xDSL Principles and Applications

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Foreword

- xDSL is widely used in the current broadband network. What xDSL technologies are there? How are they implemented? What are the differences between them?

Objectives

- Upon completion of this course, you will be able to:
  - Understand the xDSL technologies.
  - Understand ADSL/ADSL2+ technical principles.
  - Be familiar with the VDSL/VDSL2 technologies.
  - Be familiar with ultra-broadband technologies

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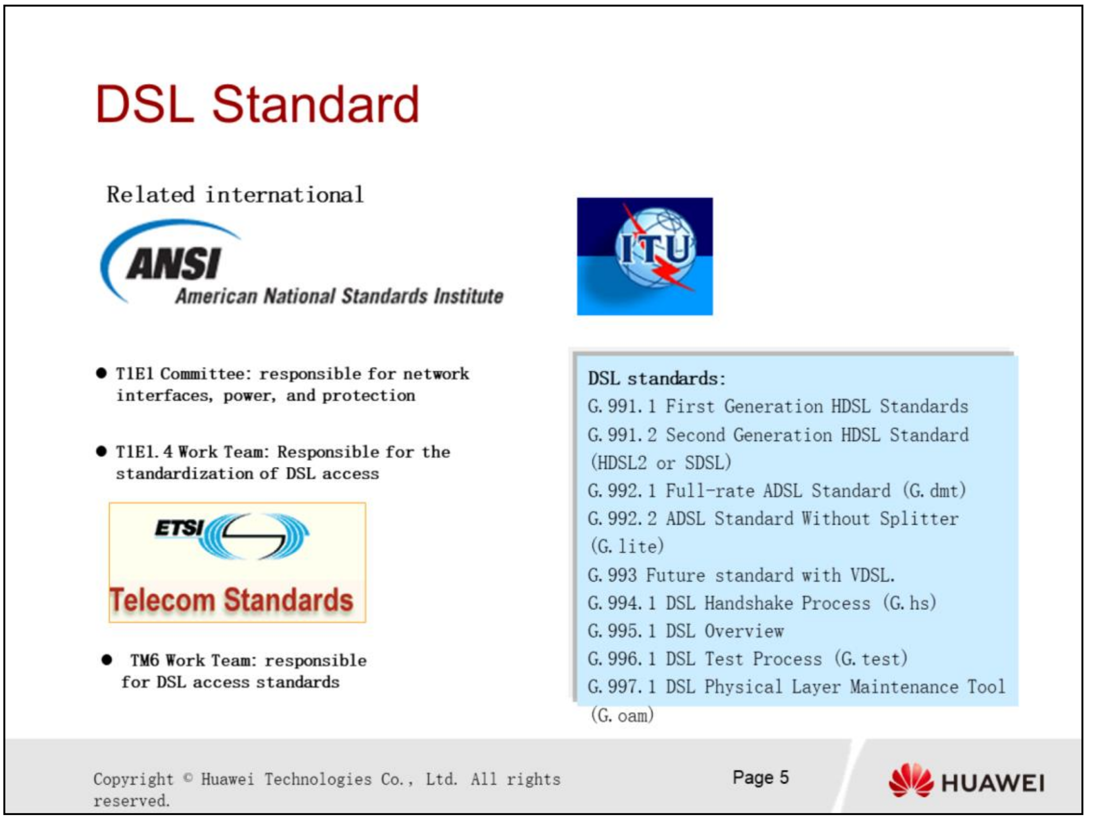

- Currently, there are many organizations working on DSL standards. The most important organizations are the American National Standards Institute (ANSI), the European Telecommunications Standards Institute (ETSI), and the International Telecommunication Union (ITU). In ANSI, the T1E1 committee is responsible for network interfaces, power, and protection, and the T1E1.4 working group is responsible for the standardization of DSL access. In ETSI, the TM6 workgroup is responsible for DSL access standards.
- ANSI and ETSI are regional standard organizations, while ITU is a global standard organization. Currently, the ITU defines the following DSL standards:
  - G.991.1 first generation HDSL standard
  - G.991.2 second generation HDSL standard (HDSL2 or SDSL)
  - G.992.1 full-rate ADSL standard (G.dmt)
  - G.992.2 ADSL standard without splitter (G.lite)
  - G.993 is reserved future VDSL standard
  - G.994.1 DSL handshake process (G.hs)
  - G.995.1 DSL overview
  - G.996.1 DSL test process (G.test)
  - G.997.1 DSL physical layer maintenance tool (G.oam)

ADSL Standard

- G. 992. 1 Annex A —— ADSL over POTS
  - The upstream and downstream spectrums are 25 - 138 kHz and 138 - 1104 kHz respectively. ADSLs of this type are classified into non-overlap and overlap ADSLs and most commonly used.
- G. 992. 1 Annex B —— ADSL over ISDN
  - Supports ISDN and ADSL on the same twisted pair.
- G. 992. 1 Annex C
  - This is an ADSL in the G. 961 (ISDN) crosstalk environment with time division duplex. It is mainly used in Japan.
- G. 992. 2: G. Lite or splitterless ADSL
  - The upstream spectrum is the same as that of the Annex A. The downstream spectrum is 138 - 552 kHz. The upstream and downstream transmission rates are 512 Kbps and 1536 Kbps respectively.

