WHITE PAPER

Wireless Backhaul Topologies: Analyzing Backhaul Topology Strategies

Ron Nadiv, VP Technology & System Engineering
Tzvika Naveh, Director of Network Solutions

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Introduction

The demand for new high-speed mobile data services has caused network planners to re-evaluate backhaul capacity requirements and TDM-to-packet migration plans. The planning process must take complex network topology considerations into account.

In this paper, we focus on microwave-based backhauling topologies. Selecting the right topology for wireless backhaul networks is an especially complicated task. Here, we take a close look at the pros and cons of tree and ring topologies, with special attention to cost considerations. We provide a case study based on the mobile backhauling requirements of a large Latin American mobile provider, and explain how the Ceragon FibeAir® IP-10 microwave backhauling platform provides an ideal solution, offering excellent adaptability to a variety of topological models.

Backhaul Topologies

There are many parameters to be considered when selecting a network topology, and even more when it comes to radio networks – where Line-Of-Sight (LOS), rain zone and other propagation factors are taken into account, as well as infrastructural considerations such as antenna sites and towers. The common topology choices for radio networks are trees or rings, or a combination of both. The tree topology in itself is a combination of two other basic topologies – the chain and the star, as shown below in Figure 1.

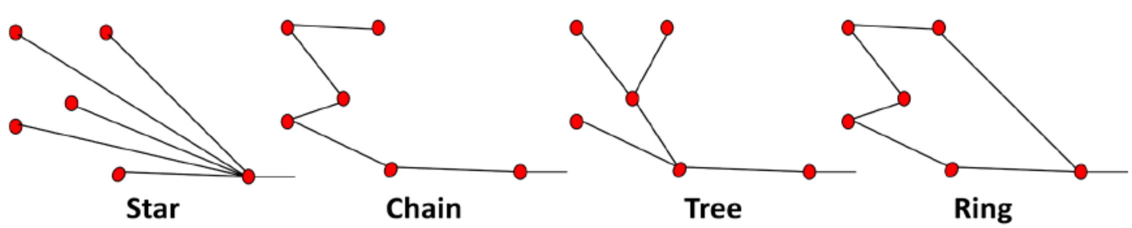


Figure 1: Common Backhaul Network Topologies

Star topologies use a separate link from a hub to each site. This is very simple, but inefficient for microwave systems, as it requires longer radio links and an LOS for each link (which may be impossible). The star topology also makes for very poor frequency reuse, since all the links originate at the same point, and interference is more likely to occur between links using the same frequency.

In chain topologies, all sites reside on a single path – solving the problems inherent to star topologies, but resulting in a very sensitive topology in which the first link malfunction can cause a complete network failure. Therefore, most of the links should be protected.

Combining the chain and the star yields a tree topology, in which fewer links can cause major network failures, and only those links require protection schemes. Alternatively, closing the chain yields the ring, which is the most efficient topology in terms of protection.

Focusing on the ring and the tree, we will discuss the advantages and disadvantages of each topology type in the following test case.

TEST CASE

Our test case describes a typical radio cluster with one fiber site and 10 cell sites requiring 50Mbps each and aggregated to a total of 400Mbps. Also, it assumes that every link that supports more than one site needs to be protected. Several aggregation topologies are suggested - tree, single ring, and a hybrid "tree of rings", consisting of two smaller rings. The tree uses protected links wherever a link failure affects more than a single site.

