Method for detecting fiber cuts in a WDM ring with saturated EDFAs

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Optical protection switching in WDM networks promises considerable cost savings relative to pure SONET protection, and has the advantage that it can also be used for protecting non-SONET signals. However, optical protection switching cannot be implemented without a fast and unambiguous method for detecting fiber cuts in optically amplified links. As the distance and number of amplifiers between the cut and the optical monitor increases, amplified spontaneous emission (ASE) from the erbium doped fiber amplifiers (EDFAs) grows; consequently, measurements of total optical power or even of power within a narrower spectral band are insufficient for detecting certain fiber cuts. Measurements in the Bellcore optical networking testbed confirm that it is not possible to set a power threshold which will allow unambiguous detection of all fiber cuts when several EDFAs are present.

This paper describes a technique for unambiguous detection of a fiber cut, either on a working fiber or on a protection fiber which carries no traffic except when protection switching has occurred. We have used simulation in the wavelength domain /1,2/ to compare detection techniques and where possible have verified our results experimentally using the Bellcore local exchange testbed. Our simulations show that neither the total optical power nor the power within a wavelength channel gives enough information to accurately detect all fiber cuts without giving false alarms. On the other hand, we show that differential power measurements of two non-signal wavelength channels provides accurate detection of fiber cuts or amplifier failures.

If a measurement is to be an effective means of detecting a fiber cut, there must be high contrast between its value when the fiber is intact and that when it has been cut or when in line amplifiers have failed. We have set the somewhat arbitrary contrast level of 10 dB. While this may appear high, it is necessary for distinguishing a true fiber cut, which demands protection switching, from a degraded power level (the result, for example, of degraded EDFA gain or of increased fiber loss) which may require a different response. The accuracy of fiber cut detection should not be dependent on the location of the cut, and a technique which gives false alarms is as unacceptable as one which fails to detect actual cuts.

Figure 1 shows two fibers, one a working fiber and the other

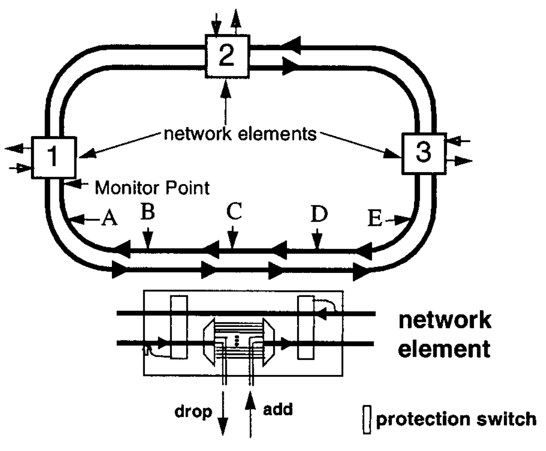

Figure 1 A schematic view of a working fiber/protection fiber pair in a WDM ring. Fiber cuts can occur on either fiber. Locations A-E are labelled for reference in the text.

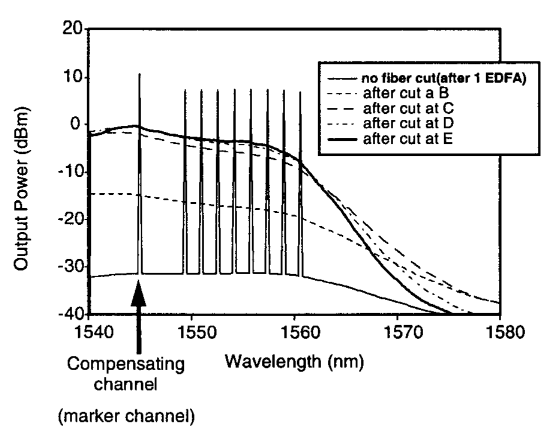

Figure 2 Optical spectrum at monitor when link is intact and after cuts at points B, C, D, and E (i.e. after 1,2,3, and 4 EDFAs.)

the corresponding protection fiber, in a four fiber bidirectional line switched ring. In this ring, the protection fiber carries traffic only when a failure has been detected. On some links there are no EDFAs beyond those in the network elements, and on others there are one or more EDFAs. We show four line amplifiers on each fiber between network elements 1 and 3. Figure 2 shows the optical spectrum detected at the monitor when the line is intact, and after cuts at points B, C, D, and E. After 3 or more EDFAs, the total power reaches a constant level. Figure 3 shows the total power as a function of time, with fiber intact and with 1-4 EDFAs between the cut and the monitor. The fiber cut begins at t = 100 μs and is finished at t = 200 μs. This Figure illustrates how detection of total power can fail to detect certain fiber cuts depending on the location of the cut and the detection threshold and how no detection threshold can detect all cuts. If a fiber cut occurs at point A, there are no EDFAs between the cut and the optical power monitor. The cut is easily detected, since optical power drops to zero, and it is thus not shown in Figure 2. However, for more remote fiber cuts, such as those at points B-E, the ASE from the intervening EDFAs provides optical power to the monitor. If only one EDFA is present, the power drop after a cut is large enough to trigger protection switching, but if there are two or more EDFAs, the power at the monitor is nearly indistinguishable from that without a fiber cut. Therefore, it is not possible to set a threshold that will allow detection of a cut with more than 2 EDFAs between it and the monitor.

Measurements in the Bellcore local exchange testbed are in agreement with simulation results. When no EDFAs lie between the cut and the monitor, fiber cuts are correctly identified. With one EDFA between the cut and the monitor, correct identification of a cut could not occur without changing the detection threshold. As Fig. 2 shows, however, when more than two in line EDFAs are present, it is not possible to set a threshold which will detect the cut.

