Reaching 10Gbits/s in the Mobile Backhaul

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
By

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Introduction

Driven to a large extent by dark fiber initiatives led by a major US wireless provider, fiber mobile backhaul deployments (also called wireless backhaul) are growing very fast. Indeed, the fast adoption of smart phones and mobile video-streaming generates so much bandwidth demand that unprecedented data rates are now being deployed in mobile backhaul, often at 10 Gbits/s. For cable operators with large access or fiber to the antenna (FTTA) networks, these dark fiber deployments are a great opportunity to generate revenues by leasing unused fibers to wireless providers.

Drawing from EXFO's close relationship with this major US wireless provider, this paper will expose why cable operators are uniquely positioned to benefit from the mobile backhaul bandwidth explosion. It will then discuss the typical topologies and challenges of these 10G wireless backhaul roll outs. While some of the common issues of 1G or 2.5G deployments certainly still apply at 10G, like fiber loss problems, new impairments emerge because of the higher data rates and longer distances covered by the mobile backhaul – impairments like chromatic dispersion and polarization mode dispersion (PMD). In addition, impairments like optical return loss (ORL) have tighter requirements at 10G than 2.5G. This paper will therefore examine the common impairments seen at 10G in wireless backhaul networks, as well as present the best testing practices to ensure trouble-free operation of these networks.

Mobile Backhaul and Fronthaul Distinction

It matters to first define what mobile backhaul refers to, and in particular how it's different from mobile fronthaul, another key part of FTTA networks.

Two important components of a mobile network are base stations, also referred to as baseband units (BBUs) or eNodeBs, and the remote radio head (RRH). BBUs perform signal-processing functions and create the digitized baseband radio signal, whereas remote radio head (RRH) converts the radio signal into an RF (or wireless) signal. In the traditional copper interconnection, the base station and RRH are kept together in a cabinet close to the cell site, with a copper/coax cable connecting the RRH to the antenna at the top of the tower. The coax interconnection has proven to be limited in providing high broadband capacity due to its high-power consumption. For this reason, the coax portion from the base station to the RRH is now frequently being replaced with fiber interconnections requiring lower power consumption. In the case of fiber connections, the RRH is located close to the antenna at the top of the cell site, and connected to the base station in the cabinet using protocols such as Common Public Radio Interface (CPRI) or open base station architecture initiative (OBSAI). The portion of the network between the base station and the metro network is referred to as the mobile backhaul network, and the portion of the network between the base station and the RRH in the cell site is called the fronthaul network, as shown in Figure 1.

