CONTRIBUTION TO T1 STANDARDS PROJECT

STANDARDS PROJECT: Specification and Allocation of ISDN Performance
    (T1Q1-10)

TITLE: On LCD and MIMO Metrics for Frame Latencies.

AUTHOR: Arjan Durresi, Raj Jain, and Gojko Babic

SOURCE: Ohio State University

CONTACT: Raj Jain

Raj Jain is now at
Washington University in Saint Louis
Jain@cse.wustl.edu
http://www.cse.wustl.edu/~jain/

n Science
)H 43210-1277
1, Email: jain@cis.ohio-state.edu

DATE: July 14, 1999

DISTRIBUTION: Working Group T1A1.3

ABSTRACT:
    This contribution analyzes MIMO and LCD metrics for measuring frame delay in ATM
    networks.

1. Introduction

In this contribution we analyze the pros and cons of using MIMO and LCD as delay metrics in performance testing. Also we shows the areas where these metrics can provide better results. In reference [1,2] LCD is analyzed using the following principles: Accountability, Additivity, Simplicity, and Non-negativity. In this contribution we will analyze LCD and compare it with MIMO using the same principles.

2. Review of Last Cell Delay (LCD) Metric:

LCD measures the latency of a frame through a switch by measuring the last-bit-in-to-first-bit-out (LIFO) latency of the last cell of the frame. For example, consider an n-cell frame passing through a switch with input speed of x and output speed of x/m. Figure 1 shows this case for n=3 and m=2. At input, each cell time is c, while at the output it is mc. In this case, the last bit of the last cell enters the switch at nc and the first bit of that cell exits at (n-1)mc. The last cell's LIFO latency or LCD of the switch is (n-1)mc-mc or (n-2)mc. As shown in Figure 1, for n=3 and m=2, LCD is 2c. For n=100, and m=100, this delay will be 9800c.
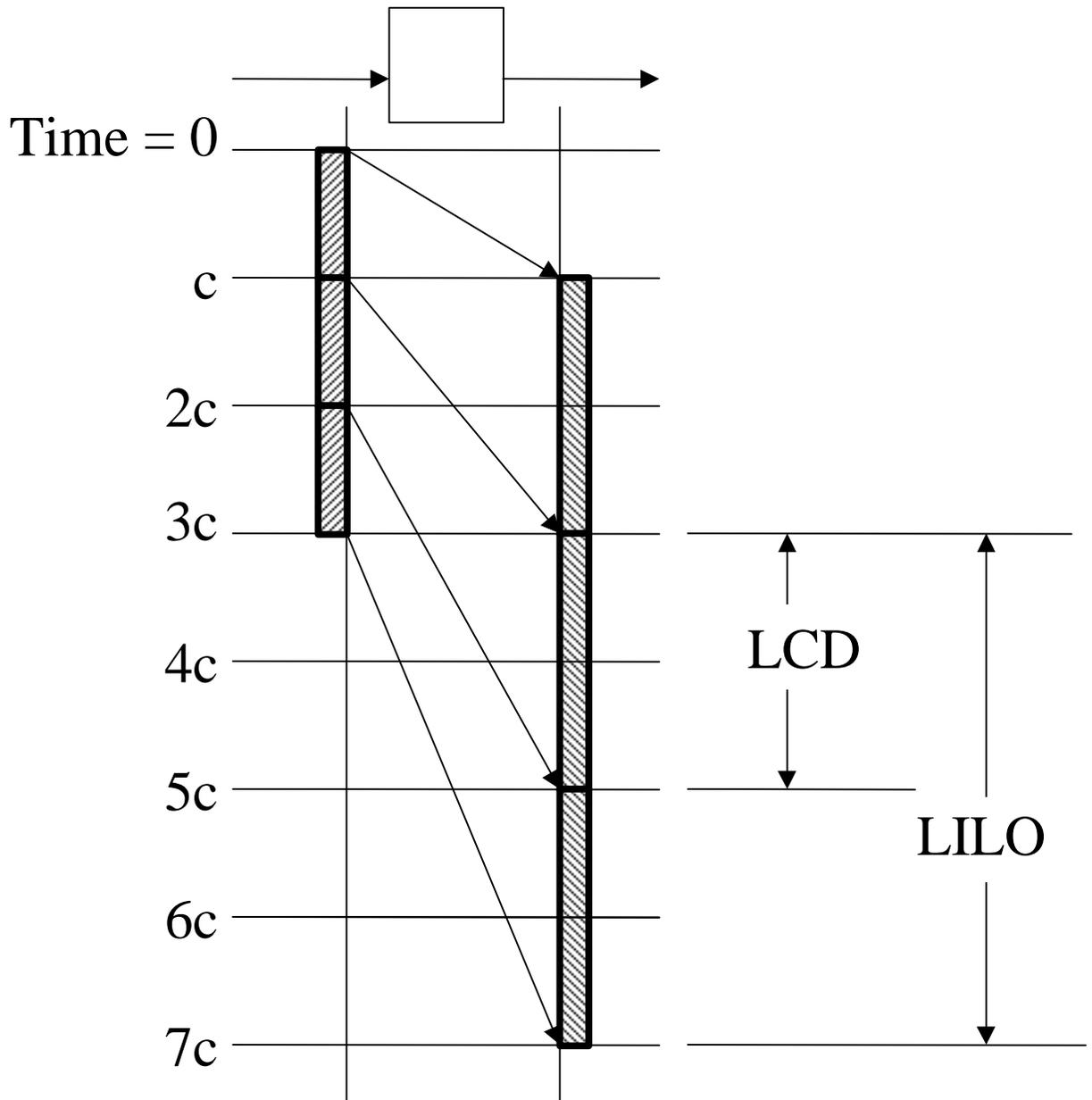
Figure 1

