Microwaves & RF

ACM Controls Cost Of Increased Spectral Efficiency

Adaptive code and modulation (ACM) technology is poised to provide cellular backhaul infrastructure with the efficiency needed to meet growing demand for high-capacity payloads.

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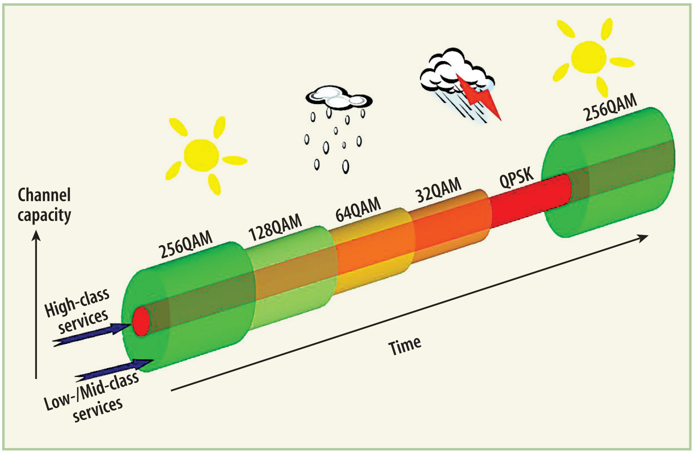
Cellular-communications system operators depend on efficient access network technologies to maximum spectral efficiency (bits/Hz) at minimum cost. Adaptive code and modulation (ACM) is an emerging wireless technology that promises to do just that. With ACM technology, cellular operators can provide high-capacity payload over microwave links and improve the link utilization; this lowers capital expenditures for the RF equipment and operational expenditures for the bandwidth to maintain these high-capacity links. Depending on the link conditions, ACM enables a link's modulation and forward-error correction (FEC) to change dynamically, without losing any data during the transaction, and while maintaining the highest link spectral efficiency at any given time in any link condition.

Most cellular users are accustomed to 99.999-percent service availability in traditional wireless backhaul transmission networks carrying mostly voice. However, new services enabled by "two-and-one-half-" and third-generation (2.5/3G) technology, such as Internet browsing and video streaming, can be operated over cellular networks at a more relaxed availability level. With evolving wireless networks, services are divided into different class types, and the required availability is allocated to each service based on its class. In this way, 99.999-percent availability is maintained for high-class services (such as voice), and a different availability is assigned to lower-class services (like video streaming). The ACM component defines which services should be provided in any link condition and which should be adapted if the link condition is degraded and the link's payload decreased. ***Figure 1*** shows how channel capacity is decreased in bad weather while maintaining high-class services like E1 channels with full bandwidth capacity and adapting the bandwidth capacity of low- and mid-class services like web browsing.



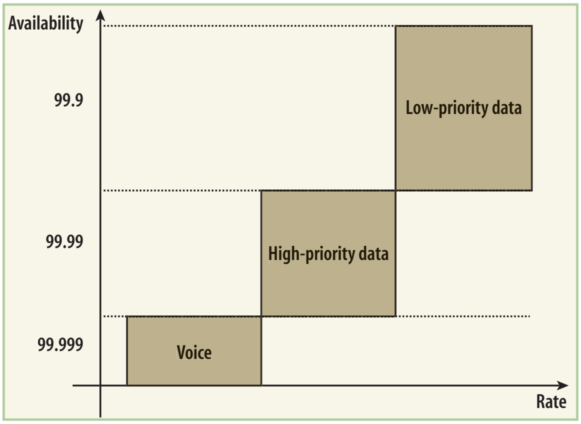
1. Adverse weather conditions can decrease cellular channel capacity, which most affects low- and mid-class services.

Different classes of services (CoS) define the guaranteed level of service for each application. ***Figure 2*** shows how CoS such as rich voice and video are mapped into different classes of availability (CoA), e.g., 99.999 or 99.99 percent. Multiple CoA increase the available capacity up to 10 times that of standard links. When link conditions are clear, the wireless link operates at maximum capacity and provides the full rate per service, while during harsh rain or other poor link conditions, the operation of predefined high-availability services is not affected, and the capacity of lower-priority services dynamically adapts to the changing link conditions by altering the service's bandwidth. ACM's ability to change the link rate among the different availability classes allows provisioning bandwidth according to the link conditions and traffic priority.

