Conclusion

As MDU FTTH deployments become a more important part of the service provider business model, it is imperative that innovative product development initiatives continue to take place. One such area of opportunity is increasing deployment velocity to the MDU living units, especially for brownfield installations. New fiber optic cable advancements such as bundling individual drop cables to enable one quick cable pull to pass multiple living units is a step in the right direction.

Efficient FTTH Design for Rural Broadband Deployment

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Executive Summary

Most of America is rural in nature. The fiber industry has offered little in a solution to deploy FTTH in rural areas since cost is a factor. However, there are ways to minimize cost and take advantage of this new technology in rural areas. The most important design question to be answered is where to place the optical splitter(s). Placement of the splitter in the CO or in a cabinet means large cables are placed for long lengths. Problems can occur if the growth exceeds the fiber cable size and long lengths will have to be reinforced with new fibers. The alternative is to distribute the splitters by carving up the routes into 32 living unit areas and deploying the splitter in these. This pushes the splitter as close to the living units as possible which greatly reduces cable size and splicing. Splitters can actually be deployed in the same closure used for drop distribution which eliminates an extra closure to house the splitter. There are various ways to obtain 32 splits of the fiber: 1 a single 1x32, a 1x4 feeding 4-1x8 splitters spread over the route, a 1x8 feeding 8-1x4's spread over the route, or a combination of 1x2's or 1x3's fed by a 1x4 or 1x8. A thorough review of the splitter options yields the 1x4 feeding 4-1x8s and the 1x8 feeding 8-1x4's as the best alternative when considering cost, loss and viability.

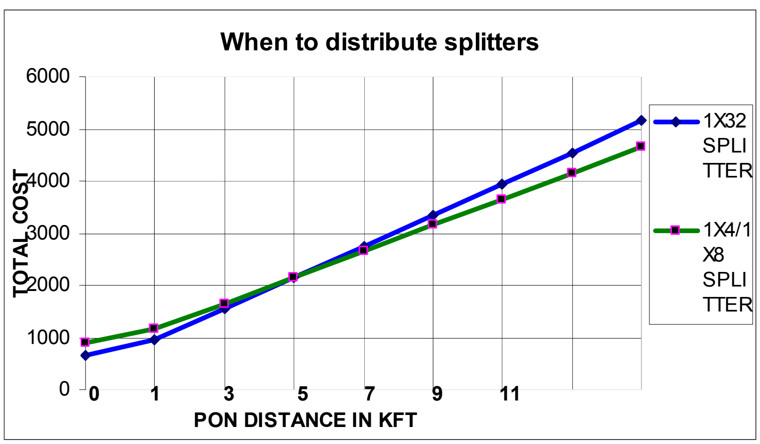
For rural applications, our cost models suggest fusion splicing the splitter and drops to reduce optical loss and increase distance, provide a higher reliability by eliminating connectors and jumpers, reduce installation time since no visit is needed to the splitter that is fully fusion spliced initially, and for labor rates under $75 per hour is an economical choice. This also reduces the number of "parts" that are needed to build a FTTH network with savings realized in stocking and material management costs.

Since customers are scattered about in rural areas, typical ways of deploying FTTH such as utilizing cabinets to house splitters or "home running" fibers with splitters in the CO become cost ineffective due to the long lengths of fiber needed between customers. A different approach to design is warranted in order to mitigate as much as possible the high cost of FTTH in these areas. Rural areas can be divided into three basic types: 1) Clusters of homes generally near intersections or family farms, 2) sporadic areas where customers are almost randomly scattered along rural roads, and 3) sparse areas where there are a few customers over several miles. Fusion splicing offers several benefits over connectorization by reducing loss and by increasing the overall reliability of the network by eliminating components (connectors and jumpers) that can cause troubles during its life. Fusion splicing the splitter initially reduces installation time since the installer only places the drop and ONT, eliminating the visit to the splitter location. FTTH offers a facility that can serve the rural areas for many years into the future with minimal or no major alterations.