Review of MIMO definition and zero-delay switch:

MIMO latency is the difference between the measured LILO latency of the frame through the system under test and that through an ideal system [3, 4]:
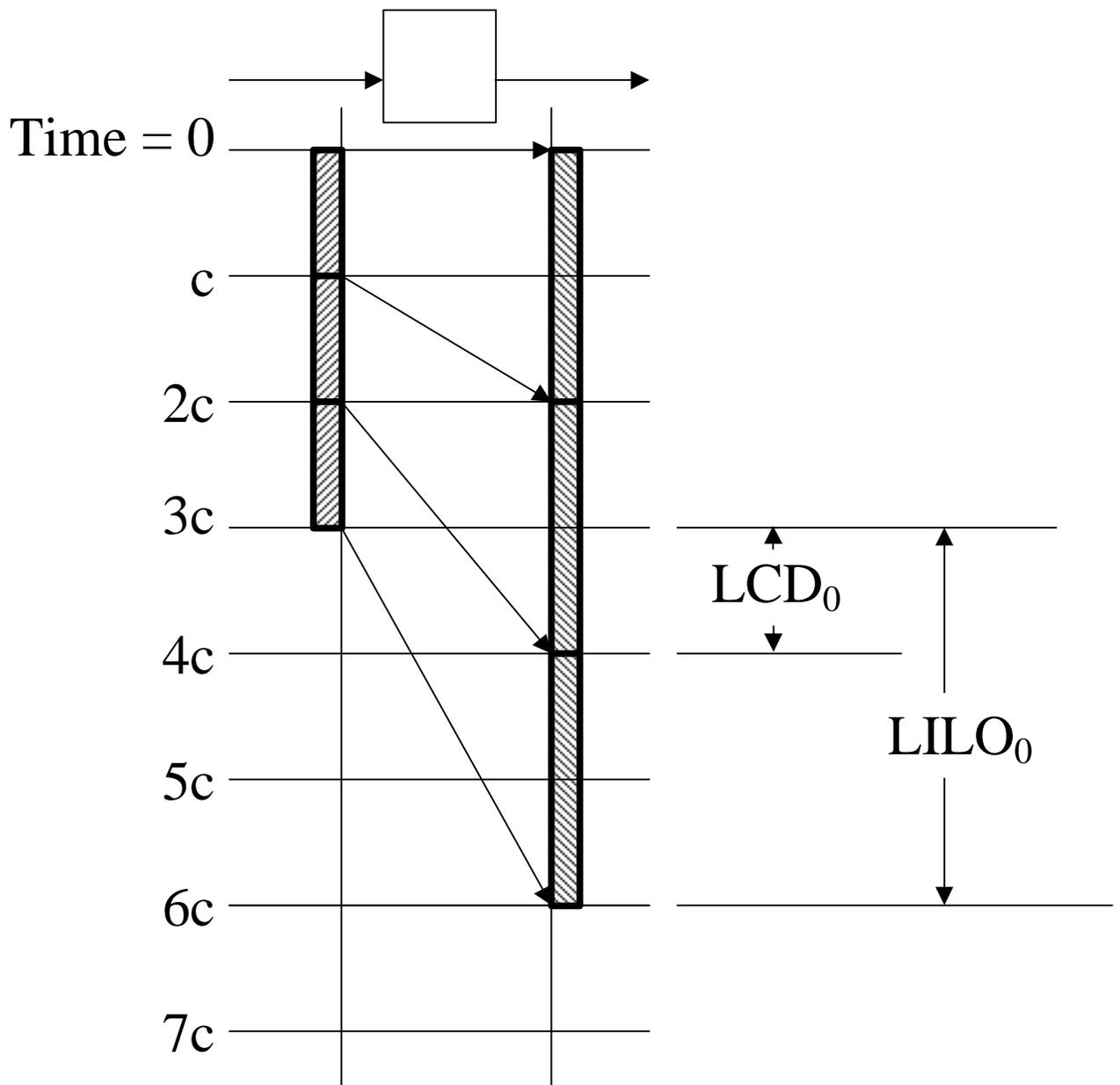
MIMO = LILO – LILO$_0$ (1)