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- G. 991. 1 first generation HDSL standard
- G. 991. 2 second generation HDSL standard (HDSL2 or SDSL)
- G. 992. 1 full-rate ADSL standard (G. dmt)
- G. 992. 2 ADSL standard without splitter (G. lite)
- G. 993 is reserved future VDSL standard
- G. 994. 1 DSL handshake process (G. hs)
- G. 995. 1 DSL overview
- G. 996. 1 DSL test process (G. test)
- G. 997. 1 DSL physical layer maintenance tool (G. oam)

ADSL2 Standard

- G.992.3
  - ADSL2 is developed based on ADSL and has been established in June 2002.
  - In G.992.3 Annex I and J, the support for the full digital loop mode is added. The Annex I is applicable to the scenario where the adjacent route pair is POTS, and the Annex J is applicable to the scenario where the adjacent route pair is ISDN.
  - G.992.3 Annex L is the so-called long distance ADSL2 or READSL2.
- G.992.5
  - Based on ADSL2, ADSL2+ extends the downstream frequency band from 1.104 MHz to 2.208 MHz, and the number of sub-bands increases from 256 to 512. Therefore, the downstream rate increases greatly.

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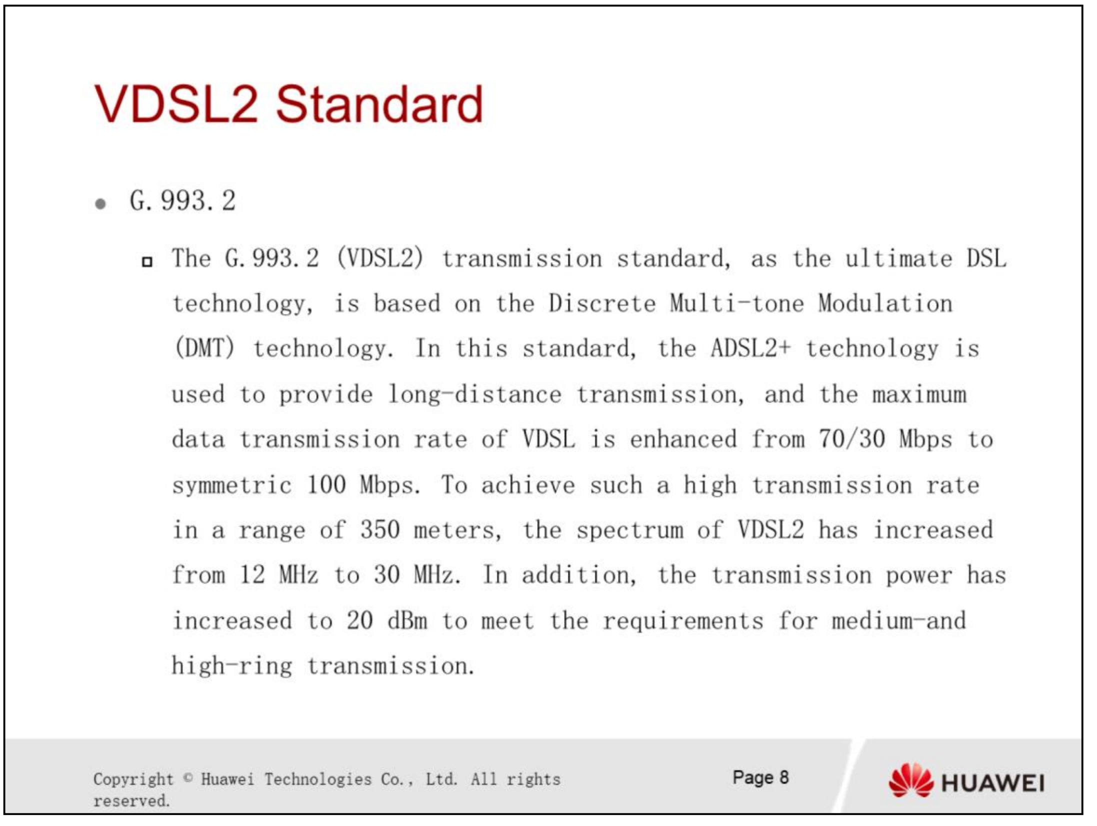

- In ITU-T, the standard numbering is G.993.2, which is a formal standard released by ITU-T in May 2005. To launch the VDSL2 standard, ITU formulated the RFC3728 MIB standard in October 2004.