Why 1 mile between the 1st and 32nd customer?

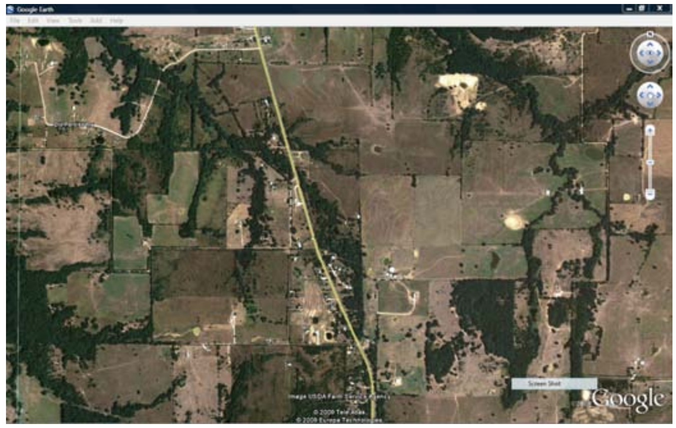
The focus will be on areas where the distance from the first of 32 customers is more than about 1 mile from the 32nd customer. Why 32 customers? FTTH PON standards are based on a split ratio of 1x32, which gives the best mix of cost between central office equipment and outside plant. One of the most expensive parts of the FTTH network is the Optical Line Terminal Card (OLT). This card terminated the fiber from the field that feeds the optical splitter and contains the laser and a receiver which converts the signal from optical to electrical and vice-versa. Some may want to try to reduce the split ratio from 1x32 to say 1x16 in order to increase the reach in rural areas. Although this will provide an extra roughly 3db or about 12 km of fiber distance, it comes at a very high cost since the number of OLT ports has to be doubled compared to a 1x32 split ratio. This can add about $200 to each home passed and could easily double overall cost. There are other ways to increase distance that offer a more economical option for rural areas.

Since the splitter has one input fiber and 32 subscriber side fibers, one should move the splitter as close to the home as possible to minimize the "32 fiber" length. Splitters can be placed in a splice case with fiber drops which eliminates the need to buy a separate housing for the splitter. Splitters are compact and in fact two splitters can be placed on a single splice tray if needed. Now we can address the 1 mile criteria. Shown below is the cost of a 1x32 splitter and cable compared to the cost of a 1x4 feeding 4-1x8 splitters and cable. Up to about 5,000 feet, the 1x32 splitter is more economical even though a larger cable size is needed to deploy the ports in an area. The cost of the cable does not offset the extra cost of using 1x4s and 1x8s since individual splitters cost more than a single 1x32. However, > 5000 feet the cable cost more than offsets the additional splitter cost and the 1x4 feeding 4-1x8's option now becomes more economical. The farther the customers are spread out, the more economical the 1x4 feeding 4-1x8's option becomes.



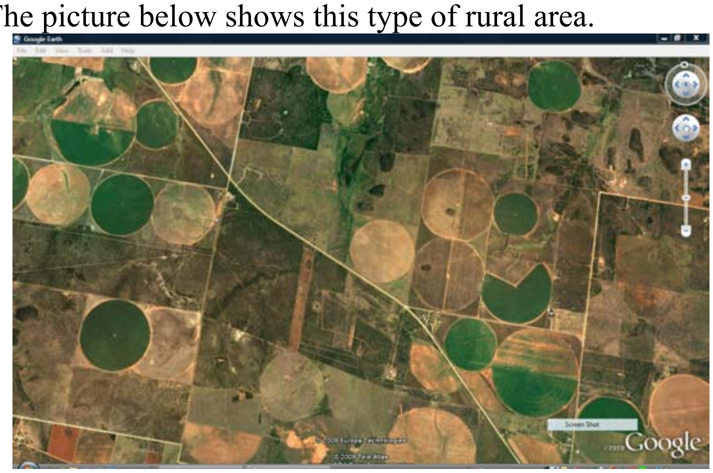
The Three Basic Types of Rural Areas in the Real World

Clusters: This may be around an intersection where a store exists, a farm with several generations living nearby, or a around a natural attraction like a lake or river near the road. Clusters are several living units grouped in close proximity, with some distance to another living unit or cluster. The picture below illustrates a cluster of homes toward the bottom of the picture in the middle.



