특 집

Services and technologies for emerging local access demand

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Abstract

Emergence of the Internet, World Wide Web (WWW), and multimedia services accelerates the demand for broadband access to mass market. As the demand for broader bandwidth for local access rapidly increases, new types of services for local access have been offered or are being developed. However, nothing has yet been shown up for a definite long-term solution. In this article, we address some issues and technological perspectives of such emerging local access demand.

I. Introduction

With the rapid growth of personal computer applications, the Internet, and local area networks (LANs), there is increasing demand for extending the data service to the local loop. The definition of the local loop as the medium by which a service provider can access the end user has serious implication for service providers. The local loop for the information industry is quite different from the traditional local loop of the telecommunication industry.

Emerging residential broadband services can essentially be grouped into three categories; data, emulated broadcast television and interactive TV(or video on demand). Data services encompass data, text, images and low-quality video whose bit-rate requirements are up to 1.5 Mbps. Recently, the use of the Internet with an enhanced Internet protocol can be applied to wide range of applications, including music-on-demand and work-at-home as well as interactive services. These features require for high bandwidth and symmetrical bandwidth for fully supported services. Emulated broadcast TV service is in fully digital format for both video and audio, and comparable to community antenna television (CATV) service. It requires a 1.5~6 Mbps bit-rate transmission for a single channel per subscriber. Interactive TV requires a sustained downstream bit-rate comparable to higher quality to emulated broadcast TV (3~10 Mbps) and a low latency upstream link.

Considering these new opportunities in the local loop, two questions should be considered. First, do these opportunities arise from new services or new methods for delivering the same services? Second, do these opportunities require deployment of new plant or simply a means to better utilize the existing structures? Since most of these opportunities require greater bandwidth capacity, which depends upon huge investment, it is indispensable to seek a far more simple and cost effective solution in a timely manner.

The explosive growth of Internet use approximately 60% annually is forcing the telephone company to face another dilemma besides the cost of second-line and long holding time: other service people such as cable television company want to get into their business. Such increasingly competitive communications market drives the telecommunication operators to seek solutions that can provide greater bandwidth and ubiquitous access to the home, while accommodating the growing public data network. In response to these competitive environments, telecommunication operators are focusing to take advantage of their incumbent facilities like copper networks, because other alternatives seem too costly and take too long time to deploy.

Bandwidth is the most significant issue concerning the capability of loop access technologies, but not the only one. Other technological issues, while they are not bottle necks at this time, could become significant. Perceived limitations and capabilities of various access technologies may become key differentiating factors. For example, it may be an effective strategy that promotes selected technological issues to the forefront of customers expectations.

Today the broadband market represents less than one percent of the total market and is mostly serviced outside the residential and small-business consumers. As major market drivers will be personal computers (PCs), PC applications and the Internet for the time being, they will lead the mass market in the near future, particularly in terms of bandwidth. New technological developments that can offer the potential of much higher modem speed in the same price range can significantly increase the market size as well as the market control.

Public switching telephone network (PSTN) has been the principle vehicle of basic access service. However, in order to keep the same role in the future, it is necessary to move from an analog to all-digital network. Although ISDN can deliver a basic rate of up to 144 Kbps, and a primary rate of 1.5 Mbps, it doesn't seem to provide an efficient solution for various kinds of new demands. Moreover, the cost is much above the consumer's willingness to pay. However, it can be an important strategic technology for local exchange companies until other technologies are to appear to meet current and near-term demand. HDSL, ADSL, SDSL, etc., collectively referred to xDSL, are being considered as a technology that can replace ISDN, while satisfying the bandwidth requirements with less expensive than ISDN[1]. If it properly evolves, xDSL technology will accommodate the emerging markets on a long-term basis.

Cable systems can be thought of as a point-to-multipoint system that can deliver many channels simultaneously. However, since they are localized unlike the telephone systems, they need to equipped with switching facility to be able to provide point-to-point services. CATV companies are trying to get into the emerging mass markets by offering an effective strategy based on their hybrid fiber/coax (HFC) network and cable modem technology. Operating telecommunication services over an existing CATV network requires the cable operator to examine issues that differentiate a traditional one-way broadband medium from a two-way interactive medium. Recent trials by Time Warner in the USA indicate that providing full services was technically successful, but not commercially, and software and network management was far more difficult than ever imagined[2]. Since only a small fraction of frequency band is usable for return path and quite susceptible to ingress noise, it is very critical to characterize the loop plant to find out the location of the good parts of the spectrum.