Figure 2

Here $LILO_0$ is the latency that the frame would experience if it is passed through the best possible (ideal) switch. In other words MIMO delay is the extra delay introduced by the switch under test compared with its corresponding zero-delay switch. For example, consider the frame and the switch of Figure 1. Figure 2 shows the output pattern when the frame is passed through an ideal switch. The ideal switch, in this case, sends out the first bit as well as the other bits as soon as it can. As shown in the figure:

$$LILO_0 = 3c$$
$$LILO = 4c$$

$$MIMO = LILO - LILO_0 = c$$

For other values of n and m:

$$LILO_0 = n(m-1)c$$
$$LILO = n(m-1)c+c$$
$$MIMO = LILO - LILO_0 = c$$

An important point, which needs to be clarified is the influence of Input/Output speeds of the switch. When we change the in/out link speed, we are operating with a different switch. Its measured delay may be very different from that of another switch with almost the same hardware but different I/O speeds. The corresponding zero delay switch is also different. For instance, in the examples given above, LILO with m=2 and m=100 are different. So are $LILO_0$s. The difference between LILO and $LILO_0$ is MIMO and may or may not depend upon the speed. Our goal by subtracting $LILO_0$ is to subtract out the workload dependent part as much as possible so that when comparing multiple switches the results are not overshadowed by the workload dependent part (for example, the part that depends upon n – the frame size). It is just a coincidence that in this case, MIMO latency in this case is independent of m. This is not always the case.

An equivalent definition of MIMO is:

$$MIMO = FILO-FILO_0$$

That is, the MIMO can also be computed as the difference between the first bit in to last bit out latency of a switch and that of an ideal switch.
Similarly,
$$MIMO = LCD - LCD_0$$
All these definitions are identical in the sense that the results obtained by using these different formulae are all same.

3. Accountability

Generally, the measured performance of a system depends upon the system as well as the workload. Some metrics are highly workload dependent while others are less dependent. A metric, which depends more on the system and less on the workload, is generally preferred particularly if the users are interested in comparing the systems and not the workloads. It turns out that the LCD frame latency as defined in [1] has the undesirable property that it depends highly on the workload. This is obvious from the example shown in Figure 1 and 2. A vendor trying to sell the switch would use small frames, say, n=2, and claim its LCD is zero while a competing vendor will use large frames, say, n=100 and show that the same switch has large delay. Notice that in this example, LCD=nmc+c of which nmc is the workload dependent part and c is the workload-independent (or switch dependent) part.

The dependency of LCD results on the input frame configuration is not a desirable feature in comparing different switches performances. However, if the workload is given and a user is interested in knowing the total delay introduced for that workload, then any of the measured latencies, including FILO, LILO, or LCD can be used. For example, LCD can be used as an indication of delay in an "in-service" measurement where the user is interested in computing total delay between the entry and exit from a given network. This is exactly why ATM forum performance testing spec allow both FILO and MIMO latencies to be specified. LCD can be used in place of FILO.

