Some Aspects about a Self-Testing Solution for Implementing the TCP/IP Protocol

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Abstract TCP is a connection-oriented, end-to-end reliable protocol designed to fit into a layered hierarchy of protocols which support multi-network applications. The paper focuses on comparing the efficiencies of realizing a hardware implementation for the TCP protocol.
In order to estimate the advantages of such a hardware implementation we show in this paper the comparative results of the classical implementation with that of a self-testing implementation of TCP.

1. Introduction

The Transmission Control Protocol (TCP) is intended to be a host-to-host protocol in common use in multiple networks; it is intended for use as a highly reliable host-to-host protocol between hosts in packet-switched computer communication networks, and in interconnected systems of such networks.
TCP is a connection-oriented, end-to-end reliable protocol designed to fit into a layered hierarchy of protocols which support multi-network applications. The TCP provides for reliable inter-process com–munication between pairs of processes in host computers attached to distinct but interconnected computer communication networks. In principle, the TCP should be able to operate above a wide spectrum of communication systems ranging from hard-wired connections to packet-switched or circuit-switched networks.

The TCP fits into a layered protocol architecture just above a basic Internet Protocol which provides a way for the TCP to send and receive variable-length seg–ments of information enclosed in internet datagram "envelopes". The internet datagram provides a means for addressing source and destination TCPs in different networks. The internet protocol also deals with any fragmentation or reassembly of the TCP segments required to achieve transport and delivery through multiple networks and interconnecting gateways.

2. TCP Operational Overview and the TCP Finite State Machine (FSM)

A *finite state machine (FSM)* attempts to describe a protocol or algorithm by considering it like a virtual “machine” that progresses through a series of stages of operation in response to various happenings.
A FSM describes the protocol by explaining all the different states the protocol can be in, the events that can occur in each state, what actions are taken in response to the events and what transitions happen as a result. The protocol usually starts in a particular *beginning state* when it is first run. It then follows a sequence of steps to get it into a regular operating state, and moves to other states in response to particular types of input or other circumstances. The state machine is called *finite* because there are only a limited number of states.

In the case of TCP, the finite state machine can be considered to describe the "life stages" of a connection. Each connection between one TCP device and another begins in a null state where there is no connection, and then proceeds through a series of states until a connection is established. It remains in that state until something occurs to cause the connection to be closed again, at which point it proceeds through another sequence of transitional states and returns to the closed state.

The full description of the states, events and transitions in a TCP connection is lengthy and complicated, since that would cover much of the entire TCP standard.

Table 1: TCP Finite State Machine (FSM)

State	State Description
CLOSED	This is the default state that each connection starts in before the process of establishing it begins. The state is called "fictional" in the standard. The reason is that this state represents the situation where there is no connection between devices—it either hasn't been created yet, or has just been destroyed. If that makes sense.
LISTEN	A device (normally a server) is waiting to receive a *synchronize* (*SYN*) message from a client. It has not yet sent its own *SYN* message.
SYN-SENT	The device (normally a client) has sent a *synchronize* (*SYN*) message and is waiting for a matching *SYN* from the other device (usually a server).
SYN-RECEIVED	The device has both received a *SYN* (connection request) from its partner and sent its own *SYN*. It is now waiting for an *ACK* to its *SYN* to finish connection setup.
ESTA-BLISHED	The "steady state" of an open TCP connection. Data can be exchanged freely once both devices in the connection enter this state. This will continue until the connection is closed for one reason or another.
CLOSE-WAIT	The device has received a close request (*FIN*) from the other device. It must now wait for the application on the local device to acknowledge this request and generate a matching request.
LAST-ACK	A device that has already received a close request and acknowledged it, has sent its own *FIN* and is waiting for an *ACK* to this request.
FIN-WAIT-1	A device in this state is waiting for an *ACK* for a *FIN* it has sent, or is waiting for a connection termination request from the other device.
FIN-WAIT-2	A device in this state has received an ACK for its request to terminate the connection and is now waiting for a matching *FIN* from the other device.
CLOSING	The device has received a *FIN* from the other device and sent an *ACK* for it, but not yet received an *ACK* for its own *FIN* message.
TIME-WAIT	The device has now received a *FIN* from the other device and acknowledged it, and sent its own *FIN* and received an *ACK* for it. We are done, except for waiting to ensure the ACK is received and prevent potential overlap with new connections.

Table1 briefly describes each of the TCP states in a TCP connection, and also describes the main events that occur in each state, and what actions and transitions occur as a result. For brevity, three abbreviations are used for three types of message that control transitions between states, which correspond to the TCP header flags that are set to indicate a message is serving that function. These are:

- ***SYN:*** A *synchronize* message, used to initiate and establish a connection. It is so named since one of its functions is to synchronizes sequence numbers between devices.
- ***FIN:*** A *finish* message, which is a TCP segment with the *FIN* bit set, indicating that a device wants to terminate the connection.

