INVITED PAPER

Combining CLOS and NLOS Microwave Backhaul to Help Solve the Rural Connectivity Challenge

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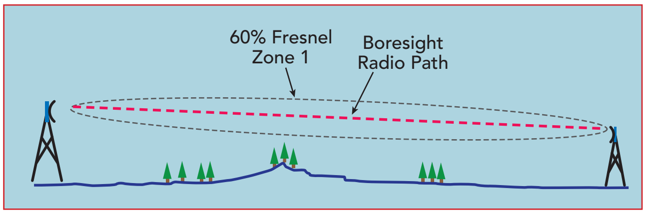
The hybrid combination of clear-line-of-sight (CLOS) and non-line-of-sight (NLOS) techniques can often be employed to create a practical and cost-effective networking solution for rural and deep-rural connectivity challenges.

The deployment of rural and deep-rural cellular networks faces many challenges, including the cost per covered population and low average revenue per user projections for many rural communities; this is especially acute in less developed countries. Globally, the population not covered by broadband networks is about 1 billion,[1] consisting largely of people in rural and deep-rural areas where network deployments suffer from business performance challenges.

A critical component of rural and deep-rural network buildouts is the cost of backhaul. Terrestrial microwaves relying on a CLOS link is often the technical design approach because of its ability to enable rapid and cost-effective buildout and deliver backhaul high capacities. Thus, a significant percentage of cell sites globally use terrestrial CLOS microwave backhaul. Although this is supported with data from GSMA,[2] the rural and deep-rural use of microwave backhaul in high capacity mobile networks (i.e., 3G, 4G, 4G+) is expected to be more prevalent than shown because the larger distances involved in this use case amplify the superior cost/distance performance.



▲ Fig. 1 CLOS backhaul radio link, not showing effects of the Earth's curvature.

Despite its utility in providing backhaul functionality, the additional cost of microwave towers for repeater sites is undesirable. In some instances, this is due to the conventional design requirement to deploy microwave backhaul networks using only CLOS paths. For example, terrain and foliage can require tower heights to be increased, towers to be located in undesirable locations or repeaters added at intermediate sites. All have the undesired effect of driving up deployment costs. In many global rural and deep-rural deployment scenarios, the target population and economic circumstances can place upward pressure on deployment costs.

In cases where terrain is a problem for CLOS microwave backhaul links, complementary, additive use of diffracted NLOS radio links may be employed. The combination of these techniques (CLOS + NLOS backhaul) may yield a cost-optimized network design.

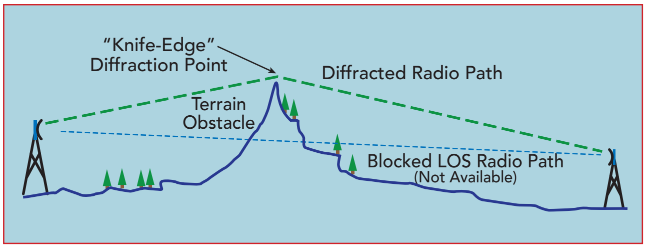


Fig. 2 NLOS backhaul radio link, not showing effects of the Earth's curvature.

WHAT IS CLOS VS. NLOS?

As shown in ***Figure 1***, CLOS refers to a radio link path that has no obstructions within 60 percent of the first Fresnel zone.[3] When there are obstructions within this zone—terrain, foliage, built structures—a link budget penalty must be included in the radio link budget. As the obstructions increase, losses also increase. When there is little obstruction in the first Fresnel zone, the incremental losses can be small; as the first Fresnel zone becomes completely obstructed, incremental losses become much larger. At the point where the first Fresnel zone becomes completely obstructed, radio propagation between the link's end sites transitions from a Fresnel blockage condition to a diffracted link condition (see ***Figure 2***).

When designing terrestrial wireless backhaul networks, CLOS radio links are preferred when feasible; however, a CLOS requirement can demand the need for high towers, towers in difficult-to-access locations and repeater sites. CLOS radio link design is generally more challenging the rougher the deployment terrain. A NLOS diffracted radio link systematically scatters the radio signal across the top of the blocking terrain features, creating a "bent" link. The use of diffraction, however, increases path losses, which must be accommodated in the link budget. NLOS links tend to be shorter range because of the incremental path losses associated

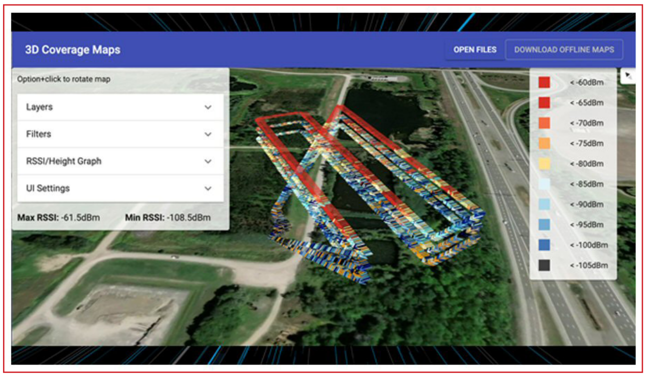


Fig. 3 3D signal survey for pre-build NLOS tower design, measured with a drone.