Sporadic: This has homes along the route in a more random pattern on both sides of the road. May be one or two homes, vacant land, and then another home with one across the street. This type of pattern is prevalent across America. The picture below shows a typical sporadic area.

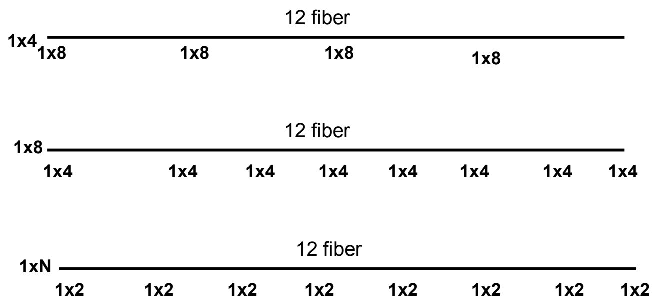
Sparse: In the Sparse area, very few homes exist and they are scattered over many miles of roads. This type of area will be the last to be served and the highest cost since the customers are few and scattered. The picture below shows this type of rural area.



In many cases, one can find all three types of these rural areas along a single road. Why is this important? We have stated previously that the most economical deployment of FTTH in rural areas is with Distributed splitting using the 1x4 feeding 4-1x8s scattered along the route. But there are alternatives to distributing the splitting that may be useful for these three types of rural areas. Options will now be examined to see if 1x4 feeding 4-1x8s is the best and only choice.

Splitter Options

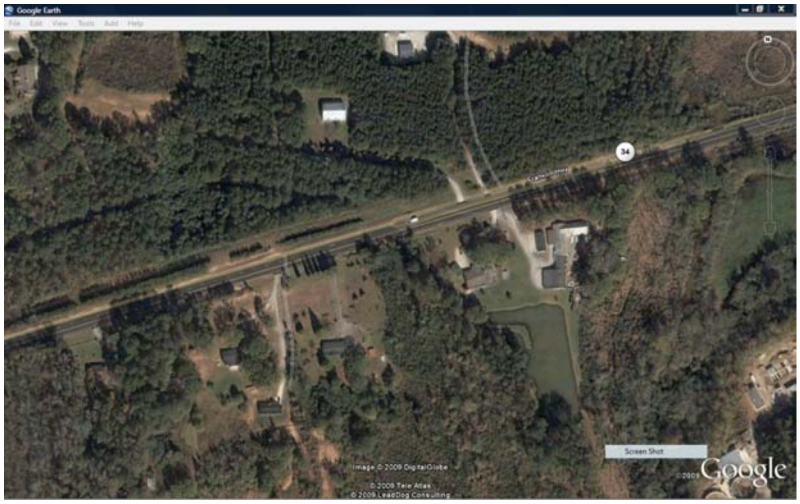
The chart below lists several different splitting techniques.



All of these choices are based on a 12 fiber cable for purposes of this study. This does not mean that we should deploy only a 12 fiber cable in size. We seek to maximize the number of subscribers supported by 12 fibers (a buffer tube), and make maximum use of the 12 fibers along the length of the cable. Not listed but studied is the use of a 1x3 splitter instead of 1x2's. The outcome was the same as the 1x2 that we will discuss later. In making this study, we need to understand the amount of optical loss that we can tolerate in a network. This is a function of the electronics on either end, specifically the transmitter and receiver. The typical loss budget given by most manufacturers is around 26db. We can break down this loss into the following:

Optical Splitter loss maximum:	18db
Fiber Cable loss for 20km:	5db
Connector/Splicing loss:	3db
Total =	26db