- ***ACK:*** An *acknowledgment*, indicating receipt of a message such as a *SYN* or a *FIN*.

A TCP connection is always initiated with the 3-way handshake, which establishes and negotiates the actual connection over which data will be sent. The whole session is begun with a SYN packet, then a SYN/ACK packet and finally an ACK packet to acknowledge the whole session establishment. At this point the connection is established and able to start sending data. The FSM states are illustrated in Table 1. The FSM is illustrated in Figure 1 which you may find easier for seeing how state transitions occur.

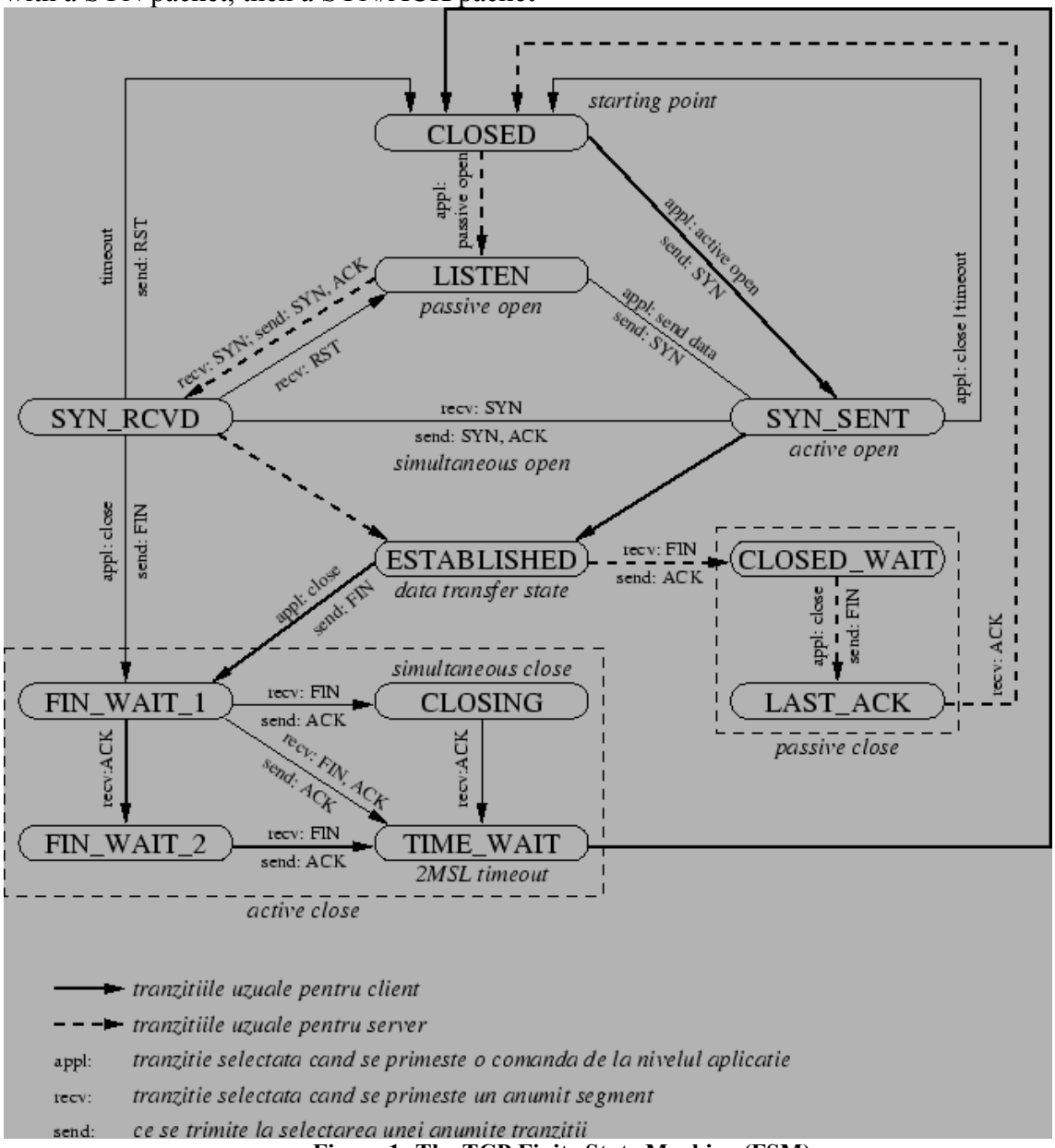


Figure 1: The TCP Finite State Machine (FSM)

It's important to remember that this state machine is followed for ***each connection***. This means at any given time TCP may be in one state for one connection to socket X, while in another for its connection to socket Y. Also, the typical movement between states for the two processes in a particular connection is not symmetric, because the roles of the devices are not symmetric: one

device initiates a connection, the other responds; one device starts termination, the other replies.

