WHITE PAPER

Flex Your Backhaul Network with Adaptive Coding & Modulation

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Adaptive Coding and Modulation (ACM) was designed to help operators maximize spectrum usage and increase the capacity of their backhaul links over any given channel bandwidth, under any weather condition, for any link budget. This paper provides an introduction to ACM and offers a number of examples that show how the technology simplifies mobile network planning and helps operators achieve better results both in the field as well as on their balance sheets.

Wireless point-to-point (PtP) microwave solutions, used in over 50% of all mobile backhaul deployments worldwide (and nearly 70% outside the U.S.A.), offer operators a simple, cost-efficient path for upgrading and expanding their networks. These solutions support higher data rates than copper E1/DS1 lines, and easily overcome the high cost and limited availability associated with fiber. Yet, wireless backhaul has its constraints. Network planners are often caught between the need to increase the capacity and availability of the network, and the need keep costs in check. In order to meet these needs, Adaptive Coding & Modulation (ACM) – an innovative transmission optimization technology – can be applied, making high-capacity PtP microwave even more attractive.

ACM refers to the automatic adjustment that a wireless system can make in order to optimize over-the-air transmission, and prevent weather-related fading on the link (the technology is discussed in detail in the last section of this paper). Ceragon's innovative FibeAir® IP-10 wireless backhaul platform offers a full-range, dynamic ACM implementation. The FibeAir platform was designed to meet the unique requirements of mobile operators, and to help network planners deal successfully with some of the more common constraints of today's mobile networks. These constraints include: capacity and availability limitations, scarce frequency resources, limitations in the distance between cell towers, and the need to reduce overall rent, licensing and equipment costs.

It's all about Offloading data...

The world of wireless telecommunication is changing. Voice is no longer the main generator of mobile traffic. Today, data generates significantly more traffic than voice, albeit with only marginal added revenue. But there's a bright spot, too. Unlike real-time services, such as voice or video, most data applications do not require stringent 99.999% availability, also known as "five-nines". For instance, while a 50-millisecond delay is unacceptable for voice traffic, a web page or email message that takes several seconds to download is tolerable. Now, planners can flex their networks, guaranteeing sufficient bandwidth for voice and other time-critical services with 99.999% availability, while *offloading* low-priority data services, forwarding them over channels supporting slightly lower availability levels (99.99% or 99.9%). Such offload models, in which mobile operators use Wi-Fi to offload data directly from mobile handsets, or ADSL to offload data from 3G NodeBs, are already in regular use. When employing ACM, this paradigm can be expanded, sending highly-modulated data over a best-effort data channel, while using more conservative, low-modulation techniques for synchronization signals and other high-priority traffic types.

The example in Figure 1 compares a legacy TDM solution with a native Ethernet solution using ACM. In this particular case, a DS3 service is delivered over a 50 Mbps link at 99.999% availability. Alternatively, the same system can provide a single service carrying 155 Mbps at 99.99% availability delivering an STM-1/OC-3 service. When introducing ACM into the equation, the Ethernet link, using the same frequency spectrum and radio equipment, can offer the following: Carrier-grade 50 Mbps at 99.999% availability, a second service providing 105 Mbps at 99.99% availability, and a third service delivering an additional 45 Mbps at 99.9% availability. This constitutes a total of 200 Mbps using the same link budget.