On the other hand, for out-of-service performance testing, where a user wants to compare multiple networks or switches, MIMO is a better indicator of the switch performance since the workload part has been taken out.

4. Additivity

In the references [3, 4], it is shown that MIMO latency of a series of components can be computed as follows:

$$MIMO_{\Sigma} = \Sigma MIMO_i + \Sigma LILO_{0i} - LILO_{0\Sigma} \tag{2}$$

Here, $MIMO_i$ is the MIMO latency of the ith component, $LILO_{0i}$ is the LILO latency of the ith component if it were an ideal switch, and $LILO_{0\Sigma}$ is the LILO latency of the entire series if it is replaced by a black box consisting of an ideal switch. Note that computing LILO latency of an ideal switch requires knowledge of only the i/o speeds and is trivial in most cases. If the input speed is same or slower than the output speed, the LILO latency of the ideal switch is zero.

LCD is additive:

$$LCD_{\Sigma} = \Sigma LCD_i \tag{3}$$

We have not mentioned the fact that LCD for each component is measured differently depending upon whether it is a switch or a wire. For switches, LCD is defined as the LIFO latency of the last cell of the frame. For wires, LCD is defined as the FILO latency of the last cell of the frame. This change in definitions is required to ensure additivity. Note that a wire <u>must</u> always follow a switch and vice versa.
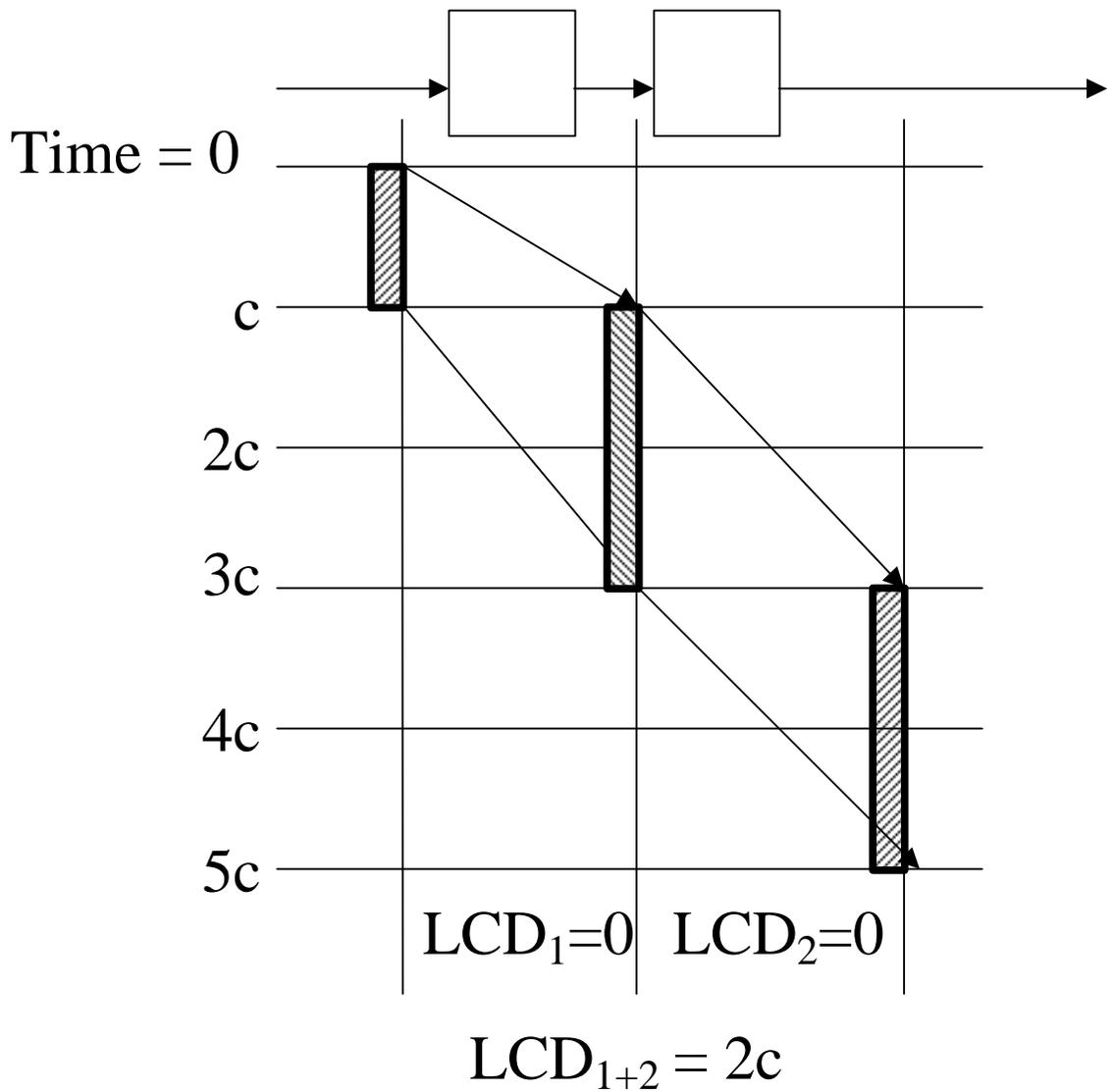
Figure 3