Given that most PON equipment accommodates a loss budget of 27–28 dB, this allows one to two dB of "maintenance margin" which is needed to cover end of life loss increase and/or additional splices for repairing cable cuts. There is a way to increase the power budget available for either longer reach with the cable or additional loss for the splitter. The three db for connectors and splicing can be minimized by fusion splicing as much as possible in the outside plant. This means fusion splicing the drop into the cable and fusion splicing the splitter into the network initially. Each connector has at least a 0.25db loss per connector. This is equivalent to 1 km of fiber cable in loss. So we can place a connector or extend the network another km. With the hardened connectors and , the loss for the connector is 0.35db and for the hardened terminal the loss is 0.5 db for a total of 0.85db or the equivalent of at least three km of cable. We should fusion splice this network and we have other models that suggest that labor rates below $75/hour warrant fusion splicing anyway. In addition there are inventory management issues with hardened connector drops given the long and varying drop lengths in rural areas.



Houses built in rural areas often are long and varying distances from the road and having connectorized drops in this environment is problematic for obvious reasons. So we can gain some dB's by eliminating connectors in the outside plant and fusion splice the drop and splitters. We also gain a more reliable network since connectors tend to cause troubles whereas a fusion splice done properly is essentially trouble proof. Another area to reduce loss is the splitter itself. There are a number of vendors selling splitters in the market today. Care must be taken to insure that the lowest loss splitter is used (typically 16.4db r less). You must also ensure that you use full-spectrum splitters that allow the passage of all available wavelengths in the G.652D fiber cable, from 1260 nm to 1625 nm. Some splitter manufacturers do not offer full spectrum splitters and we will need all the wavelengths for bandwidth growth in the future. However, for discussion purposes we will use 18db as the upper limit for splitter loss. This will become apparent later.

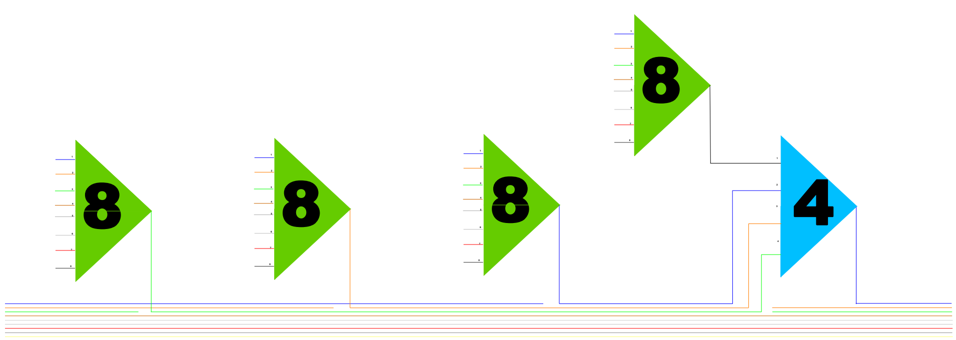
There are alternatives to a 1x4 feeding 4-1x8's. We can deploy a 1x8 feeding 8-1x4's. This may have application for lower-housing densities. However, nine splitters are required instead of 5 for the 1x4/1x8 potion. The cost of these splitters is higher by about 10 percent, adding three to five dollars per home passed. However, this additional cost may be justified if splitter utilization can be increase in a lower density area. The 1x4 feeding 4-1x8's would be the obvious choice for the cluster areas of rural areas. So we can keep the 1x8 feeding 8-1x4's as an option for now. Now let's examine the possibility of using 1x2's. There are several ways to do this. The 1x2's could be used in sequence but would allow serving 32 units consecutively exceeding the maximum PON loss budget. Each 1x2 splitter halves the power by three db. So the maximum number we could splice together would be about 6 splitters before we exceeded the 18db maximum. We could reduce the number of 1x2's in succession by deploying a 1x4 or 1x8 splitter then using 1x2's fed by this splitter. The chart below shows the 1x4 and 1x8 potion and the losses to support 32 units. It is obvious that these options create too much loss for them to be a viable candidate in rural applications. The options below show what is called "uneven" 1x2 splitters. These types of splitters distribute the light between the two ports unevenly. The concept is to drop off enough light for a customer then send the rest down the fiber to the next splitter. As can be seen from the chart, no combination of "uneven" split will meet the 18db loss budget for splitters and provide 32 splits.