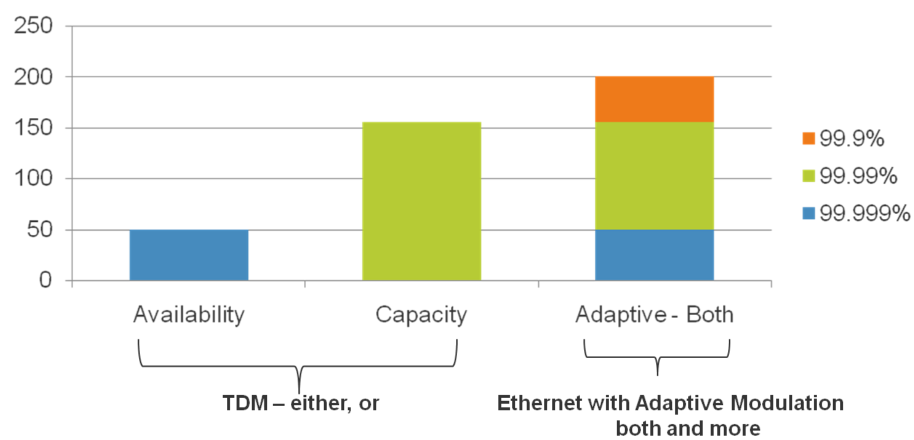


Figure 1: Ethernet Microwave with Adaptive Modulation: Gain in overall capacity while increasing availability

Network planners' peace of mind

Now that we know that ACM can increase the capacity and availability of wireless backhaul links without the need to invest in additional spectrum or revise network planning schemes, let's take a glance at a number of additional benefits the technology offers:.

- **Overcomes the issue of limited frequency resources** - In areas where frequency resources are scarce, ACM allows operators to extract more from their licensed frequencies. Meeting the demand for more bandwidth without increasing the link budget allows operators to maintain their service, business and customer-base growth even in areas in which no additional spectrum is available. Figure 2 shows the capacity range operators can expect at each frequency channel using Ceragon's FibeAir IP-10 with ACM.

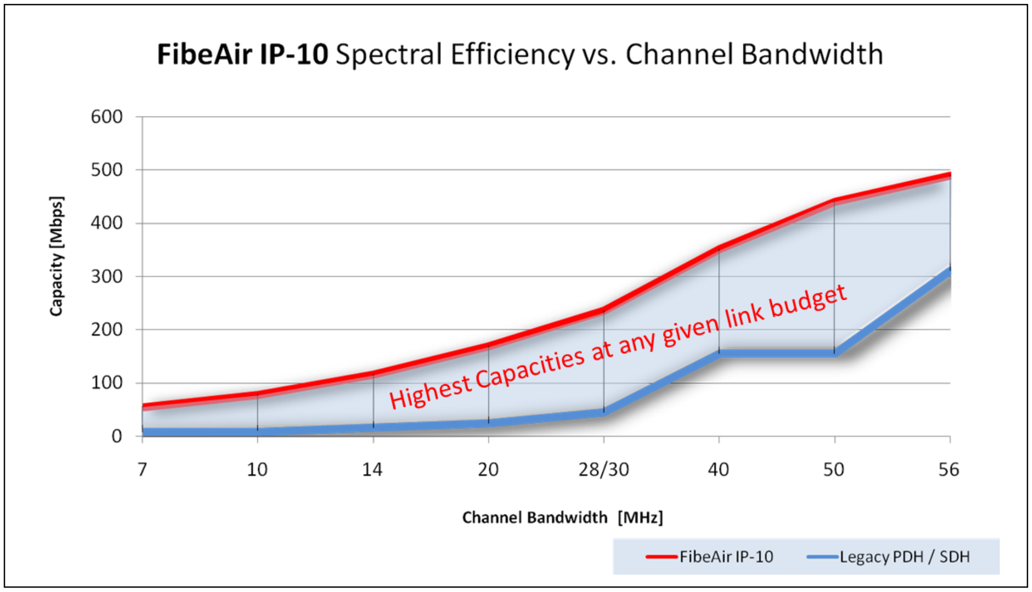


Figure 2: Enhanced spectrum utilization using Ceragon's FibeAir IP-10 with ACM

- **Cap license fees.** – By allowing operators to maximize their licensed bandwidth, ACM-enabled radios can transmit more data rates over the operator's existing spectrum. Eliminating the need to license additional frequency channels and pay additional licensing fees can significantly reduce OPEX.
- **Fewer Hops –** reducing the number of relays, or hops, has a significant and positive influence on the operator's CAPEX and OPEX. Each "hop" means additional equipment costs, licenses, real-estate fees, and sometimes even erecting an entirely new tower. ACM enables operators to increase the range of their high-capacity radio links, thus requiring fewer hops between tail and fiber sites, as shown in the illustration in Figure 3.