There are two problems with differing definitions of LCD for switches are wires. First, the LCD latency of a zero-length (or very short length) wire is c (one cell time) and not zero. The latency of a 1 km of fiber would be $c+5\mu s$ and not 5 μs. Second, if we put two switches back-to-back the total LCD is not the sum of individual LCDs. Figure 3 shows a concatenation of two switches, with each switch having an LCD of 0, but the LCD of the two switches combined is 2c.

5. Simplicity

Both LCD and MIMO are simple. For MIMO, one has to know the input/output speeds of the SUT and the cell arrival pattern to subtract out the workload dependent part. For LCD, one has to properly classify each blackbox either as a switch or a wire and to ensure that wires and switches alternate.

In cases, where one is interested in comparing multiple systems, it is important to subtract out the workload-dependent part and so the knowledge of workload is required. However, if one is interested only in in-service allocation of delays among various components for a given workload, LCD may be used.

6. Non-negativity

MIMO by definition gives always non-negative values. LCD can be negative if the first bit of the cell come out of a component before the last bit goes in. For example, a simple digital amplifier that takes in distorted waveform and outputs noise-free square bit pattern will have a negative LCD.

7. LCD vs MIMO: Further Examples

Figure 4 shows two switches. Switch A has the simple property that it takes 2c time to process every cell. The input speed is 20 times faster than the output speed. For the 3-cell sequence shown, the MIMO latency is 2c while the LCD is 39c. Of course, LCD does not reflect the true behavior of the switch and can be made arbitrarily large by increasing the number of cells in the sequence.

Figure 4b shows another switch that arbitrarily delays cells by large amounts. The input speed is same as the output. An ideal switch in this case will be able to output each cell as it enters the switch. However, the system under test delays the ith cell by 2+(i-1)19c. For a 3-cell frame, the third cell is unnecessarily delayed by 40c. If a customer wants to buy a 20x speed I/O switch this is not a very good switch to buy since the cells are delayed so much. MIMO latency correctly reflects this fact by being at 40c.

