Real-Time Communication over Switched Ethernet for Military Applications

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ABSTRACT

Full-Duplex Switched Ethernet is a forecasted new technology for advanced military aircraft system interconnection. However, it was not originally developed to meet the requirements of real-time communications. Therefore, in this paper, we analyze traffic shaping and a priority handling approach over switched Ethernet to achieve reliable transmission with bounded delays that conform to the real-time constraints, required by military applications.

Keywords

Full-Duplex Switched Ethernet, traffic shaping, priority handling, delay bounds

1. MOTIVATION

The traditional communication buses for military avionics systems, that have been widely used in various military aircraft for decades, are MIL-STD 1553B buses. These are 1Mbps command/response multiplexer data buses with a centralized system control.
Nowadays, the complexity of avionics systems still increases at a high rate and has been pushing the limits of the command/response architecture. In fact, a homogeneous interconnection system is needed to meet new requirements, such as higher transmission speed, decentralization of control, easy maintenance and low cost. So, we analyze the possibility of using general Full-Duplex Switched Ethernet, specially after the successful civil experience of A380's AFDX (Avionics Full-Duplex Switched Ethernet).
This technology is not originally designed to deliver time-constrained communications, but some of its properties, such as its reduced cost, its flexibility and its expandability for future investment, make this COTS network an attractive candidate to replace the MIL-STD 1553B and the other data buses used in the military aircrafts. Despite its popularity, Full-Duplex Switched Ethernet has a serious drawback when carrying real-time messages. The Full-Duplex Switched Ethernet LAN does not use CSMA/CD arbitration since no collision can happen but, unfortunately, congestion may occur when simultaneous traffic data attempt to share network segments and messages can be lost if buffers overflow. Thus, it is impossible to guarantee predictable delays in delivering packets to the local nodes in the general case and we have to add new mechanisms to avoid information loss and to guarantee hard real-time communication with low latency.
To achieve real-time behavior on Ethernet, several approaches and techniques have been experienced by adding a medium access control, for example:

- Token-passing methods that consist in circulating a token among the stations to allow them to transmit data;
- TDMA where stations transmit messages at predetermined slots in a cyclic fashion with a precise clock synchronization which has been successfully implemented on CAN (TTCAN [3]);
- FTT-Ethernet [?] where a central master periodically distributes a group of tokens that allows slaves to send data for a specific amount of time

In this paper [1], we show the possibility of having a reliable transmission with bounded delays over Switched Ethernet, that conform to the real-time constraints of military application, by installing traffic shapers in each local node and by providing a prioritized service to real-time packets. The rest of the paper is organized as follows: Section 2 describes our traffic shaping approach and the priority handling model to provide real-time guarantees over Full-Duplex Switched Ethernet, and evaluates experimental results on a real case traffic. In Section 3, we give an outlook of our future work.

2. TRAFFIC SHAPING AND PRIORITY HANDLING

Prior to defining our approach, military applications requirements and measures of performance must be identified. A main concern for designing military local-area networks is the deterministic nature of protocols. As a result, we have to provide real-time guarantees such as maximum end-to-end delay and jitter in the transmission. In this part, we particularly evaluate the delay bounds and compare them with real-time constraints.