Instead of copper wire technologies, the use of radio and wireless technologies in the local loop is also being considered. The wireless local loop (WLL) systems are rapidly being deployed because of flexibility and economic advantages, but they don't seem to be optimal for supporting the emerging broadband services. There are three wireless architectures that may qualify as broadband delivery systems to the home: direct broadcast satellite (DBS), multichannel multipoint distribution system (MMDS) and the local multipoint distribution system (LMDS). DBS services such as DirectPC using satellite receiver boxes with the upstream link provided by local telephone line are being offered. For a quick but limited presence, MMDS appears to be the best option for a targeted region where no other company is providing a competitive service. The LMDS system appears to offer a good full sweep of broadcast services.

In the last three decades, there have been remarkable advances in digital modulation technologies. The development of automatic equalization in late sixties, combined coding and modulation, and echo cancellation in eighties are major advances among them. In particular, in nineties, there have been several advanced technologies toward the Shannon capacity: high spectral effcient modulation, signal mapping and shaping, line probing, non-linear precoding, and software configurable modem technologies.

Conventional modulation schemes have been using a lattice type of signal constellations that can only support data rates with an integer number of bits per symbol. However, the use of variable channel bandwidth and multi-dimensional coded modulation may result in data rates to be a fractional number of bits per symbol. As a result, new signal mapping techniques have been used to efficiently support the fractional bits per symbol. Moreover, an additional gain in the SNR can be obtained from signal constellation mapping, This gain, called shaping gain, can be achieved almost independent of the coding gain[3].

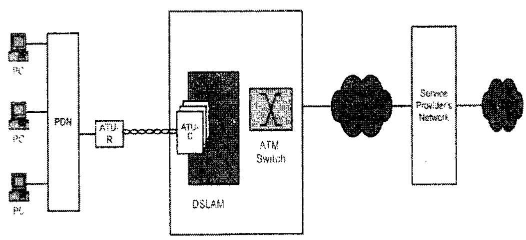
In order to achieve the optimum transmission performance under variation in the channel conditions, it is required for transceivers to adaptively adjust its operation. For this purpose, new methods for measurement of the channel quality, called line probing (LP), have recently been devised to make optimal use of the maximum available bandwidth and/or to set up the optimal operating condition.

The use of the maximum bandwidth may require powerful equalization techniques to effectively compensate for increased distortion. It is well known that the conventional linear equalizer can result in excessive noise enhancement at band edges. Moreover, the linear equalizer makes its output noise correlated, which in turn degrades the decoder performance. Not only to overcome these problems but also to support Viterbi decoding structures, nonlinear equalization schemes called the precoding technique have been applied[4,5,6].

Following this Introduction, Section 2 describes potential services for emerging local access demand in view of business aspects as well as technical aspects. Section 3 discusses some advanced modulation techniques that are being applied or applicable to the development of vehicles for emerging high-band local access services. Finally, concluding remarks are given in Section 4.

II. High-bandwidth services in the local loop

xDSL is an end-to-end modem technology that converts the existing telephone line into a broadband access network capable of delivering emerging multimedia and information services, in lieu of current 33.6 and 56 Kbps voice-band modems. Fig. 1 depicts an xDSL-based end-to-end architecture whose services are integrated into the DSLAM. The addition of the ATM switch between DSLAM and the ATM backbone can bring flexibility in the services provided and in the configuration of the network. In the last

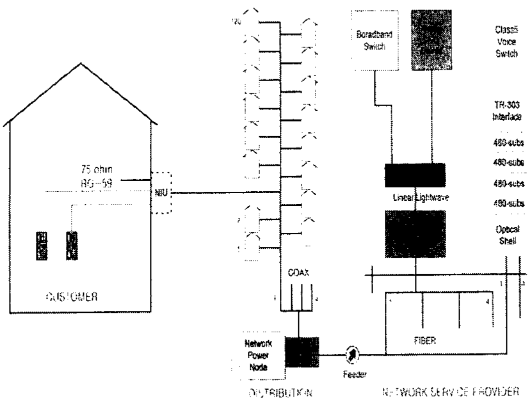


〈Fig. 1〉 xDSL service integration into DSLAM

five years, applications and technology of xDSL modem have radically evolved. For example, ADSL technology deployment varied from video-on-demand applications and data networking, to a current focus on Internet and telecommunication services. Beyond this, full support of matured transceiver technology, ATM components, hardware and software integration, and operation support may enable xDSL systems development to be used for LAN-LAN interconnection, remote office telecommuting, and multimedia applications.