1x4 feeding 1x2	total Main	Tap	1x8 feeding 1x2	total Main	Tap
35-65	22.6	25.6	35-65	17.3	20.3
30-70	20.5	24.5	30-70	16.4	20.4
25-75	17.7	22.9	25-75	15.2	20.4
20-80	15.6	21.6	20-80	14.3	20.3
15-85	13.5	21.7	15-85	13.4	21.6
90-10	6.2	21.9	90-10	12.5	23
95-5	4.45	23.9	95-5	11.75	26

So we can now focus on two types of splitter arrangements: 1x4 feeding 4-1x8's (the 1x4 scheme) and the 1x8 feeding 8-1x4's (the 1x8 scheme). Now we need to determine the arrangement of these splitters in the field so that we can maximize the use of the fibers that are available.

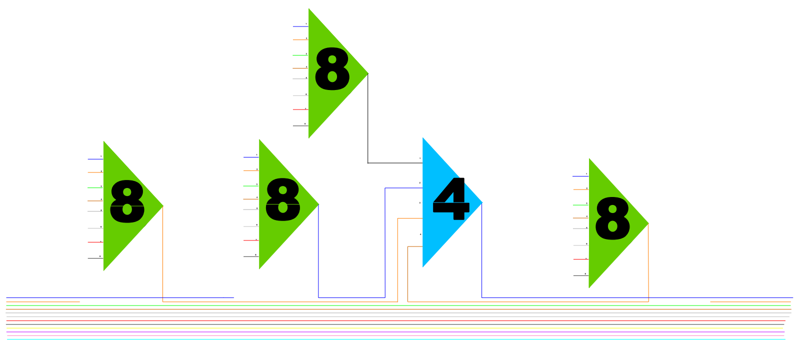
Cascaded Splitter Arrangement for Cost Efficient Rural FTTH

Our modeling of the FTTH network has yielded some interesting discoveries that are unique to this new technology. If planned properly, we can actually accommodate up to 352 living units on a single 12 fiber buffer tube. The key to this is the location of the splitters. In general, our cost models show the most economical place to put a central office, node, splitter cabinet, distributed splitter and even a drop closure, is in the middle of the area it is going to serve, to minimizes the total length of fiber from the splitter customers. Density also plays a factor as well and will tend to pull the ideal location towards a more dense area from the geographical middle. Let's apply this to the rural splitter location and start with the 1x4 option. Below we show a splicing diagram of the splitters in a 1x4 arrangement.



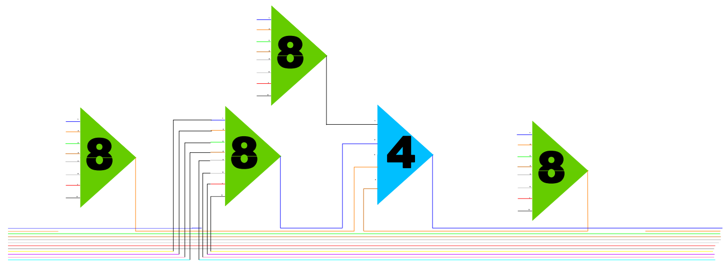
The CO is to the right and the 1x4 is fed by the blue fiber. Notice that once the blue fiber is cut and spliced into the splitter, it is dead ahead and can be reused. Therefore, the dead blue fiber is reactivated and used to splice one of the 1x8's which can be down the road a ways. Once it is cut at the 1x8, it can be reused again for distribution out of the 1x8 downstream. We now have a way to utilize dead facilities that we do not have with other technologies. This will help to maximize the investment we have in the rural areas and drive the cost down. If we do not use the 12 fibers for distribution (outputs of the 1x8's), then it is possible to serve up to 320 customers with a single 12 fiber buffer tube. Again, let me emphasize that we are not advocating placing only 12 fibers in rural areas. We are attempting to find ways to maximize the number of customers in a 12 fiber buffer tube. By doing this we will help create a more cost efficient network. In fact, this approach is true for any area- rural, urban or city.