When one compares the switches in Figures 4a and 4b, we find that switch in Figure 4b unnecessarily delays the cells and so is not a good switch. Increased value of MIMO reflects this fact. The LCD of both switches is 39c making the customer believe that the two switches are equally good when they are not. In fact, the value of LCD can be made arbitrarily bad (or good) by simply changing the number of cells in the frames.
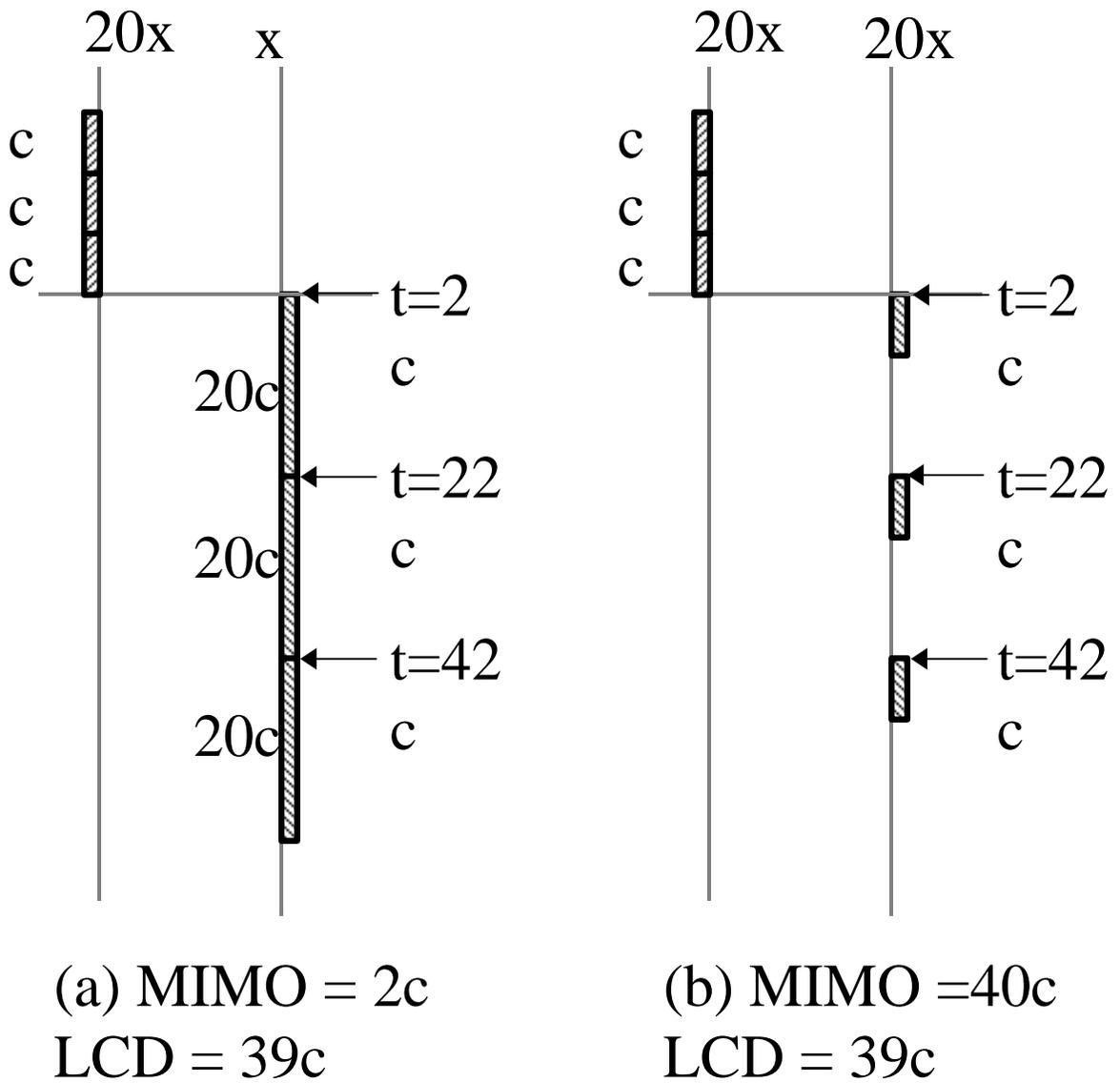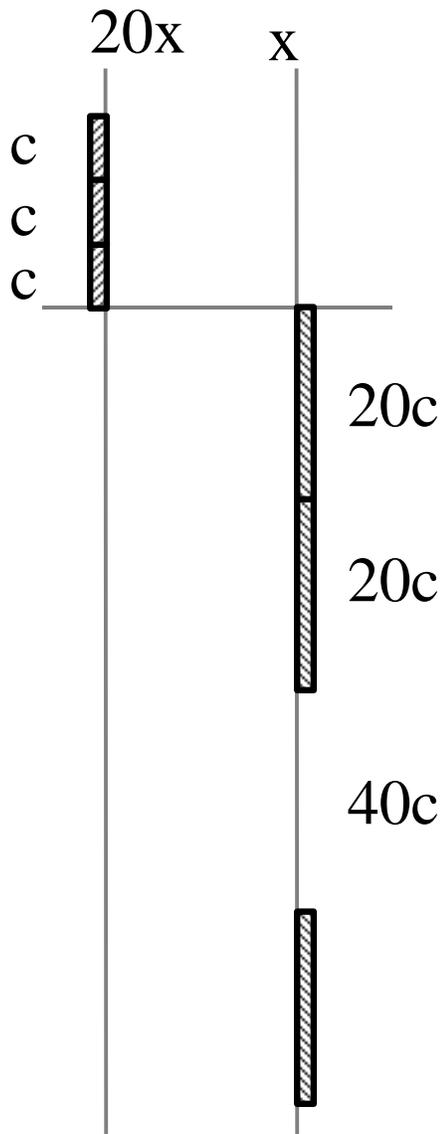
20x   x   20x   20x