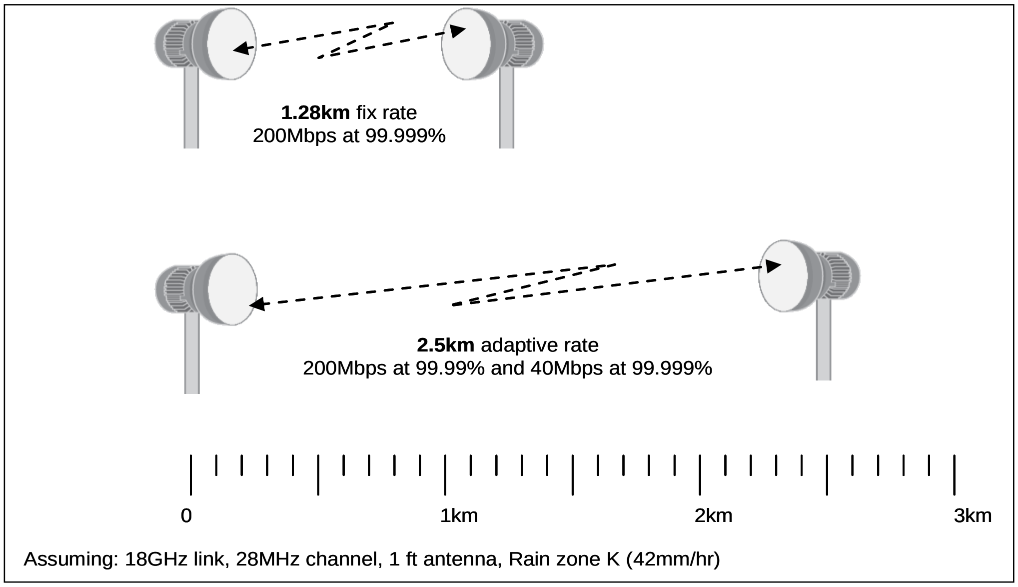
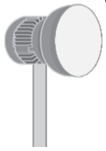
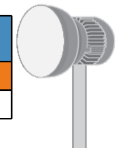


Figure 3: Increasing link span using ACM

- **Decreased tower loads** – cellular towers have finite space availability and can sustain only a limited number of radio transceivers. ACM helps network planners deal with tower loads and other real-estate constraints by allowing microwave radios to increase capacity without having to replace outdoor equipment. In fact, as shown in Figure 4 below, ACM can actually help to decrease antenna size, thus allowing operators to either reduce tower loads or serve more sites without having to set up additional towers.
- **Lower rent fees and equipment costs -** Smaller antennas help reduce roof and tower space leasing costs. In the US, for example, average rental costs amount to $100 per foot per month. A simple calculation shows that an operator would have to pay $4,800 a year for a 4-foot antenna, compared with only $1,200 for a 1-foot antenna. That's a yearly savings of $3,600 per antenna, or $7,200 per link. Needless to say, smaller antennas cost less, both to purchase and to deploy.

Without Adaptive Modulation: requires **4 ft** antennas

Modulation	Average Throughput (Mbps)	Availability (%)	Unavailability of modulation
Outage – 5 minutes and 15 seconds			
256QAM (2)	500	99.999	4min, 28sec


With Adaptive Modulation: requires 1 ft antennas

Modulation	Average Throughput (Mbps)	Availability (%)	Unavailability of modulation
Outage – 5 minutes and 15 seconds			
QPSK	100	99.999	5min, 3sec
8PSK	125	99.998	9min, 3sec
16QAM	200	99.997	11min, 4sec
32QAM	250	99.996	16min, 42sec
64QAM	300	99.995	24min, 35sec
128QAM	350	99.992	37min, 35sec
256QAM (1)	400	99.989	55min, 33sec
256QAM (2)	500	99.985	1hr,18min, 13sec

4.5km/2.8 miles path, 56MHz channel, 400Mbps, 256QAM, 99.999% availability

Assumed rain zone K, 23 [GHz] band

Source: Ceragon Networks

Figure 4: ACM enables similar performance using smaller antennas, yielding a lower cost structure

What is Adaptive Coding and Modulation?