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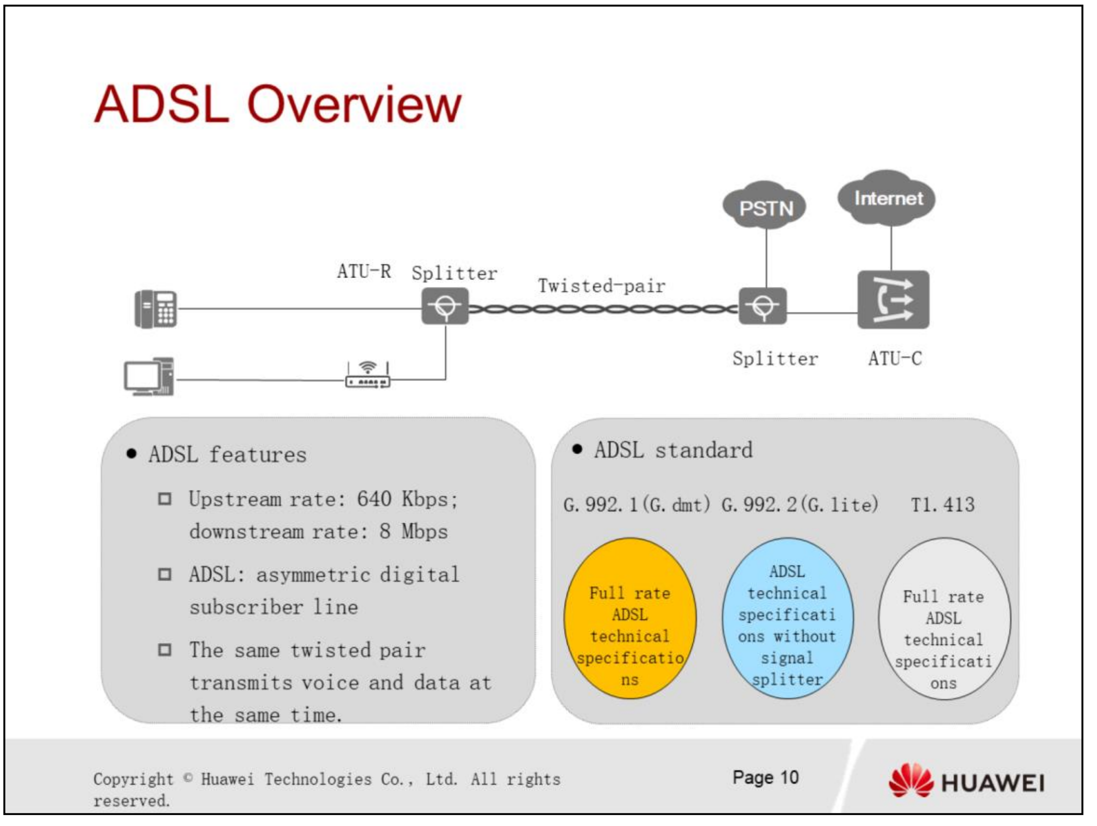
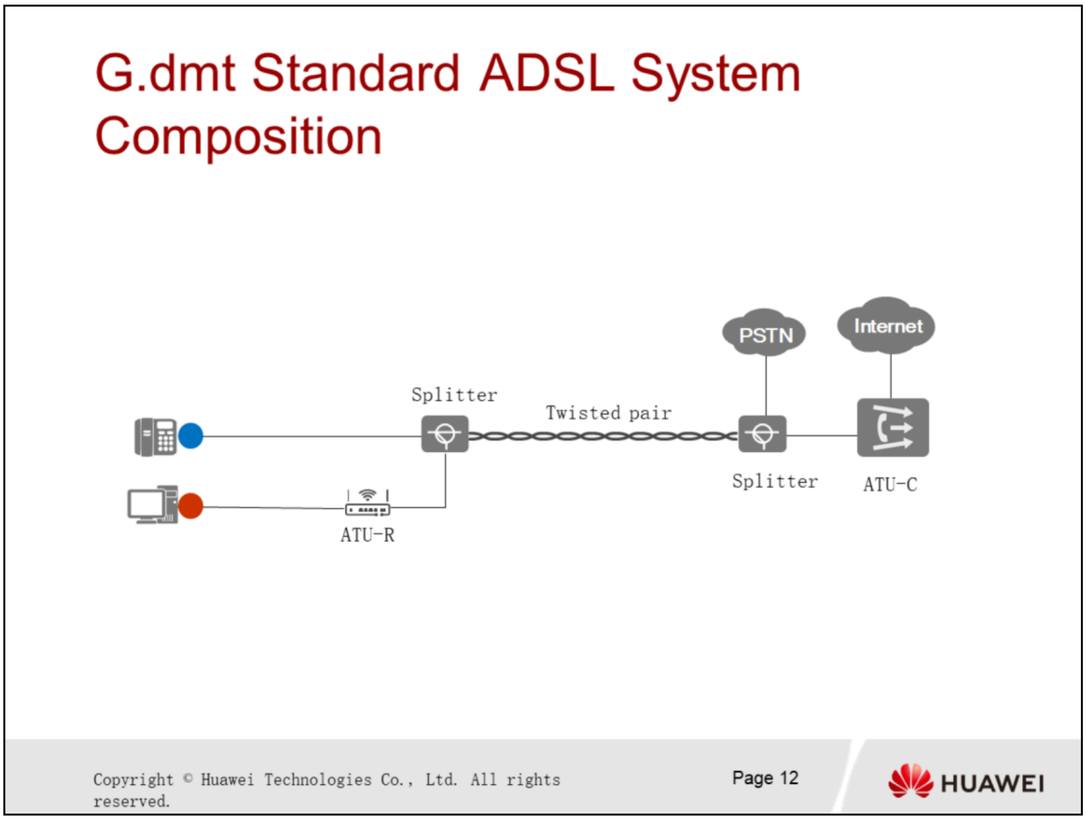
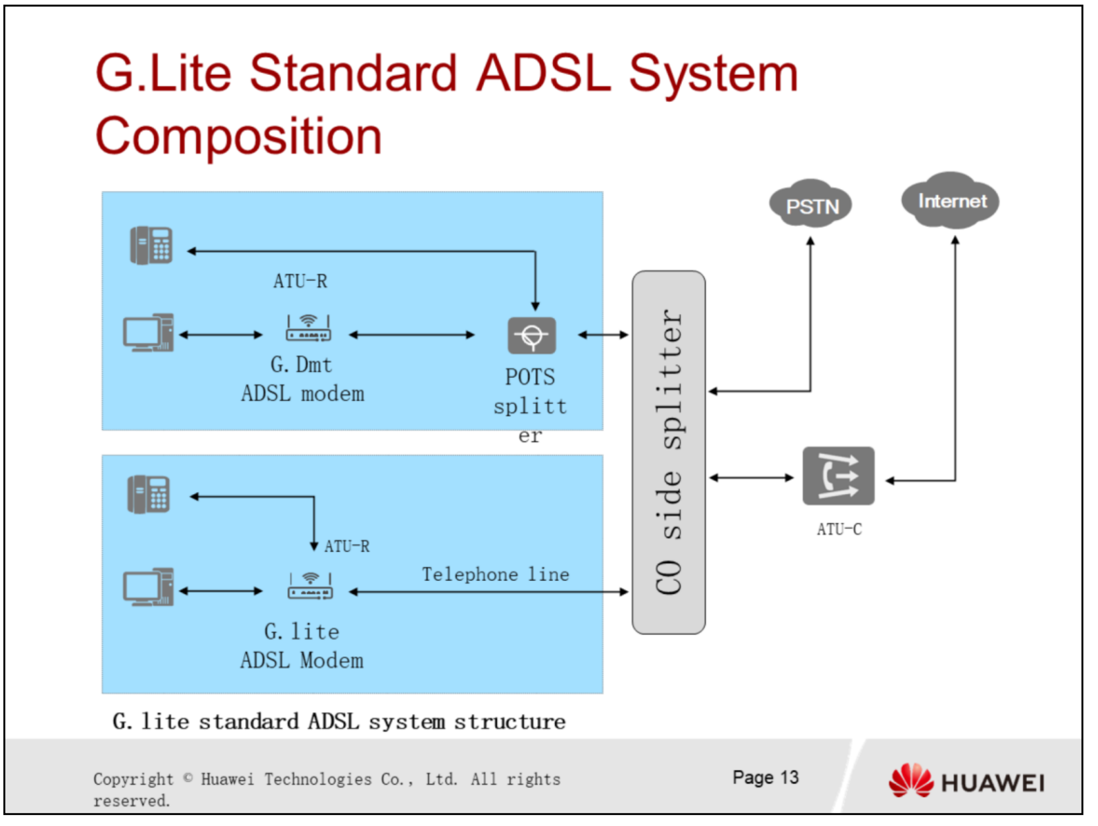