To put the cost in perspective, cost effective product development is currently under way by Globespan Tech., Texas Instruments with Amati, Aware, Analog Devices, Alcatel, Motorola, and others. For example, a top-of-line ADSL chip set from Analog Devices consists of four ASIC chips which cost less than $100, although they are in the sampling stage. It can be expected in a few years that the chip set could sell as low as V.34 modem chip set price at this time.

XDSL technology and integration into product are at a mature stage for service deployment. However, there are number of issues to be solved for fast deployment. Installation xDSL at the home requires rewiring to insert a premise splitter[7], which takes long time for installation. Also, selection of ATM as a data-transport mechanism over xDSL requires special problems to be identified and resolved. Another serious problem with xDSL technology from an access provider's perspective is that it is basically a point-to-point architecture. This is suitable for small-size markets, but it is too cumbersome for large-scale markets that may accommodates a few million access lines.



〈Fig. 2〉 Basic HFCstructure

Hence, when it comes up with a more integrated xDSL architecture consuming much reduced power, service providers will be able to offer a very high-speed integrated digital network bundled with basic telephone service.

The HFC technology has evolved from cable-TV operators' analog tree and branch coax networks. As shown in Fig. 2, HFC comprises optical nodes, power supplies, power inserters, taps, splitters, and line amplifies. An HFC/cable modem system can serve 500 homes per node, with 10 Mbps transmission upstream and 30 Mbps using about 6 MHz of spectrum for each direction. Cable modems provide LAN-type access by establishing one or more LANs over the coax portion of the HFC network. One of big problems with HFC with two-way operation is that ingress noise, originating principally from the subscribers, makes upstream transmission very difficult. As a result, HFC may not be effective for supporting a high level of POTS. In practice, ingress noise limits the available spectrum to about 40 MHz, although the theoretical upper limit for this spectrum is about 400 MHz. In addition to ingress noise, higher-performance connection is required to protect against the environment. Without significant and costly technological advance, appreciable increases in bandwidth may not be achievable. Moreover, the use of a coax star-bus architecture for LANs is an old technology. Today's high-speed LANs are rapidly migrating to a point-to-point architecture over either copper twisted pairs or fiber. In order to keep the pace with increasing service demand, cable-modem systems need to be upgrade to state-of-the-art systems and the number of simultaneous subscribers per system should be continuously reduced. However, HFC/cable modems are an effective near-to-mid-term solution for HFC-based local access providers.

The DBS can offer the largest number of homes among wireless systems, which is about the size of North America. It can provide 6-MHz downstream channels of up to 32, but sharing the system among a large number of homes may result in the dilution of some services. However, it is a very effective system for broadcast services. It can accommodate 1.3 Gbps of downstream digital data, although there is no upstream capability. DBS does not offer plain old telephone service (POTS) or data capabilities. It also cannot accommodate local programming or segmented advertising.

The MMDS microwave system covers a small metropolitan area well and several sites can be used for large cities. This system has a 15-mile service range primarily for one-way signals. Although it is limited, there can be some two-way service on these systems. The MMDS offers thirty three 6-MHz carriers downstream, but very limited upstream capacity. The rate of digital data transmission can be up to 1.2 Gbps when 64-point QAM method is applied. It is a good way to provide digital service to a large number of people quickly, including local content, which is typically missing from the DBS offerings. It has the capability to provide local channels, but the big problem with MMDS is the need for line-of-signt transmission. The MMDS seems to be cost effective only in high-density areas.

The LMDS fixed wireless system has a cell radius of only three miles, which means a large number of overlapping cells are required to serve a metro area. This results in the usual cellular mix-and-match arrangement for delivering signals to subscribers. The real strength of the LMDS system is that it can offer a reasonable presence in an area very quickly, while balancing time-to-market and cost of service. If the service area is a region where the competition is not particularly intense and where subscribers are not in good service, the LMDS may be a good choice.