c   c
c   c
c   c

← t=2   ← t=2
c   c

20c

← t=22   ← t=22
c   c

20c

← t=42   ← t=42
20c c   c

(a) MIMO = 2c   (b) MIMO =40c
LCD = 39c   LCD = 39c

Figure 4

Figure 5 shows a switch similar to that in Figure 4a except that this switch introduces an unnecessary delay of 40c in the middle of the frame. In this case both MIMO and LCD go up by 40c.

20x   x

c

c

c

20c

20c

40c

MIMO = 42c

LCD = 79c

Figure 5

Figure 6 shows a concatenation of two switches. The first switch has input speed 100 times faster than the output speed. The second switch has output speed 100 times faster than the input speed. Both switches have the property that they unnecessarily delay the cell by 2c times. As shown, each frame has 100 cells. MIMO latency for both switches is 2c regardless of the number of cells in the frame. LCD latency for the first switch is

9802c and that for the second switch is only c, leading one to believe that the first switch is really bad. In fact, it can be made to look arbitrarily worse by simply changing the workload – number of cells in the frame.

$$100x \quad x \quad 100x$$

c

c

c

$$100c$$

$t=99c$ $\quad$ $100c$

$t=100c$

$$MIMO_1 = 2c$$
$$MIMO_2 = 2c$$
$$MIMO_{1+2} = MIMO_1 + MIMO_2 + LILO_{01} + LILO_{02} - LILO_{0\Sigma}$$
$$= 2c + 2c + 9900c + 0 - 0 = 9904c$$