- ADSL is a DSL technology with asymmetric transmission rates in the upstream and downstream directions. Here, upstream transmission refers to the transmission from the user side to the central office, and downstream transmission refers to the transmission from the central office to the user side.
- The ADSL downstream transmission rate can reach up to 8 Mbps but the maximum upstream transmission rate is 640 Kbps. The downstream rate is far greater than the upstream rate.
- The ADSL technology can transmit data signals and traditional analog voice signals at the same time on the same twisted pair.
- ADSL is a widely used access technology because of its technical features and ease of use.
    - Firstly, asymmetric transmission of ADSL is of special significance. On one hand, in many DSL applications, users usually obtain a large amount of data from the backbone network, but transmit far less data to the backbone network. For example, when a user accesses the Internet and video on demand (VoD) services, a large amount of data needs to be downloaded at a high rate, but only some addresses and simple commands is sent to the backbone network. On the other hand, asymmetric transmission can greatly reduce near-end crosstalk.
    - Secondly, compared with other DSL technologies, ADSL makes it possible

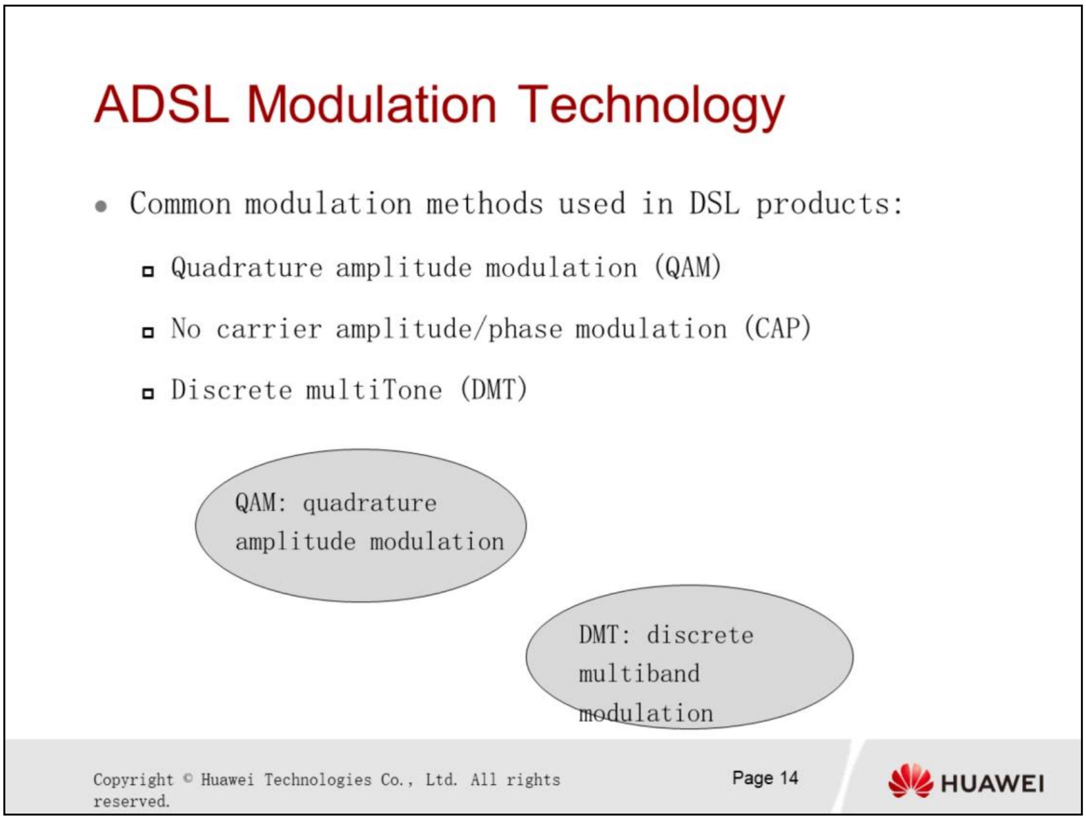
to provide traditional voice services in the same twisted pair at the same time. In this way, the cost of cable routing is saved.