There is also an alternate path taken for connection establishment and termination if both devices initiate simultaneously (which is unusual, but can happen). Thus, for example, at the start of connection establishment, the two devices will take different routes to get to *ESTABLISHED*: one device (the server usually) will pass through the *LISTEN* state while the other (the client) will go through *SYN-SENT*. Similarly, one device will initiate connection termination and take the path through *FIN-WAIT-1* to get back to *CLOSED*; the other will go through *CLOSE-WAIT* and *LAST-ACK*. However, if both try to open at once, they each proceed through *SYN-SENT* and *SYN-RECEIVED*, and if both try to close at once, they go through *FIN-WAIT-1*, *CLOSING* and *TIME-WAIT* roughly simultaneously.

3. The Hardware Implementation Of The TCP Protocol

The TCP state machine implementation using ALTERA MAX+PLUS II is shown below (Figure 2). The matrix from Figure 3 contains a timing analysis on signal propagation from inputs to outputs, showing the time for the shortest and longest paths between them. We will use the longest path (the higher value) in our computation.

In our timing analysis, we used the following values:

- Clock period =7.7 ns (the optimal value indicated by *MAX+PLUS II*).
- Segment_send = 5 X Clock = 5 X 7.7 = 38.5 ns (we considered that a TCP segment has 5 words only).
- Time_MSL = 100 ns (the maximum value for segment transmission).