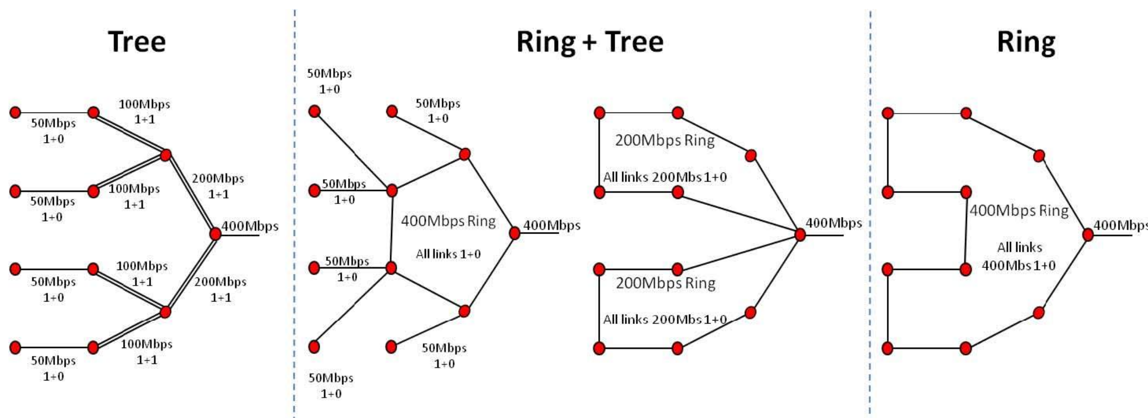


Figure 2: Examples of Aggregation Topologies

Tree	Tree + Ring		Ring
16 terminal pairs • 4x 50 Mbps • 8x 100 Mbps • 4x 200 Mbps	**11 terminal pairs** • 6x 50 Mbps • 5x 400 Mbps	**12 terminal pairs** • 12x 200 Mbps	**11 terminal pairs** • 11 x 400Mbps
20 antennas	**22 antennas**	**24 antennas**	**22 antennas**
Maximum 3 radio hops	**Maximum 5 radio hops during failure**	**Maximum 5 radio hops during failure**	**Maximum 10 radio hops during failure**

Table 1: Test Case Physical Inventory

CAPEX

Comparing the networks' fixed assets costs (CAPEX), we can see that the ring requires fewer microwave links. On the other hand, rings require higher-capacity links, usually at a higher cost and consuming more spectrum. The ring also requires some additional antennas, therefore the cost comparison is not straight forward, and can vary depending on the particular case. Another factor influencing cost is spectrum reuse. Since rings have no more than two links at every node, better frequency reuse is usually achieved and rings are often implemented using only a single pair of frequency channels.

Resiliency

A clear cut advantage of ring topology is its superior resiliency. The protected tree is indeed protected against equipment failures, but does not provide any path redundancy. Thus it is more vulnerable to heavy fade conditions, as well as to complete site failure (due to an electricity outage, or weather-related disturbances).

Consider the storm scenario shown in Figure 3. In the test case, this site is subject to complete failure (due to heavy rain or power failure), causing failure in four other sites in the tree, but no other sites in the ring.