$$LCD_1 = 9802c$$
$$LCD_2 = c$$
$$LCD_{1+2} = 9903c \neq LCD_1 + LCD_2$$

$t=9902c$
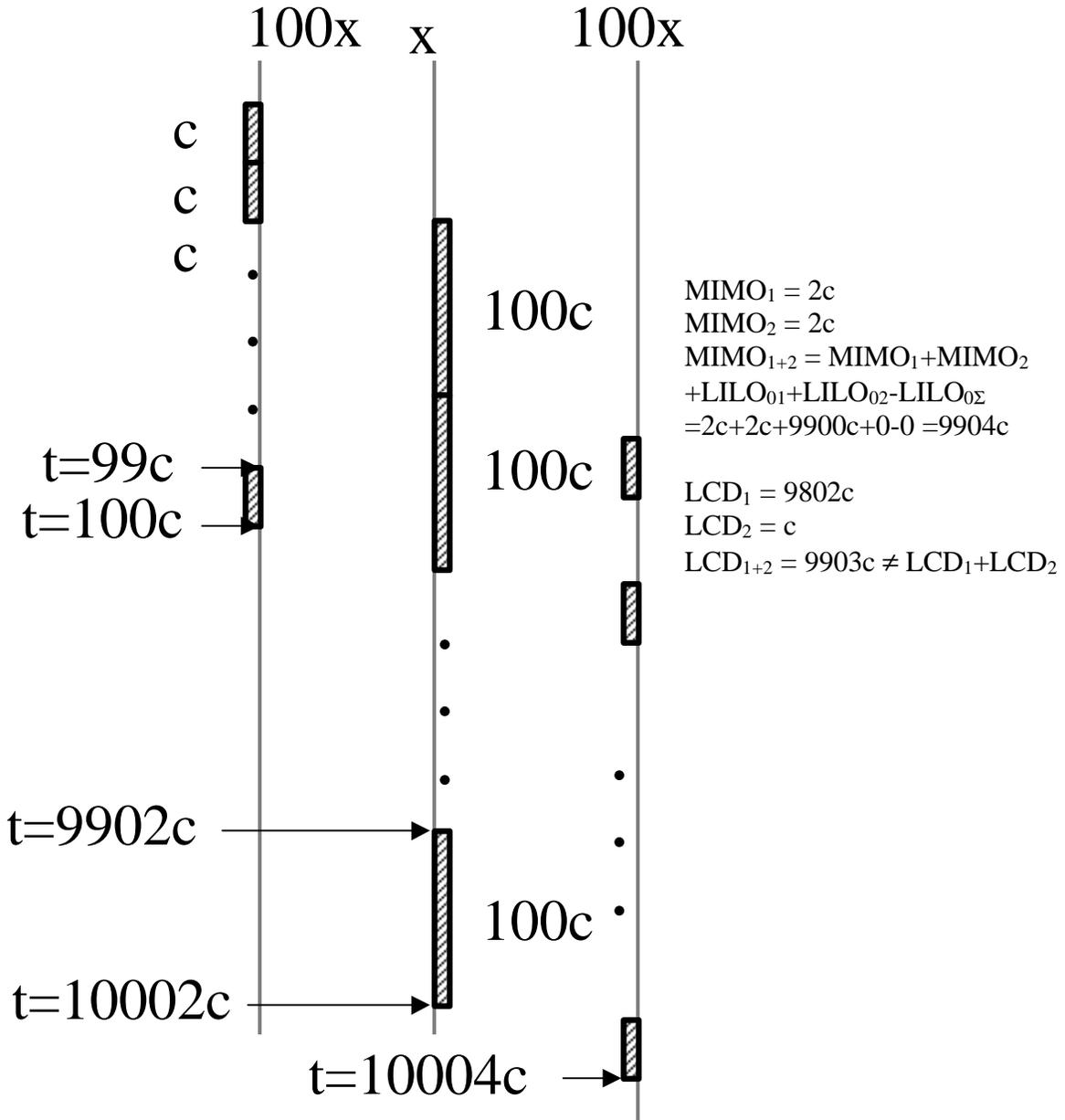
$$100c$$

$t=10002c$

$t=10004c$

Figure 6

Another point to note from Figure 6 is that while each switch is good, the system consisting of the two switches together has a bottleneck in the middle and is not good. This is reflected by the combined MIMO of 9904c. If the bottleneck is improved the

MIMO improves. Combined LCD in this case is 9903c. Note that additivity of LCD fails in this case since there is no wire between the two switches.

8. LCD vs MIMO Compromise

Based on this analysis we can conclude that MIMO and LCD have advantages and disadvantages. These metrics can be seen as complimentary because they are more appropriate in different applications. MIMO metric is better suited for comparing performance of different switches in out-of-service measurements, where it can precisely measure the delay introduced by the switch independent of the input frame. LCD can be used for in-service measurements and for user perceived delay. In this sense, LCD takes the place of FILO or LILO as currently specified in the ATM Forum testing document.

Note that if LCD is used in place of FILO, the following relationship may be useful for aggregation:

For any one component:

$$MIMO = LCD - LCD_0 \tag{4}$$

Note that this relationship applies for both switches and wires. That is, LCD can be FILO or LIFO.

For a network of switches we will have the following expressions:

$$LCD_\Sigma = \Sigma LCD_i \tag{5}$$

$$MIMO_\Sigma = \Sigma LCD_i - LCD_{0\Sigma} \tag{6}$$

Furthermore the expression:

$$MIMO_\Sigma = \Sigma MIMO_i + \Sigma LCD_{0i} - LCD_{0\Sigma} \tag{7}$$

can be used to relate the delay of the network to the delays of individual switches measured in performance testing by $MIMO_i$ and to mismatch between input and output link speeds given by LCD_{0i}.

10. Conclusion:

We have indicated the relationship between MIMO and LCD. One can be calculated from the other. MIMO is better suited for out-of-service measurements where one is interested in comparing multiple switches independent of the workload. LCD can be used (in place of FILO or LILO) for in-service measurement where one is interested in total delay for a given traffic.

11. References:

1. K. Glossbrenner, F. Kaudel, "ATM Layer Reference Events for Monitoring Frames," ATM Forum contribution 99-0282, April 1999.
2. K. Glossbrenner, F. Kaudel, "ATM Layer Reference Events for Monitoring Frames," contribution to ANSI Committee T1A1.3, May 3,1999
3. A. Durresi, Jain, and G. Babic, "Frame Delay Through ATM Switches and networks: MIMO Latency and its aggregation," Contribution to ANSI Committee T1A1.3, May 3,1999
4. A. Durresi, R. Jain, and G. Babic, "Aggregation of MIMO Latency", ATM Forum contribution 99-0243, April 1999.