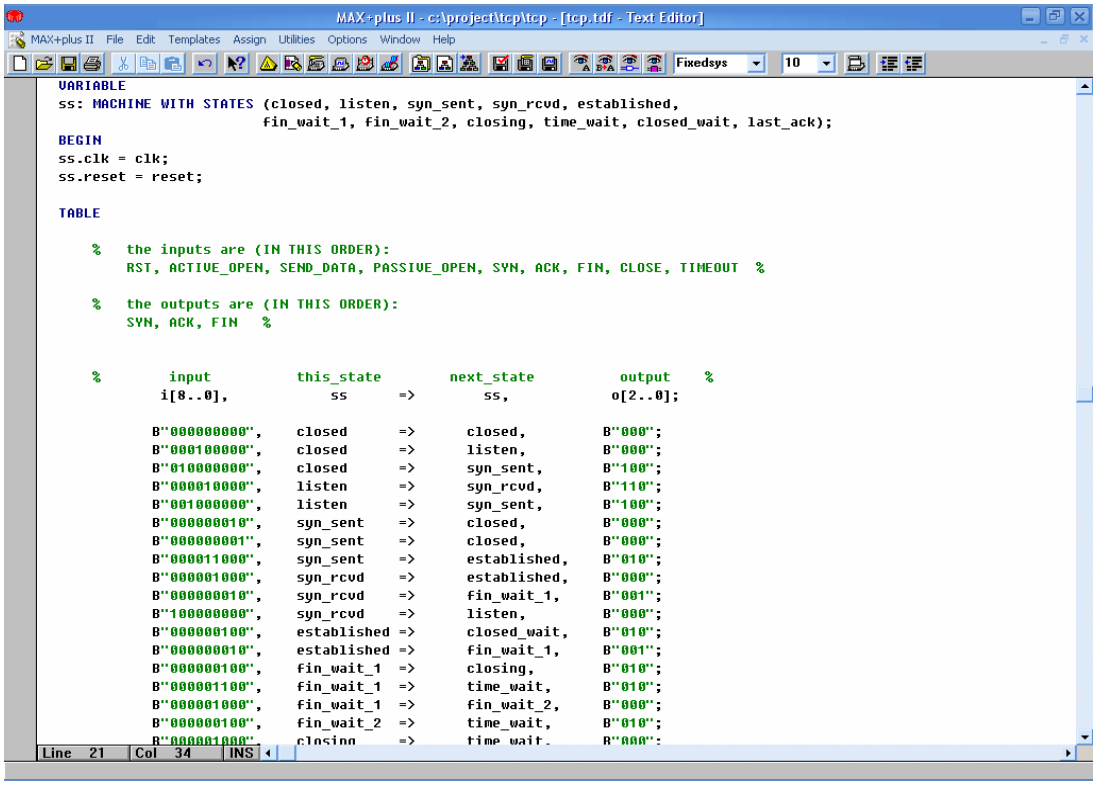


Figure 2: TCP State Machine Implementation

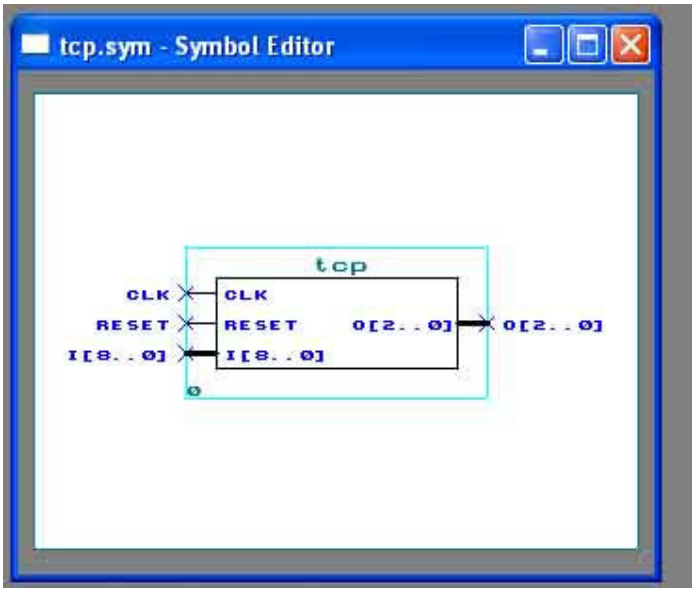


Figure 3: TCP Symbol

Based on the FSM we prepared the TCP State Machine Implementation in Altera. The encapsulated TCP circuit is represented in Figure 3.

The self-testing implementation of TCP is made up of three main components:

1. TCP chip
2. Pseudo-Random Pattern Generator (PRPG)
3. Parallel Signature Analyzer (PSA)

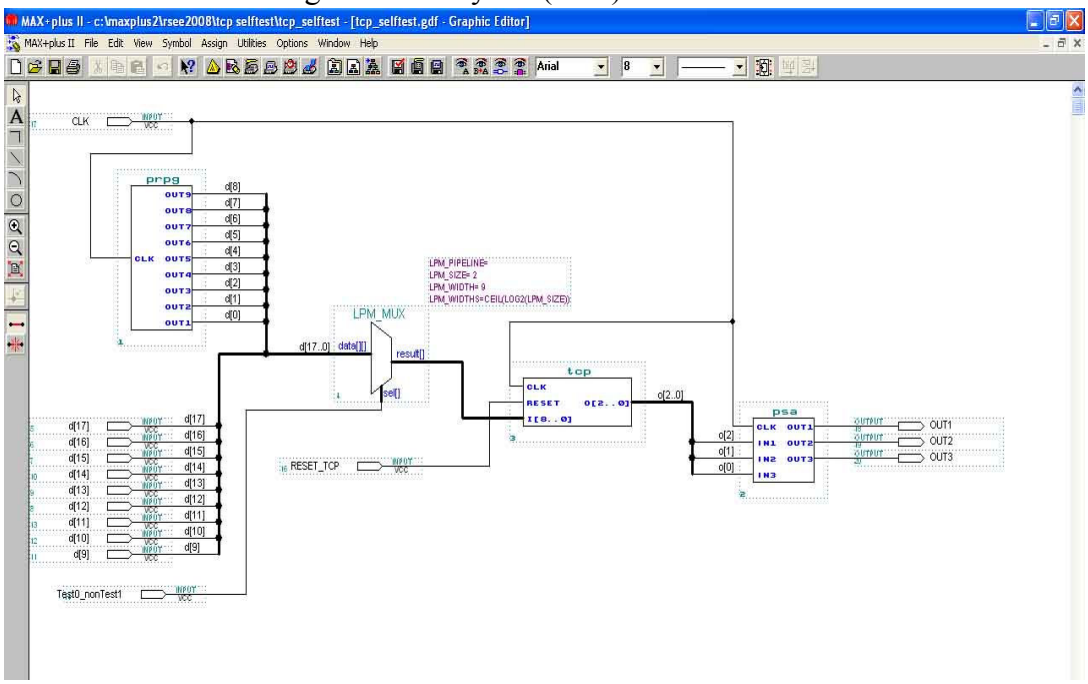


Figure 4: TCP Self Test Implementation

For the implementation of the PRPG, we used a shift register with nine flip-flops, as shown in the figure below.