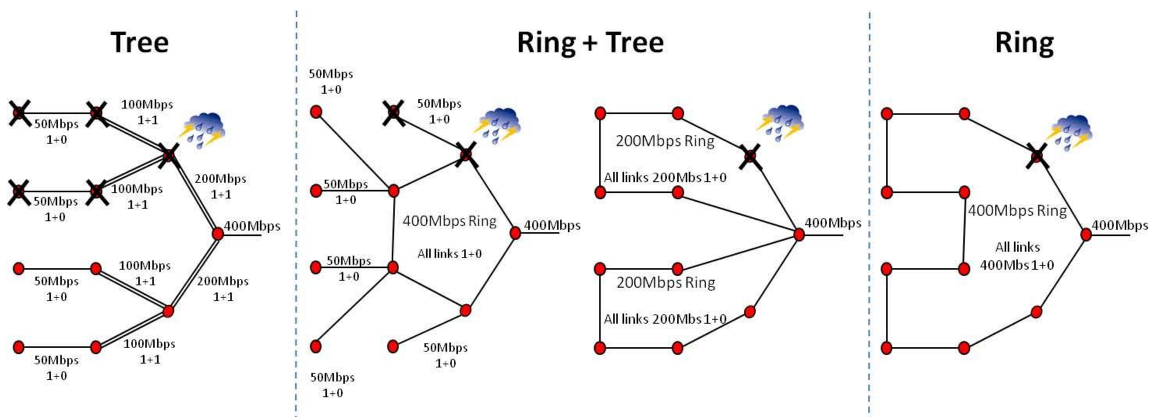


Figure 3: Protection Schemes in a Storm Scenario

Availability

The ring also provides superior availability, due to the ring's inherent path diversity. In a ring topology, service failures occur only when both paths fail. Thus, in order to achieve the same end-to-end target availability within a tree and a ring, the ring links can be designed for lower availability than the tree links. Operators can therefore reduce expenses by deploying smaller antennas, and by reducing power at the ring link sites.

The following diagram illustrates these availability considerations. If we assume uncorrelated failure events (caused, say, by rain fade) for each link, and that each link is designed for 4x9s availability, then we can see in the following example that a ring yields much better availability. In fact, the service availability in the ring is better than 6x9s, as a service failure requires both paths to fail, the probability of which is (1-0.9997)*(1-0.9992). While in real life we cannot always assume such non-correlation, it nevertheless illustrates the big difference in robustness between ring and tree topologies.

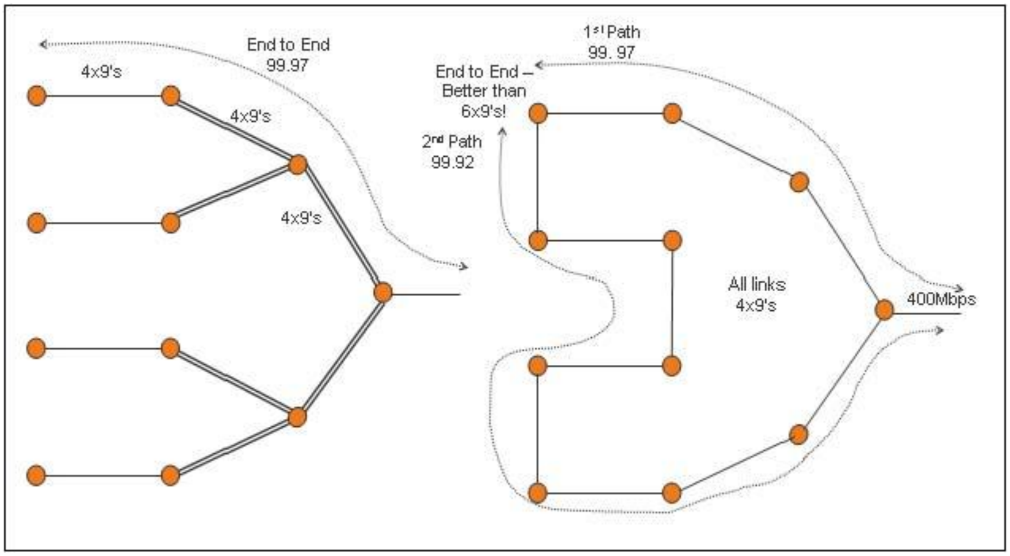


Figure 4: Tree and Ring Availability Scenarios

Latency

A disadvantage of the ring topology is that it takes more radio hops to reach distant sites. If designed properly, the shortest path can be selected for each traffic flow, but in case of a protection switch due to a cut in the ring, traffic can flow over N-1 hops in an N-node ring. The number of hops can be an issue when considering latency and delay variation, adversely affecting the delivery of synchronization signals. Still, when considering the smaller number of hops in the tree, one should remember that some of the tree's links offer lower bandwidth than those in the ring, with negative implications for delay variation, so this drawback is subject to debate. As an alternative, the maximum number of hops can be limited using a ring-tree combination, employing several smaller rings, as shown above.

Capacity & Scalability

Statistical multiplexing is more effective and easier to implement in a ring topology, as the total capacity of the links in a ring is generally greater than that of the links in the branches of a tree.

When increasing capacity, however, rings are more expensive to upgrade, as each link requires an identical upgrade. This is in contrast to tree topology, in which only the tree trunk need be upgraded when adding another branch.