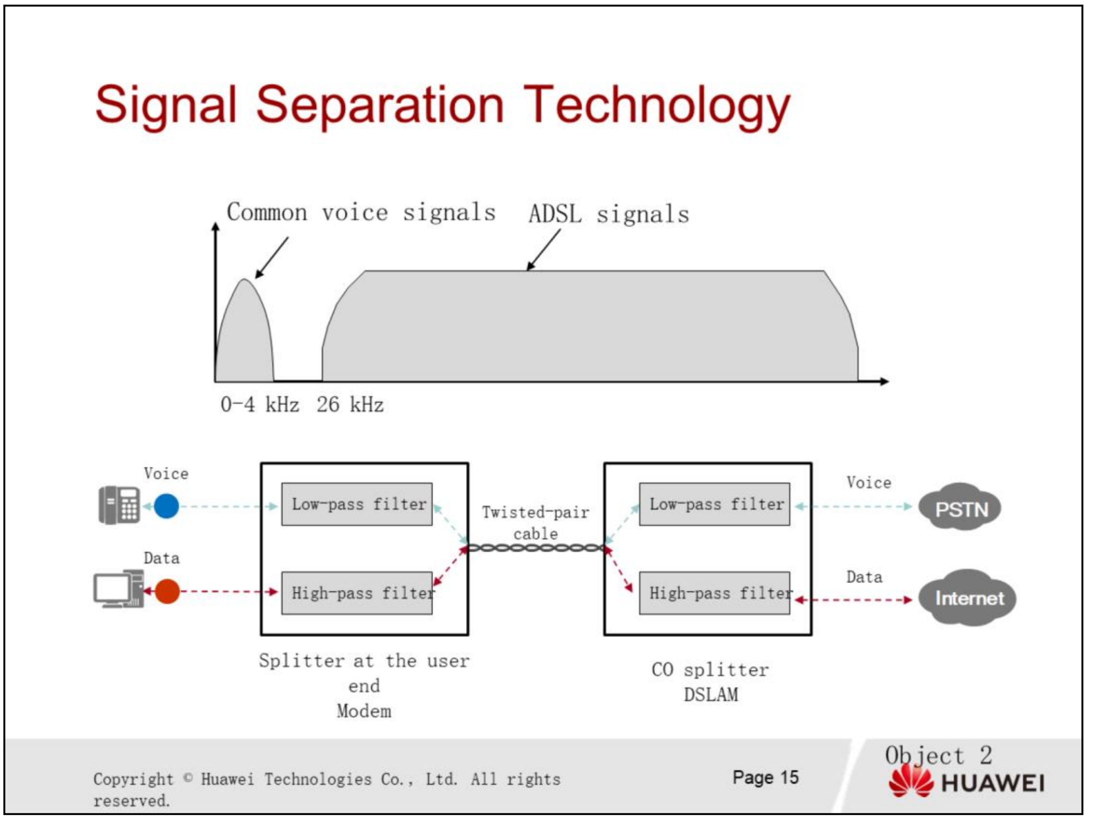
- This is the structure of an ADSL system complying with the G.dmt standard. The ATU-R refers to the modem at the ADSL subscriber side. The ADSL transmission rate is high enough to support a home network or a small office LAN. The data sent from a PC first enters the home or office network. Then the ATU-R converts the data into signals that can be transmitted on the telephone line. To transmit data and voice signals on the same telephone line at the same time, the ATU-R and telephone are connected to the POTS splitter, and the hybrid transmission of data and voice signals on one twisted pair is implemented in different frequency bands.
- After arriving at a CO, mixed voice and data signals are separated by a splitter at the CO side. Voice signals are transmitted through the telephone network, and data signals are transmitted through the high-speed data network. ATU-C refers to the ADSL CO modem. At the CO side, each subscriber has an independent splitter connected to the ATU-C. Therefore, a DSL network uses point-to-point private line transmission. After passing through the ATU-C, data is sent to the DSL access multiplexer (DSLAM) which aggregates multiple subscriber lines to transmit data streams at a higher rate. The DSLAM connects to the backbone network through high-speed network interfaces such as ATM or STM, and sends data to servers of network service providers through the high-speed data network. Currently, DSLAM devices are generally bound to ATU-C devices.



- In the G.dmt standard, a splitter is used at the subscriber side to separate data and the voice signals by frequency to ensure that the two different types of signals can be transmitted in the same twisted pair. However, installing a splitter can be very complicated. Experienced technicians are required to install and commission the splitter, and the telephone lines may need to be reconstructed to some extent. Therefore, it is hoped that ADSL can be used without splitter. The G.lite standard is therefore formulated to implement ADSL with no splitter.
- In this figure, the upper part shows the ADSL system structure in the G.dmt standard, and the lower part shows the ADSL system structure in the G.lite standard. The difference is that G.lite ADSL has no splitter, out-band signals become interference noise signals, and data and voice transmission interfere with each other. Due to the influence of the interference, the transmission rate of the G.lite is much lower than that of the G.dmt. In the ITU G.dmt standard, the maximum downstream and upstream transmission rates are 6.144 Mbps and 640 Kbps respectively. In the G.lite standard, the maximum downstream and upstream transmission rates are 1.536 Mbps and 512 Kbps respectively. It can be seen that the downstream transmission rate of the G.lite ADSL is greatly reduced.