To prevent these problems, we suggest that an additional marker wavelength be inserted into the fiber at the output of a network element (wavelength add/drop or wavelength crossconnect). If the power in that marker is high enough, or if the wavelength channel is made narrow enough, simple detection of the marker is sufficient to indicate a fiber cut. However, high power in a marker wavelength results in lower EDFA gain for the signal wavelengths, and is thus undesirable. If the marker channel has power comparable to that of a single channel, the simulations summarized in Fig. 4 show that for a filter bandpass similar to that used for the signal channels, the marker alone does not give adequate contrast after more than 2 EDFAs. If the detection threshold is placed between the power level before the cut and that for a cut at point E, it would appear that fiber cuts could be detected. However, this represents only a small loss of power, and could be the results of acceptable power variations in the network. Protection switching because of such limited power variations would be unnecessary. Using a very narrowband (≤0.2 nm) filter restores the contrast to the desired 10 dB, but places possibly unrealistic demands on marker wavelength-filter alignment.

To avoid these failures to detect a cut or identification of a cut where there is none, we propose using a differential power measurement to compare the power in the marker wavelength spectral band to *that in* a nearby, non-signal wavelength region. Figure 5 illustrates the results when a cut is made at location C; when the fiber is intact, the ratio of marker to neighbor wavelength is high; when the fiber is cut, the ratio is approximately unity. A similar change of ratios will be seen regardless of cut location. The results of Fig. 5 assume that the marker and the neighbor channel have nearly equal gain. The power ratios may be somewhat different if the two channels have different gain, but a large difference in power ratio will still be detectable after many EDFAs.

The marker wavelength can be generated easily on the working ring if optical gain clamping is used for the EDFA

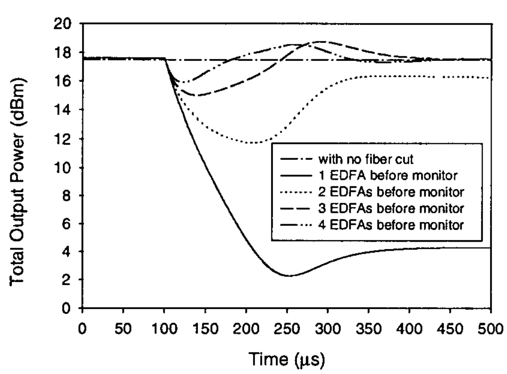

Figure 3 Total optical power as a function of time at monitor before and after a fiber cut at t=100 μs. Cut takes 100 μs to remove all light.

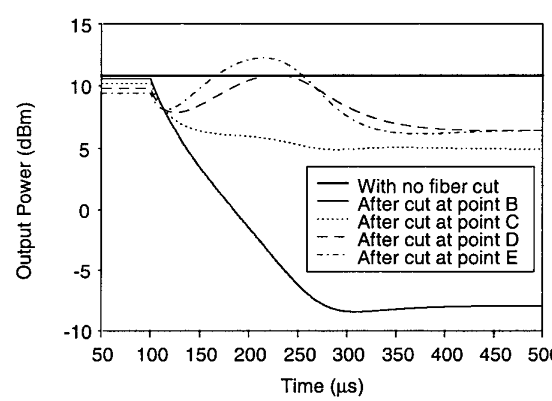

Figure 4 Optical power as a function of time in a 1 nm band at the marker wavelength, before and after a fiber cut at t=100 μs. The marker has a power equal to that of a single channel.

within the network element, and if the optical power used to gain clamp that EDFA is allowed to propagate to the next network element. /3,4,5/ Thus, if this kind of gain claming is used, inserting the marker adds no cost to the network element.

Our analysis has shown, however, that using a marker generated as a by-product of gain clamping is not an option for the protection ring, in part because the gain clamped EDFA is not needed in a protection ring of this kind and in part because we do not want to initiate protection switching due to an EDFA failure on the protection ring. One intriguing possibility is to note that when it is not in use, the protection ring will act as a large ring laser if the total gain is greater at some wavelength than the round trip loss. Such lasing has been observed experimentally in the Bellcore local exchange testbed as well as in simulation. However, it cannot be used to locate fiber cuts, because it disappears in all parts of the protection ring regardless of where the ring is cut. If protection switching were initiated upon detection of the loss of the lasing wavelength, all protection switches would be activated at the same time, which is not the desired behavior. Therefore, an additional laser will be needed at each network element to introduce a marker wavelength on a protection ring.

Using the differential measurement is not merely more accurate than a single power measurement but also provides faster detection. Fig. 5 shows that the power ratio reaches its new value in about 100 μs. In comparison, if only the marker channel is monitored, it takes about 250 μs to reach a steady power. These specific times are amplifier dependent, but the relative speeds of detection will be independent of amplifier design.

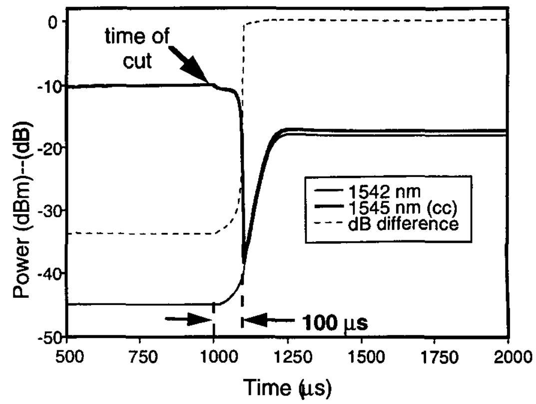

Figure 5 Optical power before and after a fiber cut (at point C) at 1000 μs, in the marker channel, a nearby, non-signal channel; and the ratio of those powers.

These results confirm that while the simplest methods for optically detecting fiber cuts do not allow detection of fiber cuts at all possible locations, modifications that add only a moderate amount of cost and complexity can provide sufficient information for rapid and unambiguous identification of cuts.

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