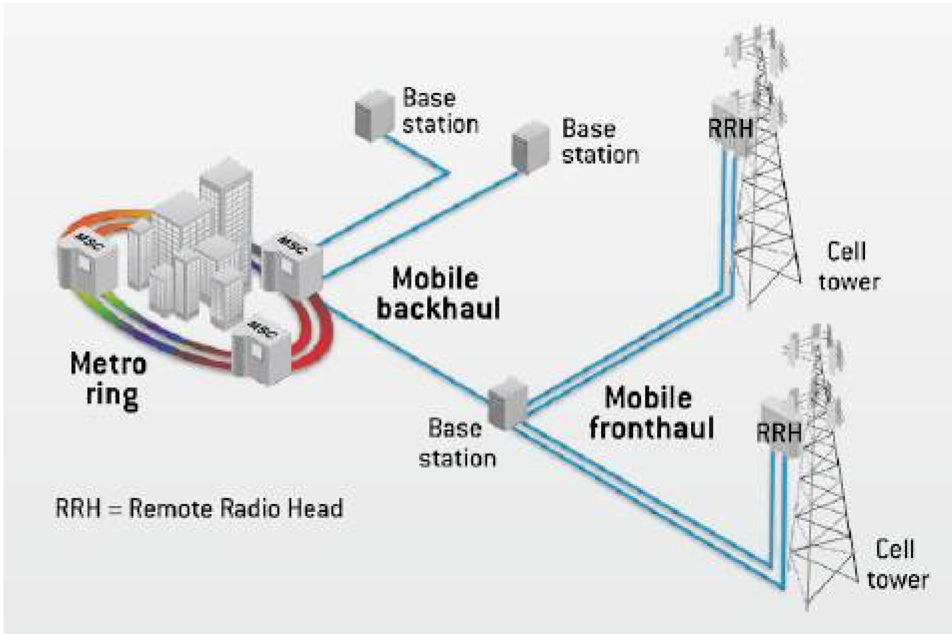

Figure 1 – Distinction between mobile backhaul and mobile fronthaul

Mobile network operators may own the mobile fronthaul or backhaul, but they usually prefer to lease fiber or purchase services from other suppliers that own access infrastructure. This trend has also opened the door to so-called dark fiber providers, who solely provide the "pipe" (the fiber) without any light or services on it, to lease their infrastructure to mobile network operators.

Relevance of the Wireless Backhaul Play for Cable Operators

The market of the mobile backhaul fiber leasing is currently dominated by dark fiber providers like Zayo, FiberLight, Allied Fiber, Wilcon, etc (http://www.fiercetelecom.com/special-reports/dark-fiber-creates-new-fortunes-ilecs-cable-and-clecs?confirmation=123). So far, according to informal feedback from wireless operators as well as official press releases, it seems few cable operators have provided dark fiber to wireless operators, apart from Wide Open West, who will add 1200 miles of fiber to connect 2000 towers in the Chicago area for an unnamed wireless provider, over the coming three years (http://www.chicagobusiness.com/article/20140819/BLOGS11/140819850/wide-open-west-plans-huge-fiber-buildout-to-meet-wireless-demand). While it is understandable that cable operators might prefer to offer full services to mobile operators, it seems the wireless operators preference for dark fibers leads them to do business, in general, with providers other than the cable operators, leaving MSOs with a small market share of the mobile backhaul business. If the cable operators were more willing to offer dark fiber, they could participate in the wireless network exponential growth, the fastest growing segment in the telecom space, much faster than any wireline segment.

Moreover, cable operators enjoy a number of unique advantages to meet the needs of the mobile backhaul market:

- Cable operators own extensive access networks, which are ideally suited to easily connect cellular towers in almost any location without major fiber investments
- Cable operators sometimes own unused fibers that could be used to generate new revenues

Mobile Backhaul Topologies

Several mobile backhaul topologies are available to connect the mobile switch center (MSC), which relays traffic to the metro network, to the base station, including point-to-point, ring and star (Figure 2).

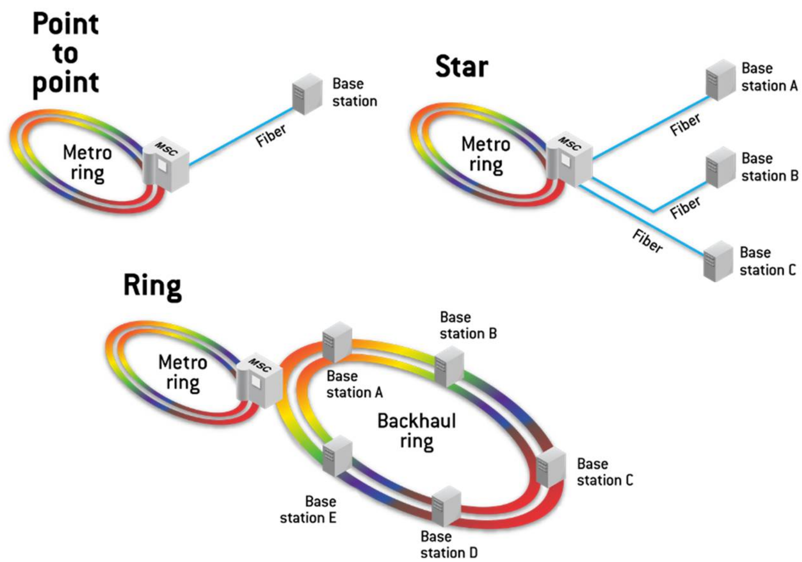

Figure 2 – Mobile backhaul topologies

EXFO has worked with a major US wireless service operator deploying 10G in many states, including California, Florida and the Mid-West, and by far the most common topology used is the ring architecture, because it offers redundancy in case of a fiber break.