However, there is a way to cover more the 320 customers with a 12 fiber cable. In the above example, if we move the 1x4 splitter to the second 1x8 splitter location, we can add another fiber for feeder. We do this by cutting a fiber in two at the 1x4 locations and using the two cut fibers to serve 1x8's. The diagram below shows how that can be accomplished.



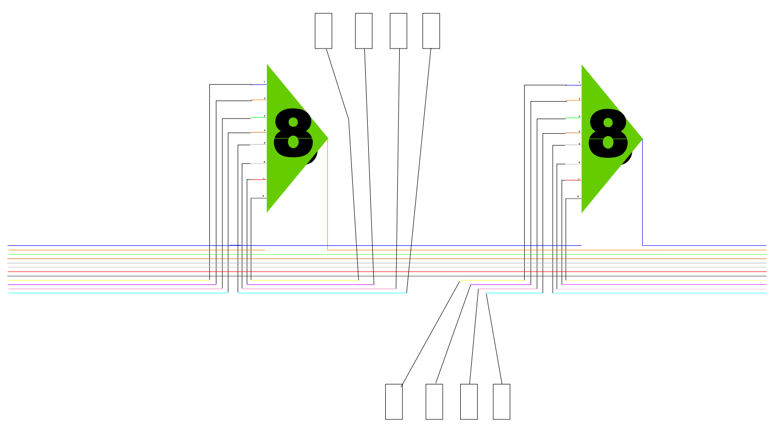
Notice we reused the blue fiber to serve a downstream 1x8 and cut the orange fiber in two and each side of the cut fiber now serves a 1x8 instead of using individual fibers. With this arrangement it is now possible to serve up to 352 customers if none of the 12 fibers is used for distribution unless they are dead fibers previously used for feeding a 1x4 from the CO. Now we have a really good method to deploy FTTH and this method also meets the 18db criteria mentioned earlier as the total loss limit we assigned to the splitters. We have also maximized the number of customers we can serve with 12 fibers and have a flexible way to deploy FTTH. Our studies indicate that we can approach the cost of using copper in rural areas making the FTTH technology a viable rural candidate.

However, the 1x4 option requires 1x8 deployments which may be suitable for cluster areas but will be a challenge for sporadic or sparse areas or clusters that have fewer than 8 customers. We will need to use some of the 12 fibers for distribution out of the 1x8's. Thus we will have to reduce the 352 ideal maximum in order to provide fibers for distribution. If we are smart about the 1x8 placement in the field, we can minimize this impact. As mentioned earlier, we need to place the 1x8 in the middle of the 8 customers it will serve. If the 8 customers are spread out in a sporadic or sparse manner, we can cut fibers at the 1x8 and feed the outputs to the customers via the cut fiber. The diagram below shows how this can be accomplished.