One way to increase ring capacity without requiring an upgrade of every link, is to evolve it into a mesh by adding crossing links, and breaking the ring into smaller rings. However, this introduces additional operating expenditures, due to the complexity of managing the additional connections and protection schemes.

Test Case Conclusion

To conclude, there is no single "correct" topology. Network planners should consider the relevant environmental and business conditions (such as available spectrum, and radio and antenna costs), reliability requirements, and application characteristics, in order to determine the best solution for their needs.

	Tree Topology			Ring Topology		
CAPEX		✓	✓	✓	✓	✓
Resiliency		✓		✓	✓	✓
Availability		✓	✓	✓	✓	✓
Latency	✓	✓	✓		✓	✓
Scalability	✓	✓	✓		✓	
Capacity		✓	✓	✓	✓	✓

Table 2: Test Case Summary

A REAL-LIFE CASE STUDY

A major Latin American mobile operator is now in the process of migrating its network from TDM to IP – introducing new 3G (UMTS) base stations with Ethernet ports, and expanding its MPLS network from the core to the aggregation network for packet-based backhaul. The operator's backhaul strategy is to aggregate all the cellular traffic in the access network, using hybrid TDM/Ethernet wireless microwave up to the aggregation/hub site. From the aggregation site, all the traffic is carried over a fiber optic infrastructure. Each aggregation site contains both SDH cross-connect facilities for TDMA, 2G and 3G voice services, and an MPLS router for the 3G HSPA Data offload, carried over a Layer-3 VPN.

While planning the network migration, the operator cited three major backhaul requirements and planning constraints:

- Higher bandwidth. Each cell site requires 45 Mbps of bandwidth for Ethernet traffic, with an additional 2-6 E1s for legacy TDM flows. For the Ethernet traffic, statistical multiplexing is employed in accordance with a selected oversubscription factor and the number of input branches.
- High network availability. In order to maintain maximum availability, the operator requires all wireless links to be fully 1+1 protected, including tail sites – for reasons such as limited accessibility to many sites, high rain-rates, and the cookie-cutter approach to site deployment of many operators.
- Scarce frequency resources. Over-the-air spectrum is a limited resource subject to regulatory allocation and fees.

In this study, two alternative topologies for providing wireless backhaul for the access network are proposed, both of them capable of supporting hybrid TDM and Ethernet services:

- 1+1 tree topology
- Ring topology with a local optimization scheme

Table 3 below provides a line-by-line comparison of the adaptability of tree and ring topologies to the requirements of mobile operators. Ceragon is able to support both topologies – without the need for external networking equipment such as TDM cross-connect (ADM/MSPP) Ethernet switches or IP routers.