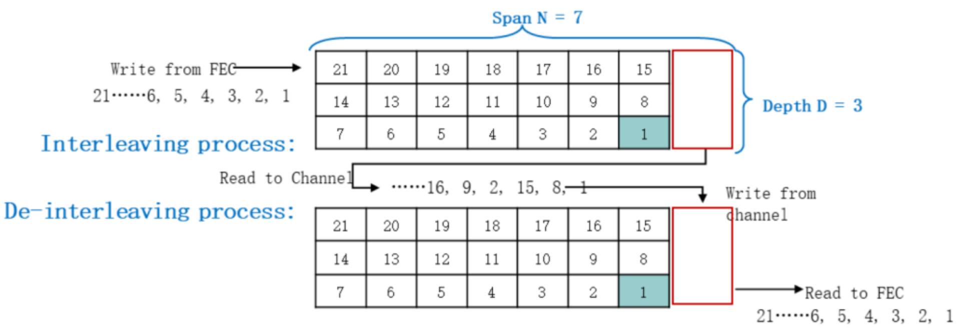


- QAM modulation uses a sine and cosine waves with the same frequency component to transmit information. All waves pass through a single channel at the same time. The amplitude of each waveform (including direction) represents a binary bit stream to be transmitted. CAP modulation is similar to QAM but has no carrier signal.
- DMT combines QAM and FDM technologies. In 1995, ANSI T1.413 stipulates that ADSL line encoding adopts the DMT technology.
- The DMT modulation and encoding technology improves the frequency utilization and can transmit signals with higher bit rates in a limited frequency band. It divides the entire channel into a maximum of 256 4.3125 kHz subcarriers, and implements 256-point constellation encoding in each discrete subcarrier according to the respective signal-to-noise ratio (SNR). In this way, one symbol in each subcarrier may represent 4 to 8 bits, greatly improving the spectrum utilization and enabling a higher ADSL transmission rate.



- In ADSL, data and voice must be transmitted on separate frequency bands. ADSL uses a frequency band higher than 30 kHz, whereas common voice signals are in a frequency band lower than 4 kHz. Splitters are used to separate the data from voice by frequency band.
- A splitter consists of a 3-port low-pass/high-pass filter group. The low-pass filter can filter allows only low-frequency voice signals to pass and suppresses the interference from data signals. The high-pass filter allows only high-frequency data signals to pass and suppresses the interference from voice signals. The voice and data signals are filtered by a splitter at the subscriber side and then transmitted on the same twisted pair in different frequency bands. Each subscriber-side splitter maps a CO-side splitter which separates the voice/data mixed signals transmitted on the twisted pair. A CO-side splitter also consists of a 3-port low-pass/high-pass filter group in which the high-pass filter separates data signals while the low-pass filter separates voice signals. After separation, voice signals are transmitted through the PSTN network, and data signals are transmitted through a dedicated high-speed data exchange network. In this way, data transmission is not restricted by the PSTN system, and can reach a rate much greater than 64 Kbps.

Interleaving Principle



Bit Sequence (Without Interleaving)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Bit Sequence (Interleaved)	1	8	15	2	9	16	3	10	17	4	11	18	5	12	19	6	13	20	7	14	21
Burst Error			x	x	x																
RX Bit (No Interleaving)	1	2	x	x	x	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Received Bit (Interleaved)	1	x	3	4	5	6	7	8	x	10	11	12	13	14	x	16	17	18	19	20	21

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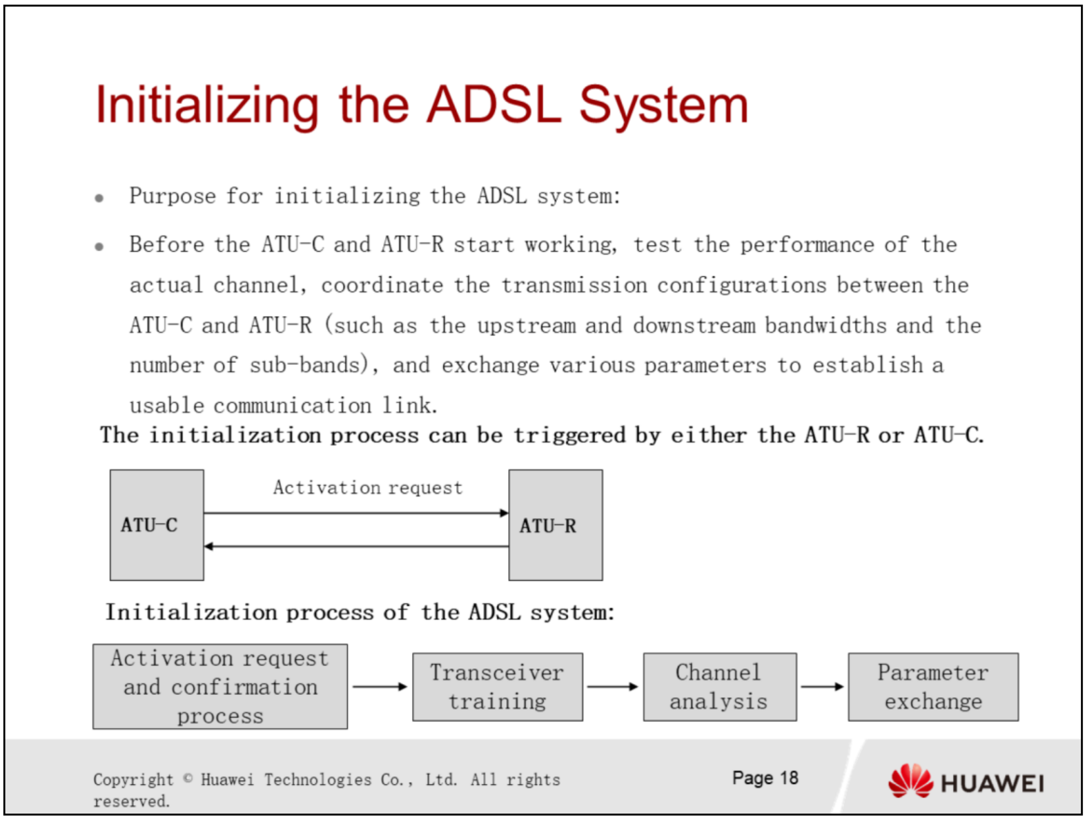
- The setting of interleaver parameters has a huge impact on the performance of the ADSL service. To facilitate the understanding of interleaving parameters, we introduce the working principles of an interleaver in detail using a typical interleaving mode as an example.
- First, let's see how an interleaver processes data at the transmit end. The elements 1, 2, 3, 4, 5, 6..., and 21 to be transmitted come out from a forward error correction (FEC) encoder, and are stored in a matrix with 3 rows and 7 columns row by row. After the matrix is full, elements are sent to the channel column by column. This is the interleaving process of an interleaver. At the receive end, how does the interleaver de-interleave and restore the original data stream? The receive end writes the received data column by column to a matrix with the same size. After the matrix is full, the receive end reads the data row by row, restores the original data, and sends the data to the FEC for decoding. This is the de-interleaving process of an interleaver.