In designing these fixed wireless access systems, the following factors should be considered: Since the service coverage of one base station is limited by the line-of-sight condition, a typical radio zone architecture will be based on pico-cell arrangement in order to avoid performance degradation due to precipitation. The variation in the received signal power depends not only on general traffic flow in the surrounding area but also on shadowing due to pedestrian or other artificial factors. Such shadowing effect cannot be compensated by simply increasing the fade margin. Therefore, an effective countermeasure to maintain line-of-sight path should be taken. Finally, it may be required to consider possibility of frequency sharing with other radio systems which may need large geographical isolation.

Despite of many advantages of fixed wireline systems, they are yet to be acknowledged as an economic vehicle, mainly due to lack of matured implementation technology. In order to widely deploy these radio system in the near future, a number of technical issues including the following may need more study: economical IF and RF bands devices feasible for software radio architecture, radio system design including mutichannel access scheme, ATM-cell transport and frequency sharing consideration, efficient antenna technology for terminals, and protocol architecture for interface between network and air.

III. Recent advances in modulation technologies

1. Spectral efficient modulation

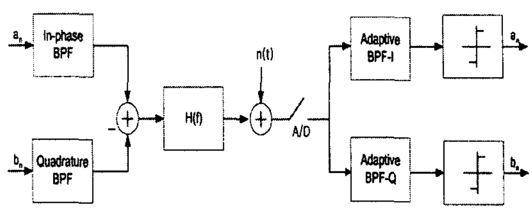
Discussion of xDSL technology are referring to transceiver implementation. In particular, modulation technology often concentrate on the use of discrete multi-tone (DMT), discrete wavelet multitone (DWMT), carrier-less amplitude/phase (CAP), quadrature amplitude modulation (QAM) and 2B1Q. We will briefly discuss three spectral efficient modulation schemes currently being considered for high-speed data transmission over copper infrastructure in what follow.

Discrete multi-tone (DMT) modulation method divides the channel into a set of parallel independent subchannels. During initialization, the line is characterized in terms of each subchannel's signal-to-noise ratio (SNR). Based on this information, the modem allocates data to the channels having higher SNR values and away from the noisier channels. Since the noise characteristics of the line are time-varying, the system continuously monitors the line and moves data to the higher-performance channels in order to maintain the data throughput. With a proper choice of subchannel center frequencies in relation to the sampling frequency, the implementation can be viable by employing the Fast Fourier transform technique. Thus, DMT can provide greater coverage, higher performance, and better immunity to spectral and impulse noises on the line[8].

The DMT was first commercially applied to analog voiceband modems as a proprietary technique in early nineties. Later, DMT was proposed for ADSL applications and has been standardized by ANSI T1.413 and ETSI Annex H which also regulates electromagnetic emission that may affect service in neighboring copper pairs in the same binder or adjacent binders. In xDSL applications, DMT divides the available channel spectrum (26 KHz - 1.1 MHz) into 256 different channels.

Recently a few DMT line-coding ASICs are commercially available off-the-shelf, but it seems that it will need more time for its performance and other technical issues to be fully stabilized like QAM. In order for DMT to obtain the optimum performance as being claimed, it is necessary to assign the optimum transmission rate and power to each subchannel based on the water pouring principle. However, the optimum assignment method is yet to be developed and its effect is not apparent when the channel bandwidth not extremely large. The implementation complexity of a single carrier modulation scheme approximately linearly increases in proportion to the symbol rate. On the other hand, DMT requires a fair amount of implementation complexity regardless of the symbol rate. Thus, it is not sure whether DMT is superior to QAM or CAP when the data rates are lower than T1. Due to excessive high peak-to-average power ratio (PAR), it requires the use of high-bit resolution signal converters, which makes the implementation cost expensive. In particular, reduction in the power consumption by the chip set, which spends about 5 watts now, is one of top priorities for deployment of cost-effective xDSL transceivers in the central offices. In spite of significant advances, the implementation of this technology seems to be still in its early stage.