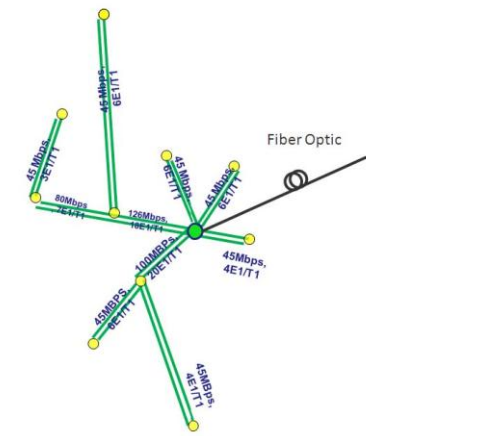
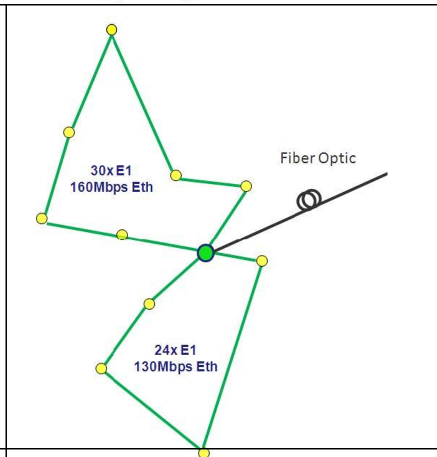
	Tree Topology	Ring Topology
	2G/3G – Cellular site Aggregation-Node 1+1 Microwave Hybrid Link 1+0 Microwave Hybrid Link	X Mbps 3G Data X E1/T1 Voice 2G/3G Fiber optic
Topology		
# of Wireless Links	**20** (1+1 protected links are counted as 2 links)	**12**
# of Antennas	**20**	**24**
Remote Site Availability Calculation (percent of uptime)	**99.97%** • Immunity from equipment failure • During site failure in a Hub-site the whole branch is affected Note: 5x9s target availability requires larger antennas => additional cost!	**99.9999%** • Immunity from site failure (e.g. power supply), equipment failure and heavy fade conditions (e.g. bad weather conditions) Note: 5x9s target availability can be reached using smaller antennas => cost reduction
Resiliency Scheme	Equipment Protection	Ring Protection and Path Diversity
Frequency Reuse	**Medium Reuse 3 frequencies required** • Several links all originated at the same Hub/Aggregation site	**High Reuse 2 frequencies required** • These rings are implemented by two frequency pairs, not more than two links at each site • Line-of-sight was available between all adjacent sites
Required Channel Bandwidth	**Medium** • 7x 7MHz @ 128QAM • 3x 28MHz @ 128QAM	**High** • 12x 28MHz @ 128QAM
Power consumption and occupied footprint	**---** Each Hub/Chain site contains between 4-6 radio units	**33% less than Tree topology** Each site contains two radio units (East/West)
Total Cost of Ownership (CAPEX & OPEX)	**---**	**• CAPEX – 19% Less** **• OPEX – 38% Less**

Table 3: Case Study Comparison

From the case study comparison in Table 3, we can see that by maintaining a comprehensive, *network-wide* perspective, (rather than a link-by-link approach), and by adoption of a ring-based topology, mobile operators can reduce their Total Cost of Ownership (TCO), while adhering to backhaul capacity requirements and planning constraints. The example above does not require a complete renovation of the backhaul network in order to build a ring. In fact, it can be implemented as a local optimization either at the access backhaul or at the aggregation backhaul to achieve better TCO.

Unlike the theoretical test-case presented in section 3, the real-life customer demanded that all the links in the network be 1+1 protected. This added to the total number of links required in the network, and made the ring topology even more attractive. Using a Ring, the number of links is significantly reduced – from 20 links to **only 12** (assuming 1+1 is counted as two links).

The real-life scenario offers CAPEX reduction of 19% and OPEX reduction of 38%. CAPEX includes microwave radio equipment and antennas, while the OPEX includes maintenance costs, power consumption, and frequency license fees.

The bandwidth capacity and high availability requirements, as well as the scarce frequency resource constraints, are all complied with by manipulating traffic flows over the ring, using ring-inherent diverse routes as illustrated in Figure 5 below.

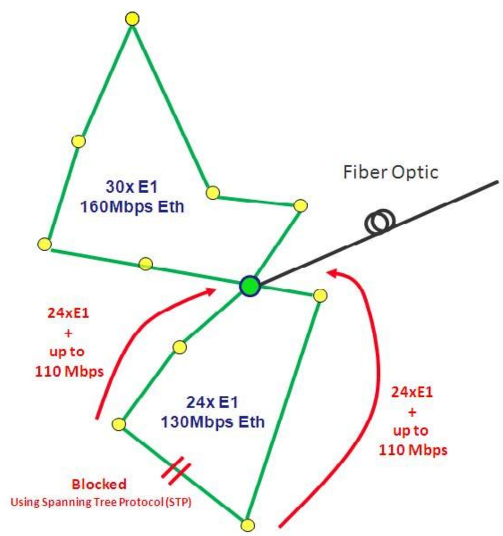


Figure 5: Doubling Ring Capacity using Spanning Tree Protocol

Resiliency Design

The concept in the Ring topology is one of ***Differentiated Services*** – or providing different levels of availability to different services. Please see Figure 6 – here we show how you can guarantee high availability to real-time, revenue-generating services such as voice, while providing lower priority to best-effort, high-volume data applications, like web browsing or youtube etc.