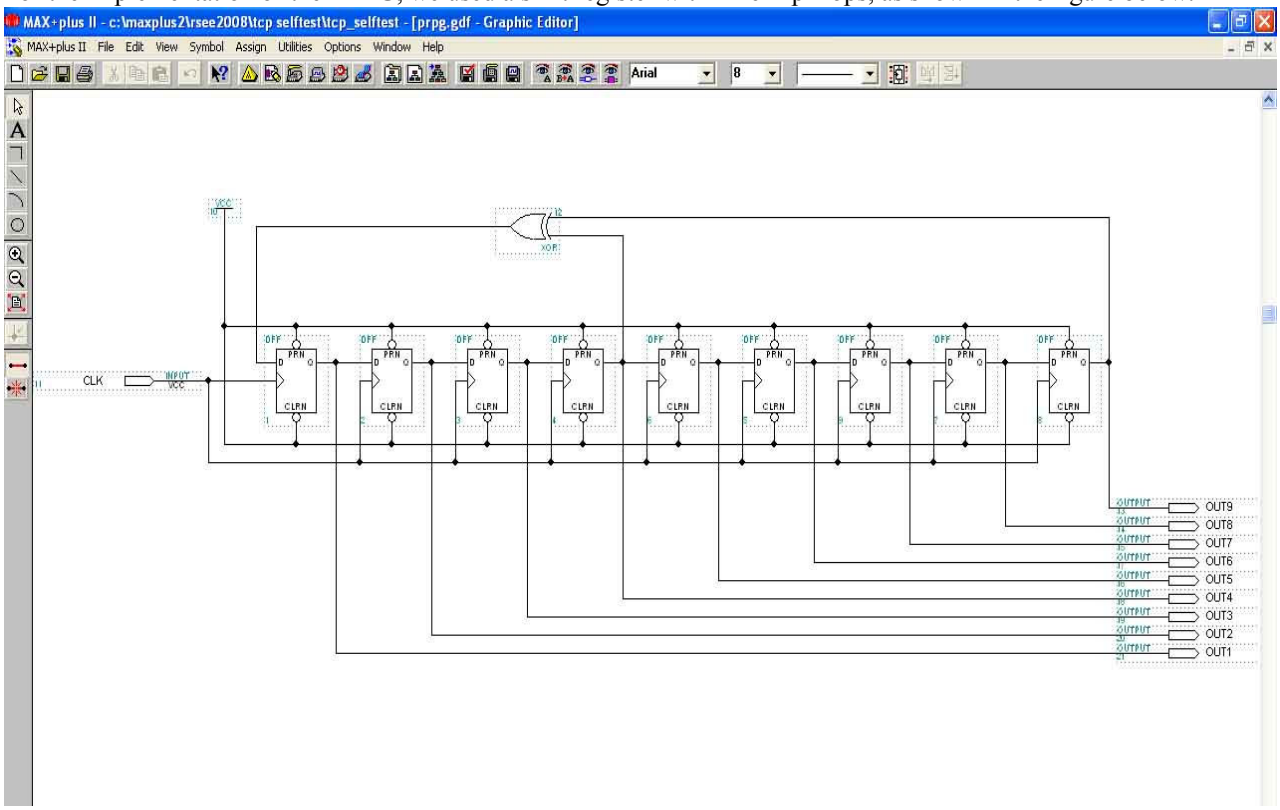


Figure 5: Pseudo-Random Pattern Generator (PRPG)

For the implementation of the PSA, we used a shift register with three flip-flops, as shown below.