Adaptive Coding and Modulation (ACM) refers to the automatic adjustment that a wireless system can make in order to optimize over-the-air transmission and prevent weather-related link disruptions. When extreme weather conditions, such as a storm, affect the transmission and receipt of data and voice over the wireless network, an ACM-enabled radio system automatically changes modulation and/or coding, allowing real-time applications to continue to run uninterrupted. Varying the modulation and/or coding also varies the amount of bits that are transferred per signal, thereby enabling higher throughputs and better spectral efficiencies. For example, 256 QAM modulation can deliver approximately four times the throughput of 4 QAM (QPSK).

Ceragon Networks employs full-range dynamic ACM in its FibeAir IP-10 line of high-capacity wireless backhaul products. In order to ensure high transmission quality, Ceragon solutions implement hitless/errorless[1] ACM that can cope with 90dB per second fading. A quality of service awareness mechanism ensures that high priority voice and data packets are never "dropped", thus maintaining even the most stringent service level agreements (SLAs).

[1] Hitless/Errorless" means that the change in modulation occurs with no errors and no loss of synchronization, thereby introducing no delay to the remaining traffic.

The hitless/errorless functionality of Ceragon's ACM has another major advantage, in that it ensures that TCP/IP sessions do not time-out. Lab simulations have shown that when short fades occur (for example, if a system has to terminate the signal for a short time to switch between modulations) they may lead to timeout of the TCP/IP sessions – even when the interruption is only 50 milliseconds. TCP/IP timeouts are followed by a drastic throughput decrease while the TCP/IP sessions recover. This may take as long as several seconds. With a hitless/errorless ACM implementation, this problem can be avoided.

So how does it really work? Let's assume a system configured for 256 QAM with 500 Mbps capacity over a 56 MHz channel. When the received Signal to Noise Ratio (SNR) degrades to a predetermined threshold, the system will preemptively switch to 128 QAM and the throughput will be stepped down to 400 Mbps. This is an errorless, virtually instantaneous switch. The system will then run at 128 QAM until the fading condition either intensifies, or disappears. If the fade intensifies, another switch will take the system down to 64 QAM. If, on the other hand, weather conditions, the modulation will be switched back to the next higher step (128 QAM) and so on. The switching will continue automatically and as quickly as needed, and can switch during extreme conditions all the way down to QPSK.

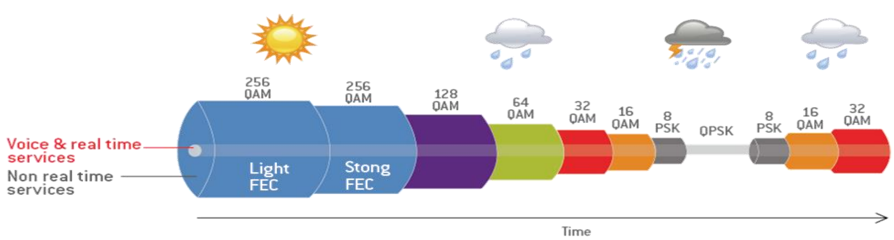


Figure 5: Ceragon's unique Adaptive Coding & Modulation

As shown in Figure 5, Ceragon's FibeAir IP-10 ACM implementation offers eight modulation and coding steps. This unmatched level of flexibility is achieved by using both adaptive modulation as well as adaptive coding functionalities. Adaptive coding allows the FibeAir IP-10 to use a lighter forward-error-correction (FEC) code when weather conditions permit, thus gaining more bits for payload. If the system senses an increase in errors over the link, it automatically implements stronger FEC coding. The following paragraphs provide additional information about the advantages of adaptive coding.

Improving Capacity with Adaptive Coding

By implementing full dynamic ACM, Ceragon's FibeAir IP-10 significantly improves the user bit rate. The user bit rate is calculated as follows: Symbol rate * modulation bits/symbol * coding rate. The actual user bit rate – or "net" bit rate for user traffic – over a given channel with a given symbol rate is determined by two main factors: One is the modulation scheme efficiency (modulation bits/symbol), the other is the coding rate.