Provigent, Inc., a fabless semiconductor company that provides best-of-breed system-on-a-chip (SoC) solutions to broadband wireless equipment vendors, pioneered ACM's use in the backhaul wireless transmission industry and has developed a new technology (ProviBand) that increases the capacity of backhaul links tenfold. Using Provigent's PVG310 single-chip modem with ProviBand allows vendors to design adaptive rate systems that can meet the requirements of mixed (TDM and IP) high-capacity traffic in next-generation cellular backhaul networks.

A network's ACM feature is implemented at both sides of the link (transmitter and receiver to ensure that modulation (and/or FEC) changes occur synchronously throughout the link. Different indicators sense the link condition, which enables rapid spectral efficiency adaptation to maintain the link during fast-fading changes. Common indicators are mean square error (MSE), bit-error rate (BER), and receive signal strength indication (RSSI). Because they better reflect the general overview of the link condition, MSE and BER are more suitable than RSSI for use as ACM indicators. In the case of co-channel interference (CCI), the RSSI indicator will not show any degradation because the received level changes little; BER and MSE indicators, on the other hand, will reflect the interference. Another RSSI drawback is its sensitivity to the receive chain variance and to variances in temperature and analog components.

ACM profiles define the link parameters (modulation and FEC) for a given range of signal-to-noise ratios (SNRs). Each profile's SNR range defines the threshold for switching from one ACM profile to another and has a different spectral efficiency, derived from its modulation and FEC ***(Fig. 3)***. As an example, the one marked High ACM Profile in Fig. 3 is suitable for an SNR range of 21 to 23 dB, enabling spectral efficiency of 6.8 b/Hz. If the link becomes degraded (SNR falls below 21 dB), a lower ACM profile will be used that is suitable for a new SNR range with a different spectral efficiency, such as the Low ACM Profile in Fig. 3, which is suitable for an SNR range of 9.9 to 11.9 dB with a spectral efficiency of 3.8 b/Hz.



2. Different levels of availability are applied to different classes of cellular service.

An ACM profile also defines the data rate of each service, ensuring that high-class services will always be allocated with the required constant bandwidth and that the link condition will determine the bandwidth allocation of other services. The data rate of some services, such as E1, is fixed; thus, based on the service's class, the ACM will enable or disable the service. The profile also guarantees that the total data rate of all services equals the link data rate.

On the receiver side, link conditions are monitored based on estimators such as SNR, RSSI, or BER. The trigger for switching an ACM profile varies from one algorithm to another, e.g., crossing either an indicator threshold or an indicator gradient threshold. Some algorithms use a combination of indicators to improve the ACM switching performance and reliability. Hysteresis is usually included in the ACM algorithm to prevent undesired switching in case the estimators' level jitters between two ACM profiles. Should the receiver-side estimators show that the link performance is not suitable for the current ACM profile, an ACM switching process is initiated. In case of link performance degradation, the new ACM profile will include higher FEC and/or lower modulation, which decreases the link bit/Hz ratio. Measured in dB per second, the switching rate is a dominant factor in ACM systems: The higher the switching rate, the better the system's immunity to rapid SNR changes or other interferences. When the switching is being executed, the payload rate is being modified to fit the aggregated data rate to the new available link data rate.

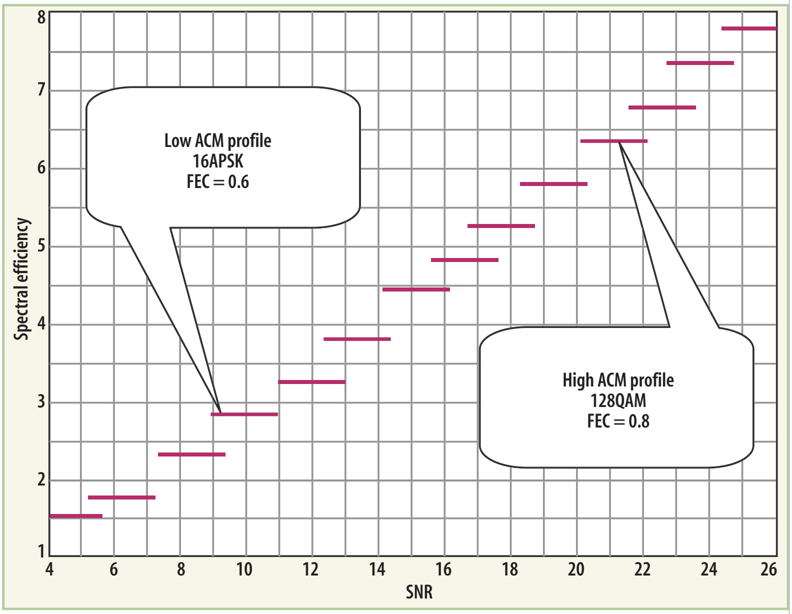
Alternatively, ACM can also be used to increase the link distance, resulting in added link spectral efficiency. The same concept is implemented as previously, with the margins that were kept for 99.999-percent bandwidth availability now used to increase the link distance. Whenever the link conditions are degraded, the system will switch to an ACM profile with lower spectral efficiency to enable maintaining the link.