- The number of available sub-carriers mentioned above depends on the result of channel analysis during the initialization of the ADSL system. This part describes the process of ADSL initialization in detail.
- The purpose of ADSL initialization is to test the performance of the actual channel, coordinate the transmission configurations between the ATU-C and ATU-R (such as the upstream and downstream bandwidths and the number of sub-bands), and exchange various parameters to establish a usable communication link before the ATU-C and ATU-R start working.
- The initialization process can be triggered by either the ATU-R or ATU-C.
- In initialization triggered by the ATU-C, the ATU-C sends an activation request and waits for a response from the ATU-R upon system power-on, signals loss, or self-check completion. The ATU-C performs this process for a maximum of 2 times. If the ATU-R does not respond, the ATU-C waits for the ATU-R to send an activation request or waits for the network to send a retrial instruction.
- In initialization triggered by the ATU-R, the ATU-R sends activation requests continuously upon power-on or self-check completion to start initialization.
- The ADSL initialization process can be divided into four steps: activation request and acknowledgment, transceiver training, channel analysis, and parameter exchange.

ADSL2 Standard

- ADSL2 is developed based on ADSL and has been established in June 2002 (G.992.3).
- The ADSL2 frequency band division is similar to the current ADSL (the upstream and downstream frequency bands are both up to 1104 kHz). Theoretically, the maximum downstream rate can reach 12 Mbps and the maximum upstream rate can reach 1.2 Mbps.
- In G.992.3 Annex I and J, the support for the full digital loop mode is added. The Annex I is applicable to the scenario where the adjacent route pair is POTS, and the Annex J is applicable to the scenario where the adjacent route pair is ISDN.
- G.992.3 Annex L is the so-called long distance ADSL2 or READSL2

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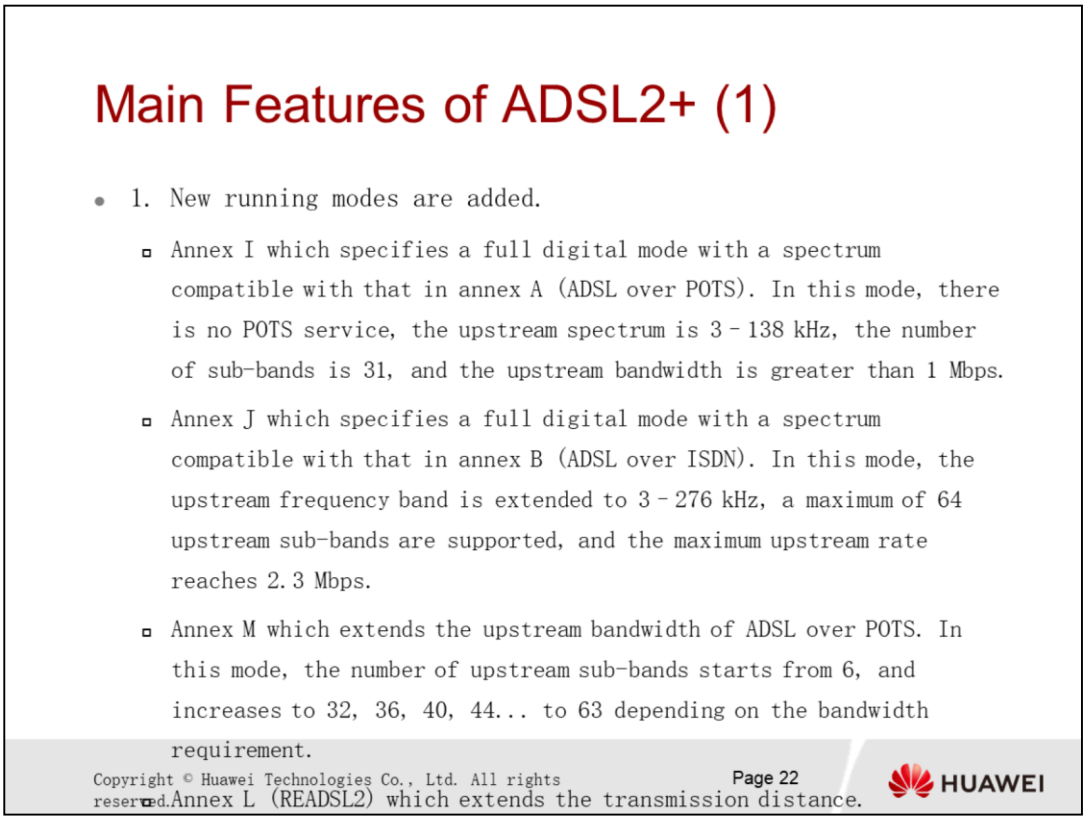
Comparison Between ADSL2+ and ADSL