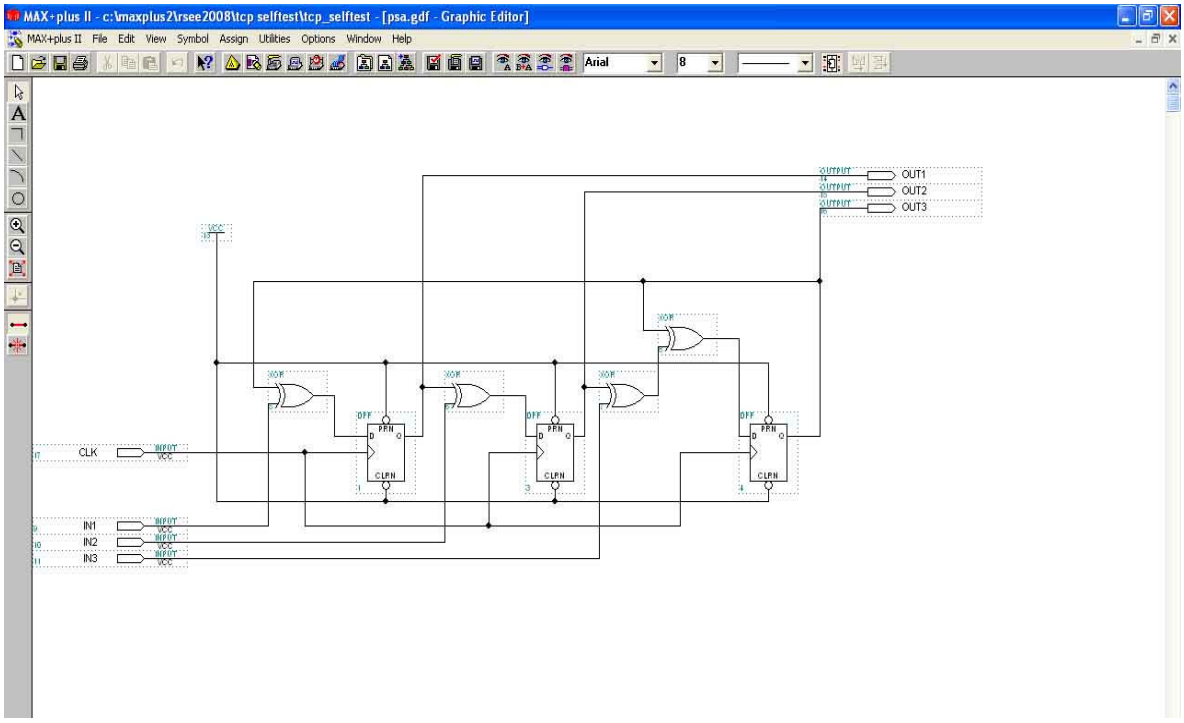


Figure 6: Parallel Signature Analyzer (PSA)

The self-testing implementation of TCP is represented in the following way:

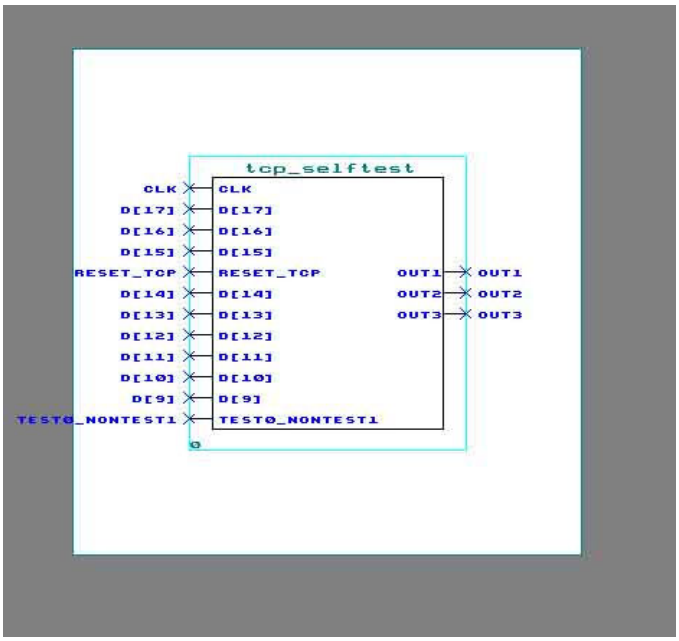


Figure 7 : TCP Self Test Symbol

The times for establishing a connection are:

Server:

CLOSED–LISTEN– SYN_RCVD – ESTABLISHED

19.7 ns + 18.1 ns + Segment_send + 17.3 ns = 93.6 ns

Client:

CLOSED – SYN_SENT – ESTABLISHED

19.7 ns + Segment_send + 18.1 ns + Segment_send = 114.8 ns

The times for closing a connection:

Server:

ESTABLISHED – CLOSED_WAIT – LAST_ACK – CLOSED

20.1 ns + Segment_send + 19.6 ns + Segment_send + 17.3 ns = 134 ns

Client (we considered only the usual transitions):