Challenges to 10G mobile backhaul deployments

Several types of problems can impair the performance of 10G wireless backhaul networks, and some of these problems are not usually present at 1G or 2.5G. Historically, common issues in mobile backhaul involved dirty connectors, excessive loss due to bad splices, macrobends and fiber cuts. At 10G, new impairments should be considered, such as chromatic dispersion and polarization mode dispersion (PMD), as well as optical return loss (ORL). To avoid all of these problems in wireless backhaul networks, it is recommended to follow the best testing practices outlined in recommendation G. 650.3 from the International Telecommunication Union (ITU-T), "Test methods for installed single-mode optical fibre cable links". This family of tests is called "fiber characterization" and clause 5.1 lists the following tests:

- Connector end face inspection
- Link attenuation
- Splice loss, splice location, fibre uniformity and length of cable sections and links

Clause 5.2 of that same recommendation describes "measurements that may be carried out to satisfy service level agreements (for example, when a dark fiber contract is signed) or to verify attributes of older links that maybe be used at higher bit rates (**10 Gbit/s or above**)". For DWDM networks, that lists contains:

- PMD
- Chromatic dispersion (CD)
- Optical return loss

Let us have a quick look at each of these impairments. Connector end face inspection, usually carried out with an inspection probe, aims at ensuring that particles of dirt or scratches on the fiber end face are small enough so that they induce low connector loss. A good rule of thumb is that connector loss should be smaller than 0.2 dB. Modern inspection probes feature complete automation: autofocus on the end face, auto centering of the fiber, and auto analysis based on standards (IEC, etc). Link attenuation, splice loss, splice location, length of cable, etc, are all measurements performed with an Optical Time Domain Reflectometer (OTDR) and they enable service providers to ensure that the loss budget of a particular fiber is met. Modern OTDRs are multi-pulse and multi-wavelength, to facilitate identification of events close and far from the testing location, as well as identify macrobends.

Dispersion Testing at 10G

At 10G, three other impairments must also be tested: PMD, CD and ORL. PMD and CD are two types of the same impairment, dispersion, that both lead to pulse broadening, as shown in Figure 3.

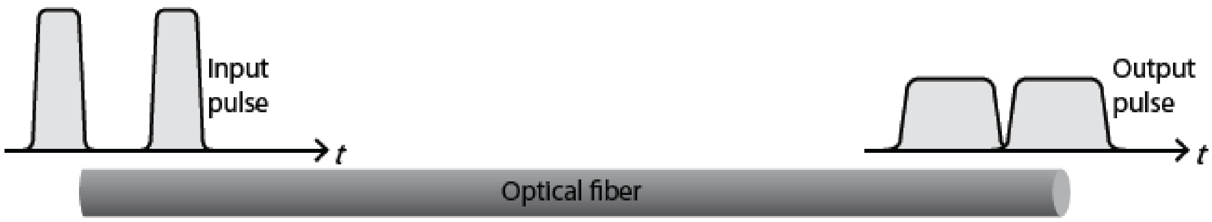

Figure 3 – Dispersion and pulse broadening

In extreme cases, pulse broadening can be so important that pulses start overlapping on top of each other in the time domain, generating inter-symbol interference or bit errors (Figure 4).