CAP modulation uses well-established QAM technology[9,10]. As a matter of facts, most of well proven technologies applied to QAM schemes can be also applied to CAP schemes. As depicted in Fig. 3, CAP modulated signals are generated using real in-phase and quadrature-phase bandpass filters whose outputs form a so-called Hilbert transform pair. This relationship makes it possible to use real coefficient receiving filters, which may result in the implementation complexity reduced. This scheme was initially applied to the implementation of HDSL modems. However, it was failed to be standardized for ADSL modems. The main reason was not the



〈Fig. 3〉 Block diagram of CAP transceiver performance problems with the CAP itself, but the implementation problems particularly related with the analog front-end circuitry. Recently, VDSL products are implemented primary based on the CAP modulation scheme, where 16-point signal constellation is used.

CAP is known to be an efficient modulation scheme for implementation when the center frequency of the signal spectrum is of the same order of magnitude as the signal bandwidth, while providing the same theoretical performance as QAM. However, its performance may seriously be deteriorated if timing and phase compensation due to imperfect clocking are not appropriately compensated. Moreover, it may not be applicable to wireless transmission systems such as LMDS and MMDS schemes.

QAM is a well known modulation method and has been applied extensively to many wireline and wireless data communication schemes. It has been considered as a third candidate method for xDSL[11,12]. It has been well known that QAM is the most matured technology among modulation methods being considered. However, it is not well claimed as the principal method. This is mainly due to that DMT and CAP are claimed by specific companies as their own technologies, but QAM is not. However, QAM is expected to keep a major position in xDSL and fixed wireless access areas as it has been in voiceband modem areas.

2. Adaptive modulation by line probing

In order to achieve data transmission at higher data rates, it is desirable to use the maximum available bandwidth. For example, consider data transmission at a rate of 19.2 Kbps over a flat channel by using a symbol rate of 2400 or 3200 Hz, which needs to send 8 and 6 bits per symbol, respectively. In this case, the use of 3200 bauds can provide about 6 dB SNR margin over the use of 2400 bauds when QAM type of modulation is used. Considering additional noise due to bandwidth expansion, which is equivalent to about 1.2 dB loss, we can get a net gain of approximately 4.8 dB by increasing the bandwidth. On the other hand, when a bandwidth is fixed, the data rate can be increased by sending more bits per symbol as the channel condition improves. It has been shown that modem performance directly depends upon the channel frequency response and the SNR. Therefore, it is quite possible to fully utilize the channel condition to maximize the transmission performance.

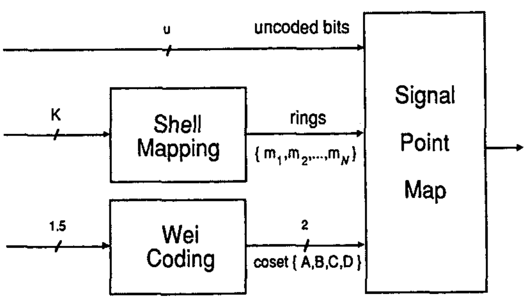
The call modem sends a known line probing signal to the remote answer modem at the beginning of training process. The answer modem analyzes the channel characteristics, such as the SNR spectrum, nonlinear distortion level and other distortion parameters from the received line probing signal. Based on these parameters and modulation schemes such as the coding scheme and equalization method, the best modulation parameters, such as the best symbol rate and transmission rate are decided and sent back to the call modem for its transmitter initialization. In the same manner, the answer modem's transmitter is adaptively controlled. Then, based on the selected modulation condition, transceivers are initialized.

3. Signal mapping and shaping

The use of adaptive bandwidth (or symbol rate) and transmission rate depending upon the channel characteristics may require the signal constellation encoding a fractional number of bits per symbol. Efficient signal mapping techniques are required to support for any combination of data bit rates and symbol rates. The use of switching constellation technique[13] or modulus conversion method[14] has been considered.

To encode signals with a fractional number of bits per symbol, while providing shaping gain in a seamless manner, the use of shell mapping techniques has recently been applied to high speed voice-band modems. The shaping gain can theoretically be up to 1.53 dB. Shell mapping is a block coding method that encodes N-bit block data into M two-dimensional $(2D)$ symbols without switching the signal constellation so that the encoded $2M$-dimensional signal approximates a $2M$-sphere. An additional advantage of shell mapping is that it can nicely support the trellis coded modulation.