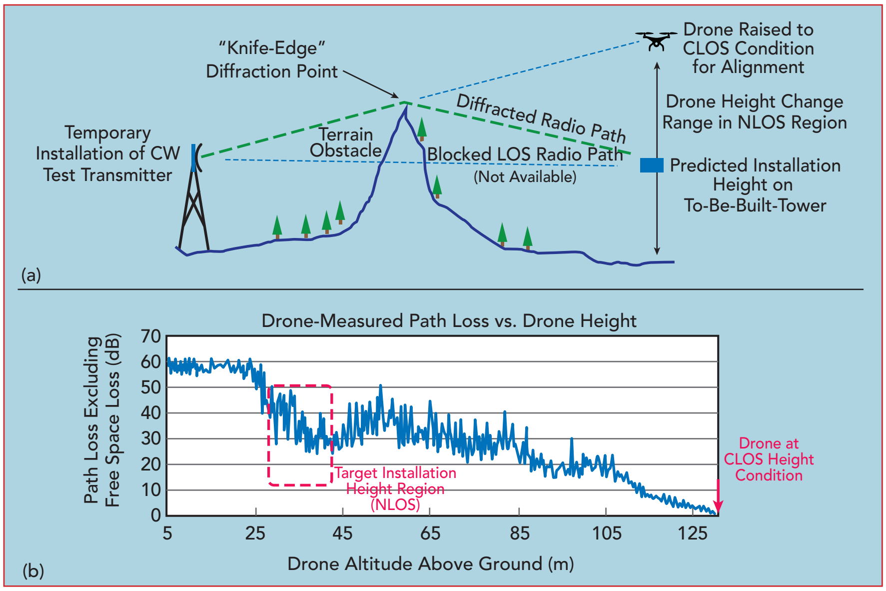


Fig. 4 Using a drone for pre-build field verifications of NLOS links (a) and example path loss measurement (b).

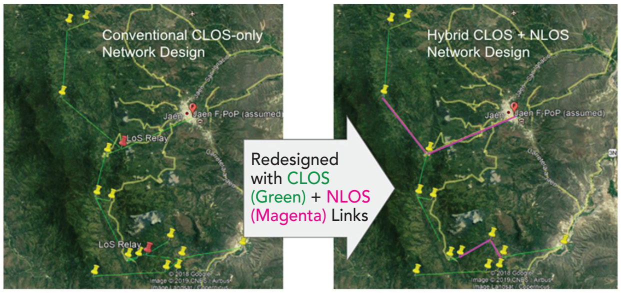
with diffracting obstacles. They do, however, enable using shorter end-site towers and expanding placement options for radio tower infrastructure. NLOS radio link design is generally more useful the rougher the deployment terrain.

CHALLENGES USING NLOS LINKS

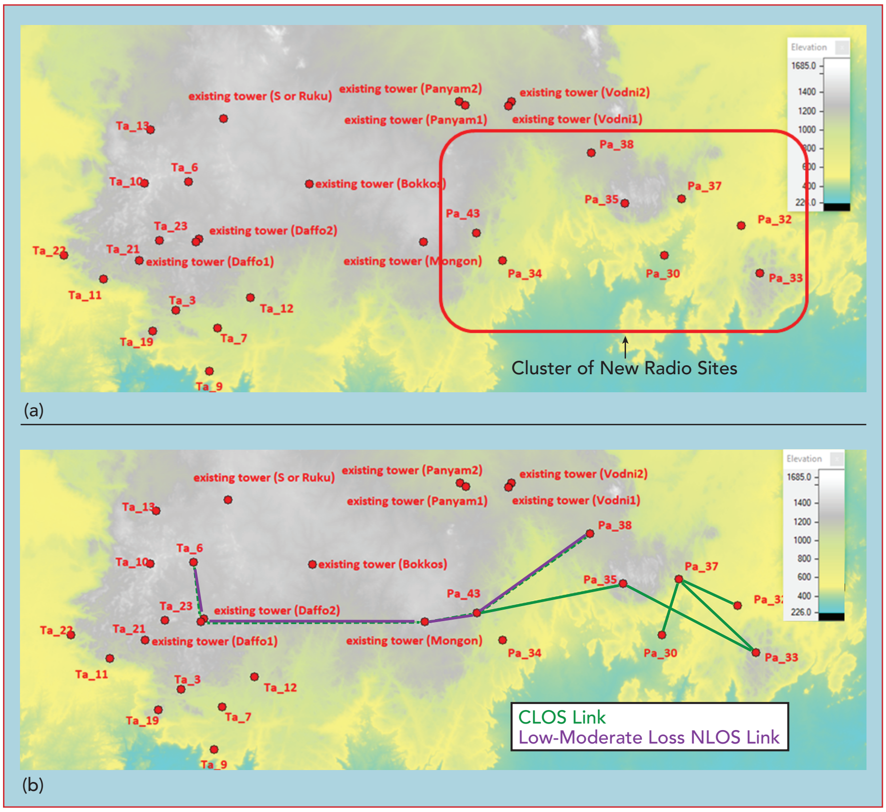
Historically, diffracted NLOS radio links have received little modeling or validation attention since the hallmark work by Longley and Rice.[4] Although much of this found its way into the International Telecommunications Union (ITU) standards[5,6] and into available predictive software tools,[7,8] NLOS links are largely in the category of "put it in and see what happens," rather than a fundamental backhaul design methodology.