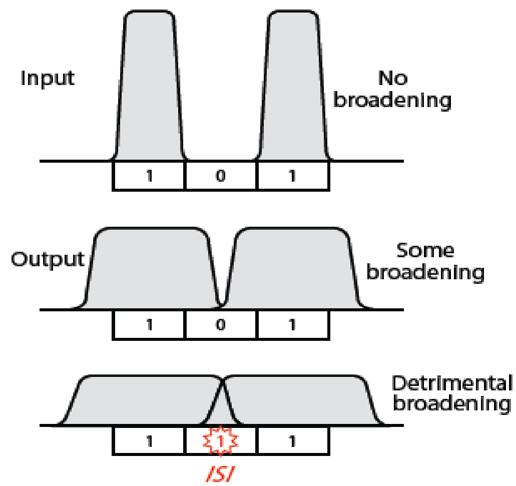

Figure 4 – Dispersion causing bit errors

Chromatic dispersion occurs because different wavelengths travel at different velocities inside the fiber. Therefore, the different wavelengths inside a single DWDM channel will propagate at different speeds, inducing pulse spreading. On the other hand, PMD occurs because different polarizations (orientation of the electrical field vector of the electromagnetic wave) travel at different velocities. PMD depends both on the fiber geometry (oval fiber cores induce PMD, for instance) and environmental considerations (mechanical stresses like fiber pulling or bending, wind, temperature changes, etc, all lead to PMD).

Dispersion issues have started to appear in the mobile backhaul for two main reasons: the increase in distances and faster data rates (10G). Table 1 shows the typical tolerances for CD and PMD as a function of data rate, i.e., the maximum values that a system can support without failures. At 1 Gbit/s or 2.5 Gbit/s, CD and PMD tolerances are very high, and dispersion is not usually an issue. At 10G, tolerances are a lot lower and dispersion should now be tested in mobile backhaul.

Table 1 – CD and PMD tolerances

Data Rate	CD tolerance	PMD tolerance[1]
2.5 Gbit/s	18 468 ps/nm	37.5 ps
10 Gbit/s	1193 ps/nm	9.3 ps

[1] Assuming an outage probability of 0.001%.

The second reason why dispersion can now become an issue in mobile backhaul networks is due to the increase in distances. Although some mobile backhaul deployments are short (less than 5 km), others can stretch up to 120 km, which becomes problematic considering that CD increases linearly with distance (e.g., doubling the distance doubles the CD), and PMD increases with the square root of the distance (e.g., multiplying the distance by four doubles the PMD). A good rule of thumb is to test dispersion in spans longer than 15 km or 20 km. To prevent CD/PMD-related failures, it therefore makes sense to test dispersion before commissioning long mobile backhaul networks or the metro rings feeding them.

Dispersion testers are available in two product families: dual-ended testers, which require a source at one end and a detector at the other, and single-ended testers, in which the source and detector are contained within a single instrument. Service providers usually prefer single-ended test sets, because they can be operated by a single technician, thereby providing operational expense savings over dual-ended solutions, which must be operated by two technicians (Figure 5).

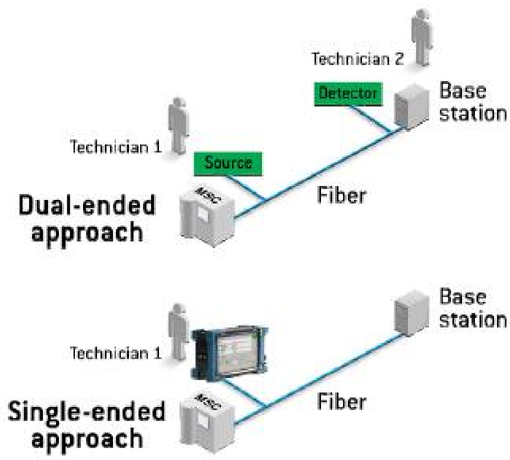

Figure 5 – Dual-ended vs single-ended dispersion testing approaches

Figure 6 shows the different topologies, in addition to the testing locations for each case when using a single-ended dispersion tester, with arrows indicating the testing direction. In point-to-point topology, two technicians are needed to test dispersion with a dual-ended solution, whereas a single technician can do the job with a single-ended approach. In a star topology, a single technician located at the MSC location can test all three fibers leading to base stations A, B and C when equipped with a single-ended dispersion tester. In contrast, technician 2 must successively travel to base stations A, B and C if a dual-ended solution is used. In a ring network, the single-ended approach again reduces traveling, because a single technician can go to three locations to test the whole ring, whereas with the dual-ended solution, both technicians 1 and 2 must travel to three different locations.