A block diagram of the shell mapping scheme applied to $V.34$ voice-band modems is shown in Fig. 4, where a four-dimensional Wei-type trellis encoder is applied together. An N-bit data obtained during the M-symbol time interval is split into the three parts: The trellis coding bits, sell mapping bits and uncoded bits. Assuming the use of a 16-state

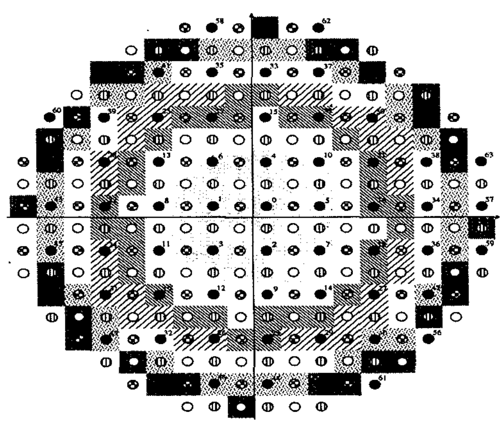


〈Fig. 4〉 Shell mapping with 4D trellis coded modulation

$4D$ Wei coder, a 2-bit coded output for each $2D$ symbol is generated from a 1.5-bit input per symbol. That is, a total of 1.5M bits is used for trellis encoding. Assuming that u bits are used as uncoded bits per symbol for trellis coded modulation, the rest K bits, equal to $N-(1.5+u)M$, are used for shell mapping.

The signal constellation is divided into L groups, called rings, each of which contains the same number of signal points. The shell mapping encoder generated an M-tuple sequence $\{m_1, m_2, \cdots, m_M\}$ from K bits. At symbol time k, $k=1,2,\ldots,M$, the Wei coder output and the uncoded bits determine the encoded symbol by selecting one of signal points in ring m_k, $0 \le m_k \le L-1$. For one-to-one mapping of a K-bit input to an M-tuple output, the size of rings, L, should be chosen such that $L^M \ge 2^K$. Thus, a fractional bits data can be mapped by shell mapping without switching signal constellation by using a two-dimensional $\mathcal{Q}$-point signal constellation, where $\mathcal{Q} = L \cdot 2^{u+2}$.

The required $2D$ $\mathcal{Q}$-point signal constellation can be generated by constructing one of four cosets $\{A, B, C, D\}$ for the Wei trellis coder. The coset A can be generated by picking the



〈Fig. 5〉 Signal constellation for shell mapping

Q 4 smallest energy signal points from two-dimensional lattice signal constellation with distance *2d* represented by $\left(\frac{d}{2}\pm 2di,\ \frac{d}{2}\pm 2dj\right)$, $i,j=0,1,2,\ldots$. The other cosets *B, C* and *D* can be generated by rotating the coset *A* by 90°, 180° and 270°, respectively. As an example, the signal constellation with *160* signal points is shown in Fig. 5, which is composed of five 32-point rings. The numbers on the signal points indicate the ordering of the signal point of coset A. Note that four different shapes represent the signal points corresponding to four cosets.

For shell mapping, rings can be constructed such that the innermost ring, with index 0, contains *r* signal points with the smallest power. The next ring, with index 1, contains r signal points with the next smallest power, and so on. Assuming that *r* is not too small, the average signal power of the rings is approximately linearly proportional to their index number. Since the cost of ring *m* can be approximated as its index number *m*, the total average power is sum of the cost of each ring selected.

The shaping gain can be obtained by minimizing the cost function *P* defined by

$$P=\sum_{m=0}^{L-1} mp(m)$$

where $p(m)$ denotes the probability of the use of ring *m*. The optimal solution can be found by using the generating function technique for the cost of ring selection[3,15]. Thus, shell mapping can be viewed as a way of supporting a signal mapping of fractional bits per symbol , while providing a shaping gain with only modest signal constellation expansion. However, when distortion due to nonlinear impairments becomes large, the use of an expanded signal constellation may result in a shaping loss.

4. Nonlinear equalization

Exploiting the use of the maximum available bandwidth can experience severe attenuation at band edges. This can cause excessive noise enhancement if a linear equalizer is used. To alleviate such noise enhancement problem, the following two methods can be applied.