A key concern of the wireless network design community is the prediction of radio link availability and performance. In the case of CLOS, the ITU has created, evolved and maintained standards[9] that have been broadly adopted by the microwave engineering community. After many decades being applied in millions of deployments, the standards have earned recognition as being reasonably representative of real-life conditions. In the case of NLOS, there is still research to be done to better quantize the margining processes needed for NLOS links to achieve specific in-field availability performance levels.

A traditional CLOS radio link deployment is usually accompanied by a field inspection or technical site



▲ Fig. 5 Optimizing a backhaul network combining CLOS and NLOS radio links.



▲ Fig. 6 A rural/deep-rural area with a cluster of new radio sites (a); most can be connected to the existing network using a combination of CLOS and low-to-moderate loss NLOS links.

survey, which confirms visual line-of-sight (LOS) between the link ends. Binoculars, balloons or mirrors can be used to verify the LOS and clearances. For NLOS radio links, inspection becomes more challenging. The specific height and geometry of the blocking obstacles and/or the height of ground cover (trees) may play a role in the overall link path loss. Using a drone can address the NLOS risks by enabling an in-situ signal measurement at relevant heights.

Alignment can also be challenging because the backhaul antennas typically must be pointed toward the crest of the obstructing obstacle or hill as a starting point for alignment. The iterative process of fine tuning the NLOS link alignment to achieve target receive-signal-levels requires techniques that, although similar to CLOS, are different.

To address these challenges, Facebook has found significant benefits constraining the application of NLOS techniques to cases with

- A single obstructing obstacle blocks the link
- Foliage cover and height on or near the obstructing obstacle or hill can be assessed
- The overall diffraction angle is less than approximately 3 degrees
- Overall predicted additive losses associated with diffraction are less than 25 to 30 dB.

In cases where NLOS conditions are more severe, Facebook uses low-cost drone technology, developed with Plexus Controls in Ottawa, to measure the path loss as part of pre-build field survey and path confirmation (see ***Figure 3***). ***Figure 4*** illustrates how signal level measurements using drones can map path losses throughout a 3D volume to determine the optimum location for a tower and its height.

NETWORK DESIGN COMBINING CLOS AND NLOS

The combination of CLOS and NLOS to optimize microwave backhaul networks has been previously reported,[10] illustrating the utility of this combination of techniques in creating improved rural and deep-rural connectivity and simultaneously reducing costs (see ***Figure 5***). In other cases, reaching a remote cluster of settlements can be impeded by challenging terrain between a developed part of the network and a target coverage area where new radio access network deployments are required. The example illustrated in ***Figure 6*** shows a targeted area for delivering coverage to a cluster of dispersed rural/deep-rural settlements. CLOS backhaul radio links within the cluster may be feasible, but the cluster itself cannot be reached easily or cost-effectively using terrestrial CLOS backhaul links.

In larger scale deployments, Facebook has partnered with Internet para Todos (IpT) in Peru to deploy 4G networks in large segments of the unserved and underserved population in rural and deep-rural Peru. In one phase of network buildout, the hybrid combination of CLOS and NLOS has achieved a significant improvement in the network's coverage. When this article was written, IpT had incorporated diffractive NLOS microwave backhaul links in its network by deploying 28 diffractive NLOS links in the production network. These links provide both backbone and endpoint connectivity. The hybrid use of NLOS and CLOS wireless backhaul in the network redesign yields a substantial increase in the network's coverage and cost performance. Further, the hybrid network enables IpT network designers to efficiently expand the terrestrial network without modifying the infrastructure, which would be necessary if only CLOS links were used.

In many target settlements, terrain and foliage obstacles make CLOS links unfeasible. Without NLOS, this means those settlements would be served with satellite backhaul. With NLOS, IpT has been able to provide wireless broadband coverage via NLOS microwave backhaul, an option available to other service providers.

SUMMARY

Solving rural and deep-rural connectivity challenges in a cost-effective manner requires the application of various technologies and techniques. High capacity mobile radio networks can be backhauled using terrestrial microwave systems; however, using only CLOS links can be impractical. The hybrid combination of CLOS and NLOS techniques can often be employed to create a practical, lower-cost networking solution.■

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