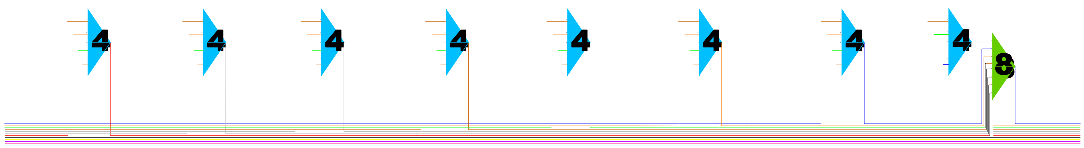


Notice that 4 fibers were cut at a 1x8 splitter and both sides of the cut fibers were used for distribution. This is the extreme case and would not be necessary since the splitter should be within reach of at least one customer who can be served with a drop directly out of the splitter. So we can reduce the number of cut fibers from 4 to 3 in most cases. This would give us the capacity to serve up to 288 customers with the 12 fibers and have capacity to deploy the distribution from the 1x8's along the route for the sporadic and sparse areas. We can also reuse these same fibers for distribution from the next 1x8 as well since they are dead now that they have been splice to a drop to serve a customer at a previous 1x8 splitter. Again, the unique feature of the splitter allows us to reuse dead fibers! Remember that we can also use the blue fiber for distribution downstream from the splitter as well since it is dead at this point. So the options are there for deployment in all three types of rural areas.

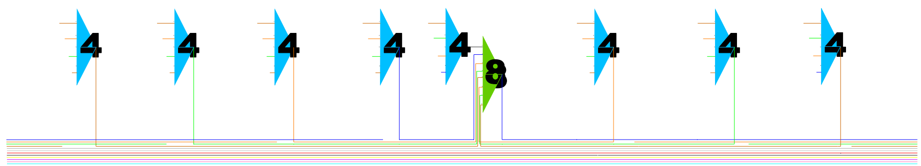
The diagram below shows the distribution deployment using fibers in the cable to illustrate the concept discussed above. The houses serves are on different sides of the street for illustrative purposes and can be randomly distributed between the two splitters.



We can do the same thing with the 1x8 splitter option that feeds 8-1x4's. However, we have a problem with this potion in that 8 outputs are needed from the primary splitter (1x8). This eats into the 12 fiber capacity and is shown below.



It is necessary to move the primary splitter (1x8) into the middle more and take advantage of cutting fibers and feeding the 1x4's this way like we did previously. The diagram below shows a more economical location for the 1x4.



This configuration will allow us to serve up to 288 customers with a single 12 fiber buffer tube. It does not allow for distribution fibers from the 1x4's which can be a problem in the rural areas. We will need to reduce the maximum in order to provide for distribution fibers in the buffer tube. However, we need only to cut 1 fiber at a 1x4 to provide distribution for 2 of the 4 1x4 output ports. As we move done the cable, dead fibers should be available if we need to distribute the third port of the splitter. The fourth port would serve a customer directly out of the splitter and would not need to be in the cable. This would drop the capacity from 288 to 256 customers, still a good amount but less than the 1x4 option discussed previously. However, since there only a difference of 32 customers and the geography may offer a way to increase the capacity, we will still keep the 1x8 option as viable. For example, we can serve two 1x4's directly out of the 1x8 in the same closure and save a fiber for an additional PON downstream. They can fit on a single splice tray easily. This would yield a 288 capacity and be equivalent to the 1x4 option. So we have a way to serve the three rural areas using either the 1x4 or 1x8 option or a combination of both. There is nothing wrong in mixing these two along a route if needed and this is possible with careful planning.

The following discussion addresses some of the questions from customers on the Cascaded Splitter design technique. This technique has been deployed by customers for several years now with success.

What about records?

Granted, the Cascaded Splitter technique does make record keeping more difficult but not impossible. In the USA, we have addresses through the 911 process. We can use this to assign a "name" to each splitter location. This is not without precedent especially in the Telephone companies in the USA. In the copper world, tandem crossboxes are often used. One crossbox feeds a second crossbox and have similarities to this splitter technique. In the rural area, it is paramount that accurate records are maintained since the facilities are scattered over a large area and we need to know where everything is located, especially to reduce the windshield time for the technicians. The perceived "complexity" can be greatly reduced by fusion splicing the splitters in place initially. This allows the installation technician to avoid having to deal with the splitter and he can go directly to the customer and begin placing the drop since the optical signal now passes through his drop closure. Installation time is greatly reduces since he does not have to visit the splitter. This is an advantage of this technique over having splitters in a cabinet or home run from the CO since a technician would have to visit the splitter to place a jumper. So for each splitter that is fusion spliced, 32 visits to the splitter can be saved on installation.