ESTABLISHED–FIN_WAIT_1–FIN_WAIT_2–TIME_WAIT – CLOSED

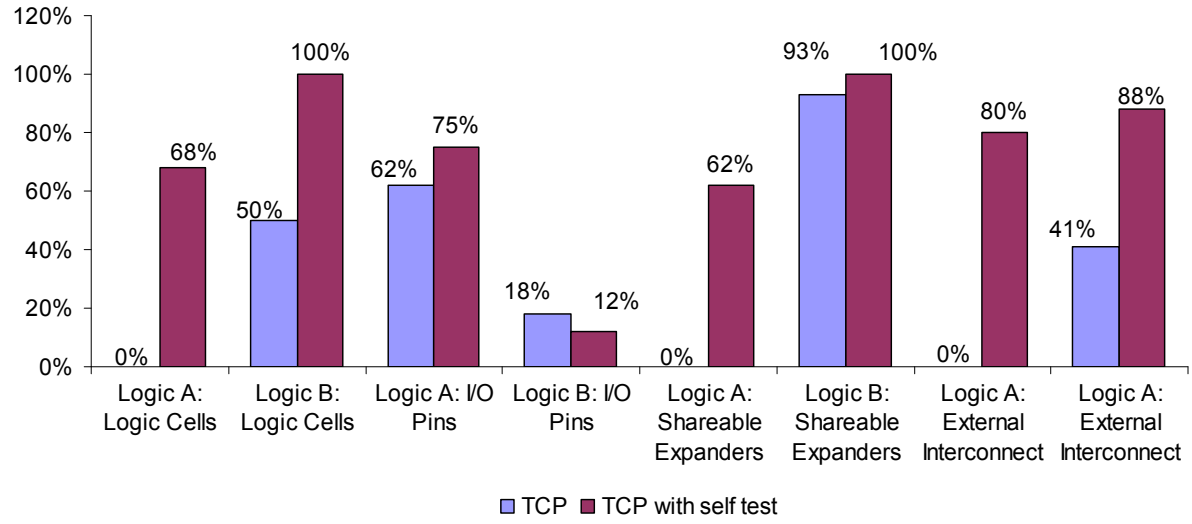
19.6 ns + Segment_send + 17.3 ns + 20.1 ns + Segment_send + 2 X Time_MSL = 334 ns

5. Conclusion

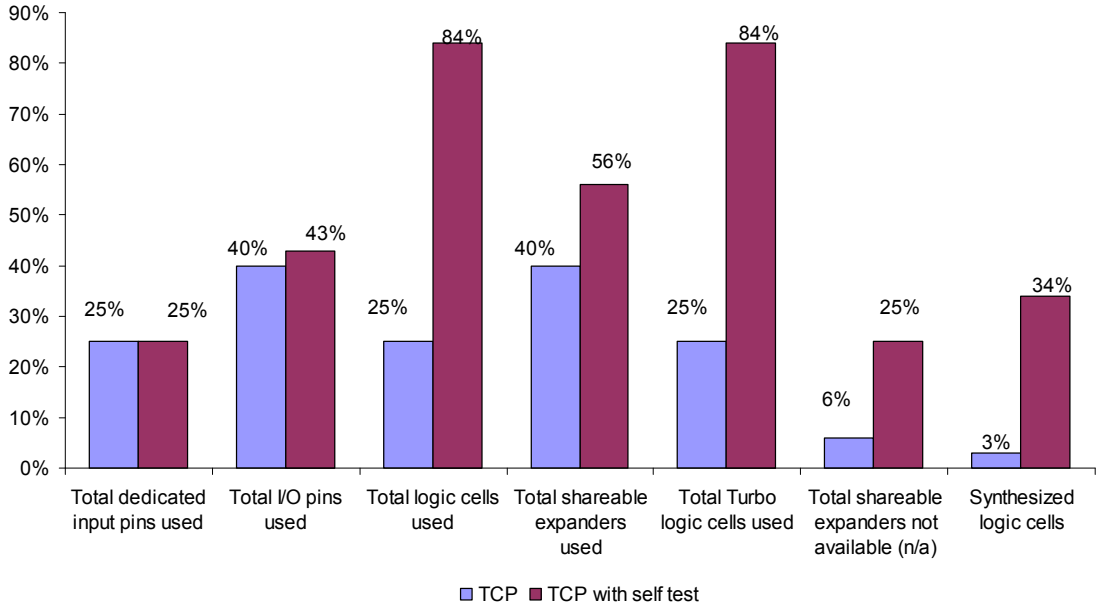
We made our comparation on the duration of transmitting and receiving TCP segments for different samples. SO, figure 4 shows the comparative timing results for the hardware and software implementation. This graphic demonstrates that the hardware implementation is much more faster than the software one.

The TCP state machine and the Self Test Logic used to test the TCP device can be built in the same chip. The PRPG provides the test patterns, so there is no need for an external generator.