Mobile operators can reallocate redundant protection bandwidth over the ring for other uses, such as low-priority, high-volume data transfers. During this reallocation, real-time services are not compromised.

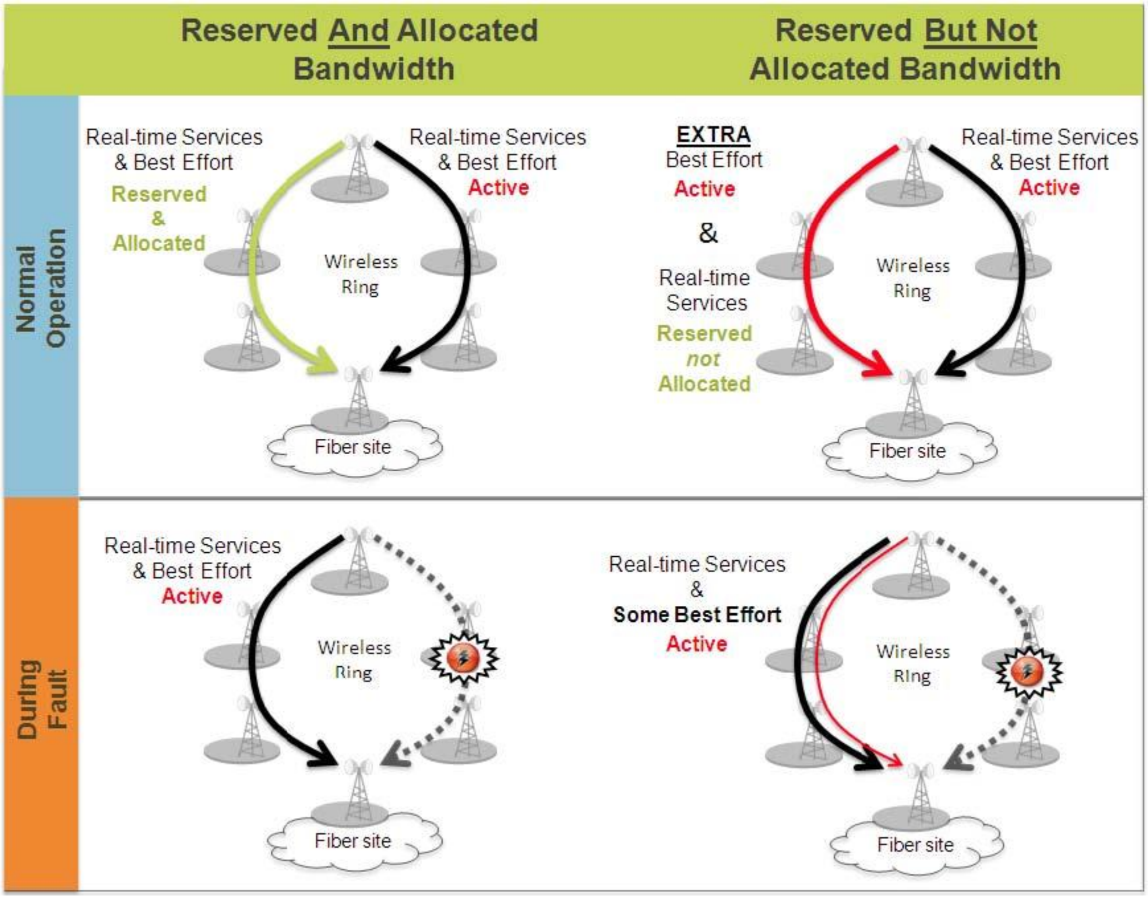


Figure 6: Service Resiliency - Reserved & Alocated versus Reserved but not Alocated

