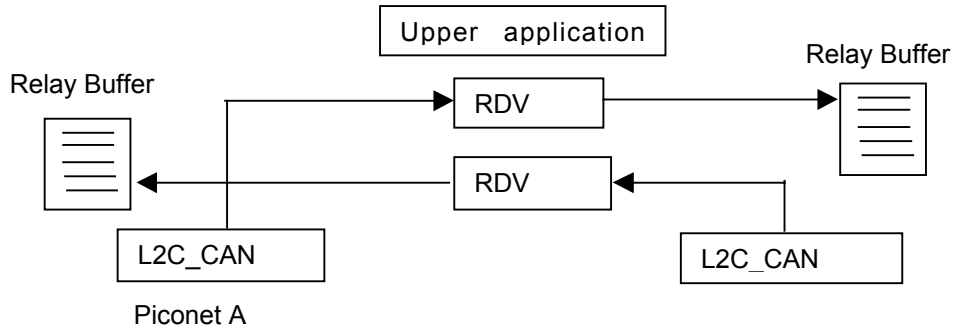


Fig. 13: Upper Layer to L2C_CAN Software Organization.

The relays nodes can transfer data in both directions. Several routing methods [Murphy 96], [Bhagwat 99] have been explored, but these solutions are too much sophisticated for our application because they cover a complete set of packets sending, multicast and broadcasting, that they are not suitable in our position. More they use the LC2_AP and upper layers decreasing the global response time in a "Best Effort" QoS. As we have to transmit a limited number of significant data bytes (2), the local solution we suggest is to implement in the embedded relays a small micro-controller with a romable RT kernel including "rendez-vous" communication system. Many solutions exist and are easy to implement. Fig. 13 gives the diagram of this implementation

IV Conclusion

In this paper, we have considered the feasibility to interconnect two types of LAN very different in their concept for an industrial application. All the long of this analysis, we tried to determine the latency time of the emitted messages and to know the worst-case situation to keep in mind the determinism of the application.

The BT Technology has been selected because a lot of commercial products are available at low cost, and this technology presents the best sales development. Bluetooth specifications are in discussion to be defined in a new IEEE 8023.15

The application presented is object of a development, that will be shortly finished. A feasibility study to use others wireless networks is in progress [MER 01].

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