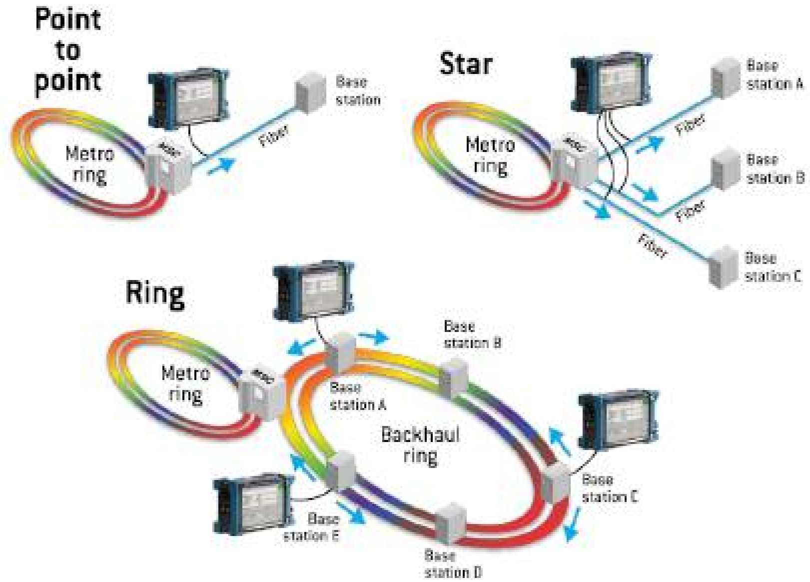

Figure 6 – Mobile backhaul topologies and testing locations with a single-ended dispersion tester

Optical Return Loss Testing at 10G

Optical return loss is a measurement of the total reflection of the entire link, which is the sum of the reflections of discrete events such as connectors or splices as well as distributed reflection from the fiber itself. ORL can pose a problem if it's too high because the reflected light goes back in the transmitter and might interfere with its output stability (Figure 7). Connectors, fiber cracks, splices, etc cause reflections because of a process called Fresnel reflections, which states that light is reflected off the boundary of two mediums with different indices of refraction. Another phenomenon called Rayleigh backscattering describes the reflections coming from the fiber itself, because of the impurities and the fiber glass.

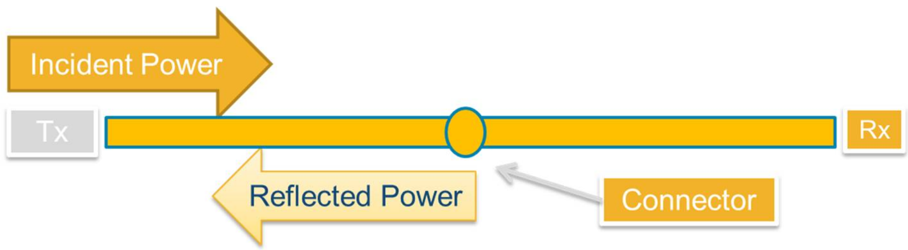

Figure 7 – Depiction of ORL

Several standards specify acceptable ORL values, but a common trend can be found among them: ORL thresholds are more stringent at 10G than at lower data rates. It therefore follows that ORL testing is recommended in 10G mobile backhaul roll outs.

Conclusion

This paper described the common topologies for fiber mobile backhaul networks: point to point, ring and star. Per EXFO's experience, the most common wireless backhaul architecture in the USA is the star topology. While below 10G the main potential issues were connector cleanliness, link and splice losses, at 10G, additional types of issues appear, like chromatic dispersion, PMD and optical return loss. Dispersion problems mainly stem from the combined effect of longer mobile backhaul (sometimes up to 120 km) and the tighter dispersion tolerances at 10G vs 2.5G. It was shown that single-ended dispersion testing is preferable for all types of topologies, vs dual-ended approaches. In conclusion, best practices for 10G mobile backhaul deployments are to perform the following tests on all fibers: connector inspection, OTDR, CD, PMD and ORL.

Abbreviations

BBU	baseband unit
CD	chromatic dispersion
DWDM	dense wavelength division multiplexing
ORL	optical return loss
OTDR	optical time domain reflectometer
PMD	polarization mode dispersion
RRH	remote radio head

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