Ceragon demonstrates how a similar approach for differential services is adapted to mixed Ethernet and TDM traffic modes, otherwise known as Native2 or hybrid. Real time traffic such as native TDM (E1/DS1) is most often protected using the SNCP 1+1 method. This reserves and allocates capacity for both the primary and alternate paths, leaving very little for emerging Ethernet data traffic in new 3G deployments. Ceragon's protected-ABR (Adaptive Bandwidth Recovery) is based on SNCP 1:1. This enables TDM traffic to be protected by reserving bandwidth on the alternate path, but only allocating the capacity in case of a failure state on the primary path. This extra bandwidth is made available at normal state for data applications and in effect almost doubles the capacity of the entire ring.

Summary

The rapid growth in demand for bandwidth-hungry mobile data services requires operators to rethink the backhaul networks that support those services. Traditionally, microwave backhaul networks have been based on tree topologies. However, as they rethink their backhaul networks, operators are finding that they can enhance quality and minimize costs by introducing ring configurations.

The shift to Ethernet transport technologies has changed the economics of the microwave ring architecture. Unlike with traditional TDM-based SONET/SDH rings, network operators can optimize network resources by using statistical multiplexing and differentiated classes of service. This approach allows all of the cell sites on the ring to share the ring's bandwidth, prioritizing time-sensitive traffic such as voice, and supporting bursts of lower priority traffic from individual sites when sufficient bandwidth is available.

As the full efficiencies of Ethernet-based mobile backhaul are realized, ring architectures become less costly than tree topologies, while providing higher levels of reliability. The case study presented in this document does not necessarily require a complete renovation of the backhaul network, but rather is implemented as a local optimization either at the access or aggregation backhaul level in order to achieve better TCO.

The purpose of this document was to provide general, high-level design concepts for planning microwave backhaul networks, without taking into account operator-specific network planning constraints. Ceragon wishes to play an active role in the design and implementation of backhaul networks, and therefore offers service providers the opportunity to focus on service provisioning and revenue enhancement, as they free themselves from the task of the network architecture specialist.

For more information, please visit our web site: www.ceragon.com.

Ceragon's Wireless Backhauling Solution

The FibeAir® IP-10 is Ceragon's family of high-capacity microwave backhauling products, offering integrated Layer 2 networking capabilities. With its integrated MEF-certified Carrier Ethernet Switch and integrated TDM cross-connect facility, the platform enables operators to build LTE-ready backhaul networks today - offering a risk-free migration all the way from 2G to LTE, while reducing Total Cost of Ownership (TCO).

Reducing CAPEX

FibeAir® IP-10 provides operators with an all-in-one-box networking solution - serving both as an Ethernet Switch, and as a TDM cross-connect system. By deploying the carrier-class FibeAir® IP-10 at network junctions, operators can reduce or eliminate the need for stand-alone Layer-2 equipment such as Ethernet switches, or SONET/SDH-based ADMs – reducing capital expenditures (see Figure 7 below). Ceragon's **Native2** hybrid solutions carry both

TDM and Ethernet traffic over a single microwave link, saving additional CAPEX by alleviating the need for separate TDM and packet infrastructures.