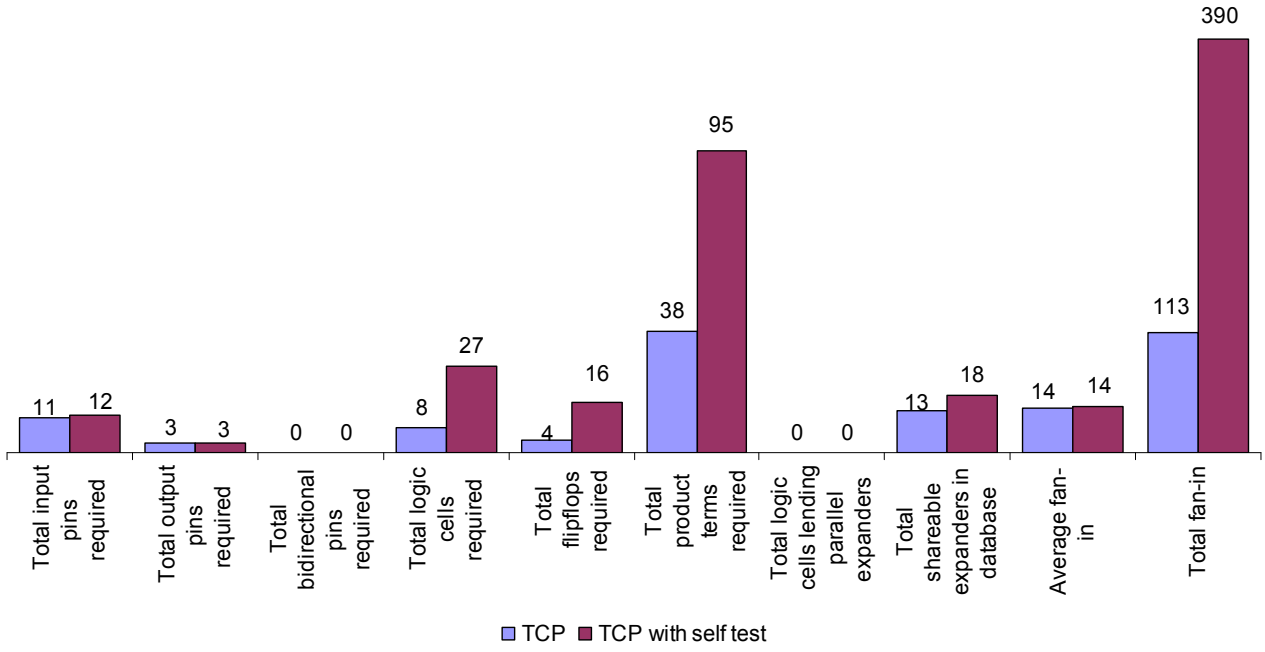
Resource usage 1



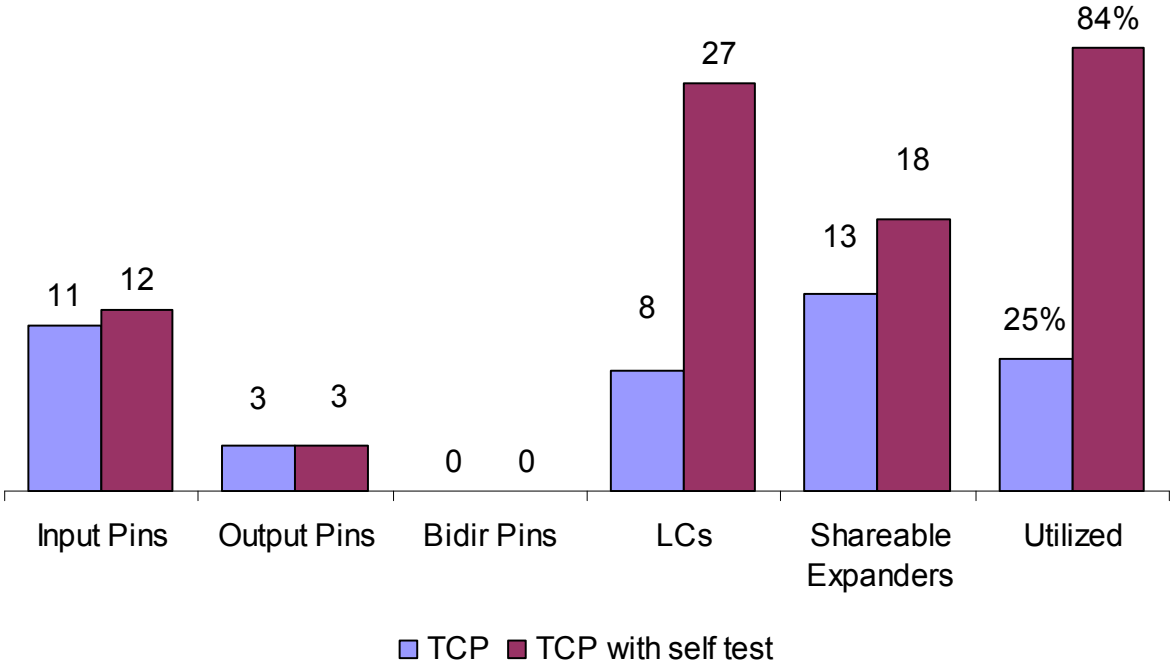
Resource usage 2



Resource usage 3



Device summary



As shown in the charts above, the self-testing implementation of TCP uses the resources almost completely, whereas the classical implementation uses about one quarter of the total system resources.

References:

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