Modulation scheme efficiency is defined as the number of bits that are carried by each transmitted symbol. For example: QPSK carries 2 bits/symbol, while 256 QAM carries 8 bits/symbol. The coding rate represents the quantity of payload bits as a percentage of the total amount of transmitted bits (in contrast to redundancy bits, which are used for coding). For example: a coding rate of 0.9 means that we add one redundancy bit for every nine bits of payload. In this particular case, the code consumes 10% of the bandwidth. When the system needs to use a stronger code (to make up for bit-errors for instance), the coding rate is changed to 0.8. This ensures a better quality of transmission, but reduces the percentage of payload bits as more bandwidth is consumed by coding.

Modulation scheme efficiency and coding rate influence the radio system's signal-to-noise ratio (SNR) and system gain. As the modulation bits/symbol ratio rises, there is a need for higher SNR which results in lower system gain. As the coding rate goes down, by introducing a stronger code, SNR is lowered, resulting in better system gain. So, by dynamically adjusting both the modulation efficiency and the coding rate using ACM, a FibeAir IP-10 solution ensures the highest available bit rate. This automatic adjustment of modulation and channel coding gives operators more flexibility and a finer resolution on the curve representing system gain versus delivered bandwidth.

The Power Adaptive Perspective

When planning ACM-based radio links, the radio planner attempts to apply the lowest transmit power that will perform satisfactorily at the highest level of modulation. During fade conditions requiring a modulation drop, most radio systems *cannot* increase transmit power to compensate for the signal degradation, resulting in a deeper reduction in capacity. Ceragon's FibeAir IP-10 is capable of adjusting power on the fly, optimizing the available capacity at every modulation point, as illustrated in Figure 6 below. In the diagram, it is shown that operators that want to use ACM to benefit from high levels of modulation (say, 256 QAM) will have to settle for low system gain, in this case, 18 dB for all the other modulations as well. With FibeAir IP-10, operators can automatically adjust power levels, achieving the extra 4 dB system gain that is required to maintain optimal throughput levels under all conditions.

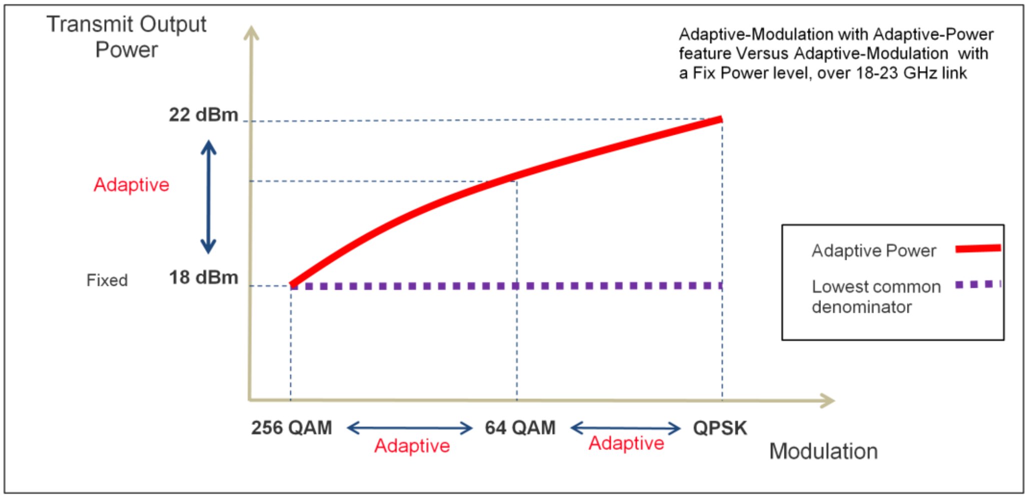
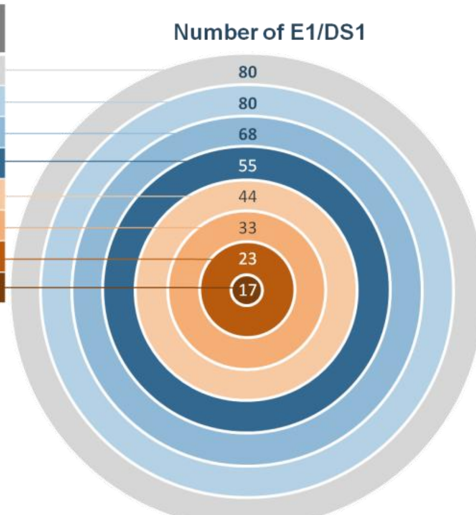