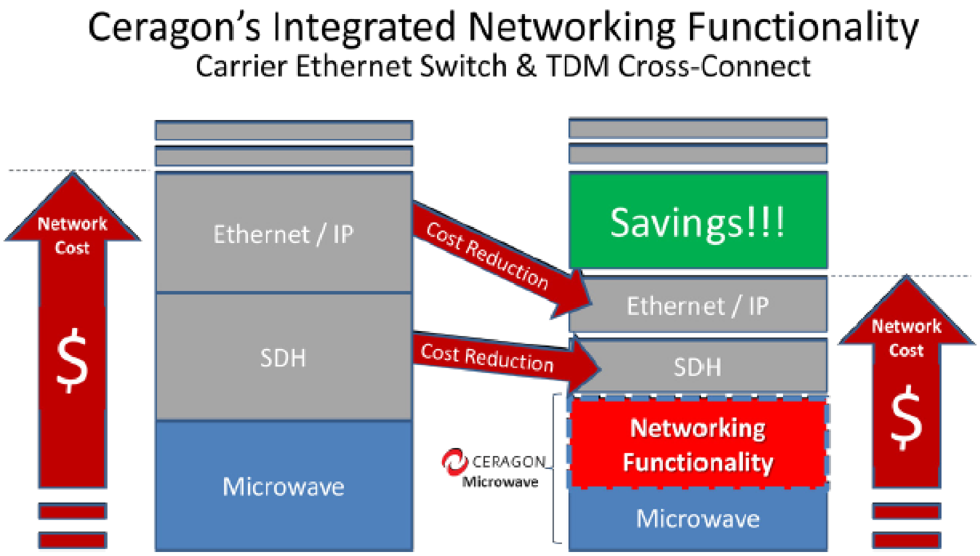


Figure 7: Cost Savings with Ceragon's Integrated Networking Functionality

Reducing OPEX

FibeAir® IP-10, as a one-box, multi-service solution, reduces footprint size at the cell site, lowering rack-space leasing costs. It also reduces electricity costs, automatically suiting power consumption in accordance with current traffic loads and environmental conditions.

In addition, the FibeAir one-box approach saves on maintenance costs, requires less cabling, and reduces network down-time.

The FibeAir® IP-10 is managed by **PolyView**, Ceragon's powerful and user-friendly network management system. Using PolyView, operators can reduce operational expenditures with its end-to-end provisioning facility, efficient network maintenance capabilities, and fast, powerful troubleshooting tools.

Capacity

The FibeAir® IP-10 family of microwave backhauling products covers the entire licensed frequency spectrum and offers a wide capacity range, from 10Mbps to 500Mbps (full duplex) over a single radio carrier, using a single RF unit. FibeAir allows carriers to expand capacity to 1 Gbps, using XPIC (Cross Polarization Interference Cancellation).

Availability

In addition to its SONET/SDH protection switching capabilities, Ceragon wireless backhaul solutions offer additional LTE-ready, Ethernet and radio traffic resiliency capabilities. The FibeAir® IP-10 platform supports ring-based protection using Rapid Spanning Tree Protocol (RSTP), assuring path protection with fast restoration, delivering service restoration within the requested range of 50ms - 250ms as specified in the Next Generation Mobile Networks (NGMN) Alliance document.

Scalability

Ceragon's FibeAir® IP-10 is a unique, modular nodal solution that enables carriers to cost-effectively scale their backhaul networks. Multiple FibeAir IP-10 indoor units (IDUs) can be combined in a modular way to form highly integrated and fully redundant nodal configurations with an extended number of supported radios, TDM and Ethernet interfaces. Using this approach, any tail site can be seamlessly upgraded to become chain or node sites, fully re-using the installed equipment.

Glossary

ABR	Adaptive Bandwidth Recovery
ADM	Add/Drop Multiplexer
CAPEX	Capital Expenditures
HSPA	High Speed Packet Access
IDU	In-Door Unit
IP	Internet Protocol
L3 VPN	Layer 3 Virtual Private Network
LOS	Line Of Sight
MPLS	Multi Protocol Label Switching
MSPP	Multi-Service Provisioning Platform
OAM	Operation, Administration and Maintenance
OPEX	Operating Expenses
PDH	Plesiochronous Digital Hierarchy
QoS	Quality of Service
RSTP	Rapid spanning tree protocol
SDH	Synchronous Digital Hierarchy
SNCP	Sub-Network Connection Protection
STP	Spanning Tree Protocol
TCO	Total Cost of Ownership
TDM	Time Division Multiplexing
XPIC	Cross-polarization Interference Cancellation

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