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The MIL-STD-1553 data bus is a serial data bus which provides a centralized system control [4]: the bus controller polls remote terminals to allow them to access the bus and it determines the sequence used thanks to its transaction table. Military applications require two types of traffic: periodic and sporadic and the polling cycle time shall be no smaller than the biggest message period to fulfill real-time guarantees. In our case study, the biggest message period is about 160 ms, so a major frame (160 ms) is defined for the 1553B bus to transfer all periodic messages at least once; and the smallest message period is about 20 ms, so minor frames (20 ms) are established to meet the requirements of the higher update rate messages. At the beginning of each new minor frame, an interrupt occurs, and the bus controller starts issuing the messages for that minor frame.
Thus, the MIL-STD-1553B is a shared-media network that supports precise timeliness in a deterministic way but introduces a considerable overhead due to the master requests. As opposed to this transmission control approach, Switched Ethernet with traffic shaping approach is based on the fact that reliable transmission with bounded delays is possible when the traffic is controlled.
In our approach, we characterize every periodic message i by (T_i, b_i) where T_i is the period of the transfer and b_i the length of the message; and every sporadic message j is described by (T_j, b_j) where T_j is the minimal inter-arrival time between two consecutive messages and b_j its length. We suppose that every station generates at most one sporadic message of each type once every minor frame (20 ms) and a traffic shaper regulates every packet stream i using a token bucket characterized by its maximal size b_i and its rate $r_i = b_i/T_i$. Since real avionics systems transmit multiple flows, we model these connections by one traffic shaper per connection and multiplex them inside the node by a FCFS multiplexer before sending them over a physical link with bandwidth $C = 10Mbps$.
In order to have a performance evaluation of Full-Duplex Switched Ethernet, we developed a software implementing our approach model. We use the Networks Calculus introduced by Cruz [1, 2] to determine the maximum queuing delay that depends on the traffic arrival curves ($R_i(t) = b_i + r_i t$) and the multiplexer policy. In the case of FCFS multiplexer, the bounded latency is:

$$D = \sum_{i \in S} b_i/C + t_{techno}$$

where S is the set of connections flowing through the multiplexer and t_{techno} is a bound on the relaying delay.
Despite the relative speed ratio between Switched Ethernet (10 Mbps) and 1553B (1 Mbps), our results show that some real-time constraints are violated. So, having a Switched Ethernet with a higher rate is not sufficient to satisfy the real-time constraints required by the military applications. In order to meet the delay requirements of the urgent packets, we use the priority model of 802.3 (802.1p). So, within a local station, packets are given different priorities depending on their type and we consider 4 priority types:

- priority 0 for the urgent sporadic messages with a requested maximal response time of 3ms
- priority 1 for the periodic messages
- priority 2 for the sporadic messages with a requested maximal response time ranging from 20ms to 160ms
- priority 3 for the sporadic messages with a maximal response time bigger than 160ms.

In this case, we use a 4-FCFS multiplexer, that is to say a strict priority multiplexer with four queues, one for each priority. We generalize each priority's maximum latency as:

$$D_p = (\sum_{i \in \bigcup_{q<=p} S_q} b_i + \max_{j \in \bigcup_{q>p} S_q} b_j)/(C - \sum_{i \in \bigcup_{q<p} S_q} r_i) + t_{techno}$$

where S_p is the set of connections of p priority flowing through the multiplexer.

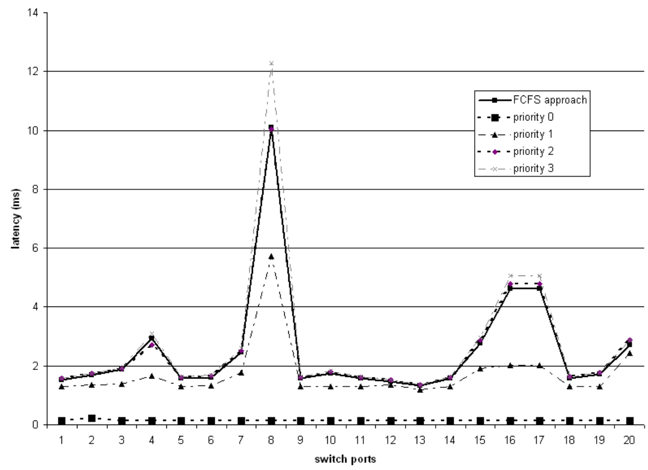

Figure 1: Delay bounds for the two approaches

The figure compares the delay bounds obtained by the two approaches applied to a real traffic and we notice that the real-time constraints are respected when using the prioritized handling of traffic. In fact, the latency bound for messages with high priority is lower than 3ms, which represents their maximal response time. Moreover, the latency bound of periodic messages (priority 1) is smaller than the one obtained with the FCFS approach. This shows that priorities is a good mean to improve the predictability of the message transfers.

3. CONCLUSION

In this paper, we have shown that traffic shaping and priorities handling can be used to achieve reliable packet transmission with bounded delays that conform to the real-time constraints required by military applications. Future work will target other QoS guarantees, like jitter which is inherently low on 1553B applications.

4. REFERENCES

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