Figure 6: Ceragon's unique ACM with Adaptive Power vs. plain ACM

The TDM Perspective

Another unique advantage of the FibeAir system is its ability to use these sophisticated adaptive techniques also in a hybrid, TDM/packet model. Using Ceragon's innovative **Native[2]** migration solution, in which TDM and Ethernet traffic is natively and simultaneously carried over a single microwave link, E1/DS1 services can be forwarded at a higher priority. When more than one E1/DS1 channel is connected to a cell site, one of the channels can be given a higher priority in order to maintain network synchronization as well as a minimum level of service. The rest of the E1/DS1 channels may be forwarded at a lower priority.

Yearly Downtime	Availability	QAM
178 min	99.96	256 H
132 min	99.97	256 L
105 min	99.98	128
71 min	99.986	64
60 min	99.988	32
37 min	99.993	16
26 min	99.995	8
11 min	99.999	QPSK



Assumptions

- Frequency band: **15 GHz**
- Rain Zone: **N (120 mm/year)**
- Antennas: **1.2 m**
- Distance: **18 Km**
- Polarization: **Horizontal**

Figure 7: Ceragon's unique Adaptive Coding & Modulation adaption for TDM

There are substantial benefits to be reaped from applying ACM in TDM networks as well. An operator may increase capacity on an existing link while maintaining the same availability for its existing revenue-generating services. Additional data E1/DS1s are easily offloaded in this virtual link to a channel offering slightly lower availability. Optimally, one E1/DS1 can be given a higher priority connection to maintain synchronization and a minimum level of service at all times (higher than five-9s).

The rest of the E1s/DS1s may be associated with a lower priority. When migrating to a packet network, this model can still be effectively applied. It is important to note that it is possible to define packet-based services at a higher priority than for TDM services, as some real-time services may run on new Ethernet ports, while other, best-effort data services are forwarded over legacy TDM networks.

Conclusion

High capacity wireless backhaul solutions provide a superior alternative to wired backhaul solutions in terms of available bandwidth (copper), cost (fiber) and ease of installation (both). Adaptive Coding and Modulation (ACM), which was designed to maximize spectrum usage and increase the capacity of wireless backhaul links for any link budget, now makes wireless solutions even more attractive. With ACM, network planners can better utilize their existing resources to increase the capacity and availability of their backhaul network.

Ceragon's FibeAir IP-10 microwave backhaul solution employs full-range dynamic ACM. This advanced, field-proven solution sets new benchmarks in terms of capacity per-channel over any link budget, and enables carriers to significantly reduce the costs of equipment, frequency licensing, real-estate and more.

To learn more about Ceragon and its broad portfolio of Ethernet and TDM high-capacity wireless backhaul solutions, please visit our website at: www.ceragon.com

ABOUT CERAGON

Ceragon Networks Ltd. is a leading provider of high-capacity LTE-ready wireless backhaul solutions.

We provide a broad portfolio of innovative, field-proven, high capacity wireless backhaul solutions for wireless service providers as well as private businesses. These solutions are designed to deliver voice and premium data services, eliminate the backhaul capacity bottleneck, significantly reduce backhaul costs and transition to next generation IP-based networks.

Ceragon's focus on backhaul is a significant advantage as it serves all types of access technologies, and any type of network. The main driver of Ceragon's business is its modular FibeAir® product family, a cutting-edge, high-capacity solution for wireless backhaul transport of broadband services over IP and SONET/SDH networks.