ACM can be implemented together with automatic transmit power control (ATPC), complementary features that enhance overall system performance. ATPC reduces the average transmitted power as well as CCI and adjacent-channel interference (ACI), which is caused by extraneous power from a signal in an adjacent channel. It also enables a more efficient and cost-effective network frequency plan and deployment, as well as eliminating some of the receivers' "upfade" problems by changing the transmitted power according to the link momentary conditions. The lower average transmitted power also extends the equipment's mean time between failures.

ATPC can be used together with ACM to control the transmitted power in any given ACM profile. Different algorithms can be implemented to achieve maximal spectral efficiency or minimal transmitted power using both features in combination. One implementation could target maximal spectral efficacy by trying to reach the highest ACM profile, while the other is willing to compromise on some of the spectral efficiency enabling CCI and ACI interference reduction. In any chosen algorithm, ATPC reduces the average transmitted power, benefiting each ACM profile and any link condition.

ACM technology allows manufacturers and operators save on RF equipment costs in existing and new systems. In existing systems, for example, ACM enables utilization of higher spectral efficiency by replacing the indoor unit only; the already-deployed RF equipment can be reused in the upgraded system. The original link was designed to support a given spectral efficiency with 99.999-percent availability in any weather condition, with the spectral efficiency limitation being derived from the RF equipment's power and noise figure. Trying to reach higher spectral efficacy normally requires higher-performance RF equipment. However, because ACM supports spectral efficiency adaptation on the fly, the upgraded network can usually accommodate higher spectral efficiency; using the original link design's margins—and only when the link condition is degraded—the spectral efficiency will be reduced back to its original value. When designing a new system, the same savings can be reached if ACM usage is included in the link budget calculations.

One of the major system costs in a wireless link is the radio. Producing a highly linear low phase-noise radio adequate for high-capacity modulation is very expensive, due to the usage of costly RF modules and low production yield. The radio is mostly an outdoor unit that operates in an industrial environment. ACM also enables overcoming some radio defects and performance degradation that might occur after system deployment. Although RF performance degradations in regular systems will automatically break the link in severe weather conditions, ACM networks enable keeping the link alive while adjusting the spectral efficiency to the degraded RF equipment. Obviously, a low-end CoS might suffer from limited bandwidth, but the link keeps providing full bandwidth for the high-end services. ACM permits the operator to use a low-cost (higher-yield) radio that might degrade performance in some extreme environmental conditions, such as very hot or cold weather or impact from hail.



3. The spectral efficiency of each ACM profile is different, derived from its modulation format and FEC.

ACM, by its nature, supports a wide range of modulations in a single link. In many cases, this capability can combine with complementary features to strengthen the ACM benefits. An example is the phase-noise immunity (PNI) implemented in Provigent's SoC solutions. PNI enables decreasing the phase-noise level by canceling the estimated phase noise on the receiver. The PNI enables using low-cost radio equipment while overcoming similar phase noise as the higher-end radios. This demonstrates how the new technology, based on an ACM mechanism, can pave the path to cost-effectively building next-generation wireless access networks by taking advantage of traffic evolution from synchronous TDM traffic to packet IP-based traffic.

The end-to-end ACM solution from Provigent supports a wide range of modulation changes, from quadrature phase-shift keying (QPSK) to 256-state quadrature amplitude modulation (256QAM). In addition, it manages the physical layer and, based on link conditions, automatically changes the modulation and FEC code rate. In order to reach maximum spectral efficiency in any given link condition, the most suitable ACM profile is chosen in real time out of a wide range of available profiles, and each service's bandwidth is automatically adjusted based on the service's CoS. To enable maintaining the link even during highly rapid SNR changes, the switching rate is exceptionally fast, complying with a fade rate of 100 dB/s.

In short, ACM techniques enable cellular operators to support high-end applications with the advantages of 2.5/3G technology, while maintaining low operational and capital expenditures, even when the bandwidth increases up to ten times. ACM is poised to move 2.5/3G cellular networks backhaul forward as they continue to migrate from traditional voice traffic to mixed voice and data traffic. As a result, operators will be better able to meet consumer demand for new services with higher speeds and payload capacity while, at the same time, generating more revenue for a given spectral efficiency. MRF