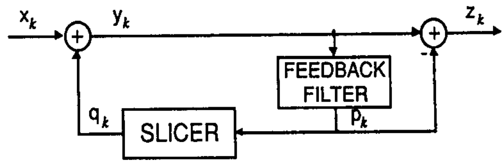
The first method is to employ a linear pre-emphasis filter in the transmitter, whose coefficients can be calculated depending on the channel characteristics. In principle, the use of a filter that compensates for 50% of the channel distortion is optimal on an additive white Gaussian channel (AWGN). An interleaving scheme may be required to remove noise correlation caused by the linear pre-emphasis, which is desirable for trellis decoding. The use of a pre-emphasis filter may result in increase of peak-to-average power ratio (PAR).

The second method is to employ nonlinear equalization techniques. It is well known that the performance of an ideal decision feedback equalizer (DFE) asymptotically optimal for non-ideal Gaussian noise channels. When a DFE is combined with trellis coding, it can approach the Shannon's channel capacity as closely as the capacity on an ideal AWGN channel[4]. However, the DFE cannot be directly applied to coded modulation schemes, due to the processing delay by Viterbi decoder. Moreover, the DFE suffers from performance degradation due to error propagation.

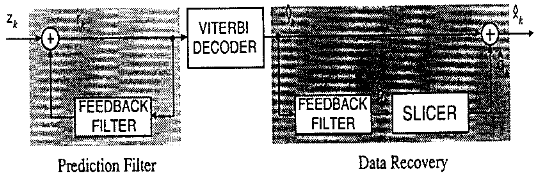
This problem can be overcome by employing the precoding techniques originally proposed by Tomlinson[16] and Harashima[17]. Tomlinson-Harashima (TH) precoding avoids the error propagation problem by simply moving the feedback filter of the DFE to the transmitter with a nonlinear modulo operation. The coefficients of the feedback filter can be calculated by the remote receiver during the training period. Assuming the characteristics of the channel are slowly varying, the mismatch due to variation can be sufficiently compensated by a linear equalizer. The TH precoding can be nicely applied to trellis coded modulation schemes, but it can support only lattice types of signal constellation.

Recently, new forms of precoding have been proposed to overcome the drawbacks of previous precoding[5,6]. They can be used with any signal constellation mapping and shaping scheme. New precoders employs a slice instead of a modulo operator in the TH precoder. A new flexible precoding scheme adopted for V. 34 is depicted in Fig. 6. The feedback filter in the transmitter is analogous to the feedback filter in the TH precoder. The use of a few taps may be practical for the finite impulse response feedback filter. The use of the precoder increase the average signal power in the transmitter, but the loss due to this is less than 0.3 dB for rates higher than 5 bits per symbol. When the attenuation at band edges is not severe or the rate is low, it may not be advisable to employ this precoding technique.

It should be noted that the above two methods need to be properly applied depending on the channel conditions. It is known that both perform identically on ideal AWGN channels. On non-ideal Gaussian noise channel, however, precoding is known to be better than pre-emphasis, particularly when



(a) The transmitter for flexible precoding



(b) The receiver for flexible precoding

⟨Fig. 6⟩ Structare of flexible precoding

the channel band edges are severely distorted. On the other hand, pre-emphasis is less susceptible to non-Gaussian signal-dependent impairments. In practice, depending upon the major concern of channel impairments, employment of equalization methods should be considered as an implementation option.

IV. Concluding Remarks.

In response to rapidly emerging local access demand, local exchange carriers (LECs) may use basic rate ISDN as a short-term strategy while xDSL technologies are being matured. However, point-to-point xDSL systems will provide LECs a mid-term solution unless more integrated xDSL architectures are developed. Similarly, cable modems with HFC networks are likely to give carriers a near-term strategy while other alternatives can be developed. On the other hand, there have been significant breakthroughs in the digital modulation technologies in the last few decades. The development of automatic equalization, combined coding and modulation, echo cancellation and signal shaping and coding techniques are major advances among them. Most of these technology progress successfully applied to the implementation of voice-band modems including V.34 can also be applied directly to other local access applications with the help of dramatic advances in VLSI technologies. With the appearance of general purpose DSP chips having a processing horse power of up to 1600 MIPS, it is quite feasible to implement multiple modulation schemes on a single DSP chip as a software configurable modem. Although there is no definite long-term solution for local access service providers including LECs and CATV companies, these advances in technologies combined with strong market demand will make it possible to develop an integrated, ubiquitous transmission architecture for a long-term solution shortly after the turn of the century.

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