How should one size the cable in rural areas?

Rural areas have a random growth pattern that is not always discernable up front. It is difficult to determine the growth pattern in rural areas but this is not a unique problem with FTTH. This is true for copper or HFC. How many copper pairs do you need in a rural area? The problem is the same regardless of the technology being deployed. Where do you taper a copper cable in a rural area? There is no magic formula that I am aware of but we can study the area, understand how many customers are there today, project those numbers into the future and arrive at a reasonable cable size. FTTH technology does offer one tremendous advantage over other technologies. The optical splitter can be placed anywhere in the network and generate up to 32 individual port for up to 32 customers. So when a farm is converted into a trailer park with 30 trailers at the end of a long rural route, we can deploy a 1x32 splitter fed by one fiber and solve the problem. In the copper world, we would probably have to build a new cable from a long way away to serve the new trailers. The flexibility of the optical splitter placement enables us to be wrong on our growth forecast and still be able to recover nicely with a strategic splitter placement. We can now tune and massage the network in a way not possible before.

Is it harder to grow bandwidth with the splitters in the field versus a cabinet or CO?

No. Let's consider how bandwidth will be added in the future. We can look at the new 10G GPON standards that are being developed now. To gain more bandwidth, additional frequencies are being utilized. This is the trend that will continue in the future. We should insist on bandwidth growth by a change out of the electronics on both ends, not by reducing split ratios or the like. We need to be able to button up our outside plant, leave it alone and grow bandwidth with more frequencies. When we consider that each of the 16 available frequencies today have the capacity of 129 Terabits, why do we need to try to manipulate the outside network? We have the capability with this technology to build a network and leave it alone which will extend the life of the plant, reduce troubles significantly, increase revenue because of high reliability, reduce maintenance technicians, better utilize our investment by using dead fibers, and having a low loss network. So bandwidth growth will be via additional frequencies, not reducing the split ratio.

I have been told that I have to have a cabinet for testing.

Unfortunately, there is a lot of misinformation propagated by those wanting to sell cabinets. They do not offer economic reasons, so they revert to operational reasons that are not accurate. Most of the troubles encountered will be single customer troubles. Now consider the FTTH network: There are 32 customers working beyond the 1x32 splitter. If one customer calls in with a trouble, you can quickly determine the problem location by observing the other 31 customers signal. If they are working, you have a trouble that is probably unique to that customer such as a cut drop, power outage at the ONT, or ONT failure. The dispatch would be to the customer's location. If a test needs to be made, it can be performed from the house and there is no need to have a test point. The optical splitter is a highly reliable device that rarely fails if it is properly spliced in place and protected from the environment. A cabinet can add to the trouble potential since it contains connectors and jumpers. Connectors and jumpers are the week spot of a fiber network and can add to the maintenance of the network. Electronics vendors have excellent management system that monitors the health of every ONT in the network. That information can be used in a smart way to determine trouble resolution. Vendors of test equipment have excellent test gear on the market today that can test through a splitter if necessary.

Summary

There is an opportunity to utilize Broadband Stimulus funding to provide what many consider to be the “ultimate” broadband- FTTH. To utilize Stimulus funds to their fullest, we have developed a cost efficient rural FTTH design approach that allows this new technology to be deployed economically. The cost will be higher than an urban or city deployment since the customers are scattered in a rural area. Using the advantage of the optical splitter to its fullest capability can help to reduce these costs to a more reasonable level. The two Cascaded Splitter options discussed (1x4 feeding 4-1x8’s and 1x8 feeding 8-1x4’s) offer low loss, highest reliability, minimized installation time and flexibility that is needed in rural areas. I have designed rural areas for around $200 per home passed in material cost in a sporadic and a cluster area. Obviously a sparse area will cost more. Hopefully this information provides a new perspective on a design technique that has proven to be successful for many companies.

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