- Better performance
- Broadband test function
- Lower transmit power
- The ADSL2+ provides a higher rate for subscribers in a short loop within 2.5 km. In large and medium cities in China, more than 80% of subscriber loops is within the 2.5 km.

- The ADSL2 standard adopts an enhanced modulation mode, which can better reduce the impact of line noise on signals, obtain higher line encoding gain, and increase the connection rate. ADSL2 uses variable overhead bits with an overhead rate of 4 - 32 Kbps while the ADSL overhead rate is fixed at 32 Kbps. It can be considered that ADSL2 increases the speed by 50 Kbps and transmission distance by 200 m compared with ADSL (6% greater coverage area).
- The ADSL2 standard requires the line noise and signal attenuation of each carrier in DMT mode to be tested to determine whether ADSL services can be provisioned on the line. It also requires real-time monitoring over ADSL connections.
- The ADSL2 standard implements traffic-based power control. When a large amount of data needs to be transmitted, for example, during large file download, the line power increases to the standard ADSL power level L0. When a small amount of data or no data needs to be transmitted, for example, during web pages browsing, the power decreases to L2 and L3 specified in the ADSL2 power levels. Decreasing the line power can effectively reduce the crosstalk between line pairs.



- 1. New running modes are added.
- There are 3 ADSL running modes: ADSL over POTS (ADSL annex A in which the POTS service exists on the same line pair), ADSL over ISDN (ADSL annex B in which the POTS service exists on the same line pair), and ADSL annex C (ADSL in the TCM-ISDN crosstalk environment, which is mainly used in Japan). In addition to the preceding 3 modes, the following modes are added to the ADSL2/ADSL plus:
- Annex I which specifies a full digital mode with a spectrum compatible with that in annex A (ADSL over POTS). In this mode, there is no POTS service on the line, the upstream spectrum is 3 - 138 kHz, the number of sub-bands is 31, and the upstream bandwidth is greater than 1 Mbps.
- Annex J which specifies a full-digital mode with a spectrum compatible with that in annex B (ADSL over ISDN). In this mode, there is no ISDN service on the line (used when ADSL over ISDN coexists), the upstream frequency band is extended to 3 - 276 kHz, a maximum of 64 upstream sub-bands are supported, and the maximum upstream rate reaches 2.3 Mbps.
- Annex M which extends the upstream bandwidth of ADSL over POTS. In this mode, the number of upstream sub-bands starts from 6, and increases to 32, 36, 40, 44,...to 63 depending on the bandwidth requirement. In this way, with the same total transmit power, Annex M achieves the upstream transmission rate of Annex J, and achieves the downstream transmission rate of Annex B in overlap and non-overlap modes.
- Annex L (READSL2) which extends the transmission distance.
- In addition, the ADSL standard supports only STM (such as PCM interface) and ATM (UTOPIA) interfaces, while ADSL2/ADSL plus also provides PTM (packet) interfaces to carry HDLC on ADSL in non-ATM transmission mode.

Main Features of ADSL2+ (2)

- 2. Higher transmission rate
  - The modulation rate is improved, the encoding gain is improved, the frame header overhead is reduced, the initialization state machine is improved, and an enhanced signal processing algorithm is adopted. ADSL2 improves the modulation efficiency by making trellis encoding and 1-bit constellation encoding mandatory.
  - Less overhead: In the first generation ADSL standard, the overhead is fixed to 32 Kbps. In ADSL2, the overhead rate can be adjusted within 4 – 64 Kbps, which generates obvious effects in the case of a line transmission line.
  - ADSL2plus uses a wider frequency (tone 32 – 511) and more sub-bands (512) to support a maximum downstream rate of 24 Mbps.

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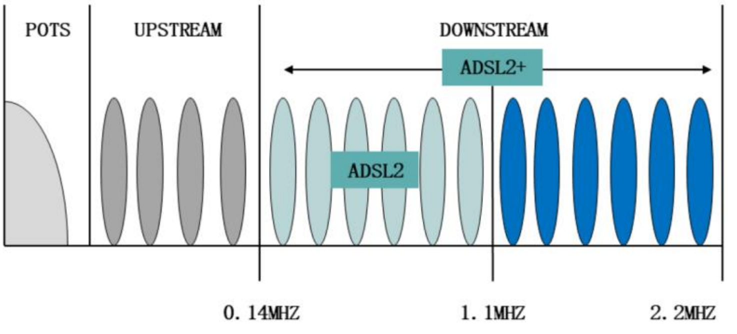
Main Features of ADSL2+ (3)

- ADSL, ADSL2, and ADSL2+ spectrum distribution



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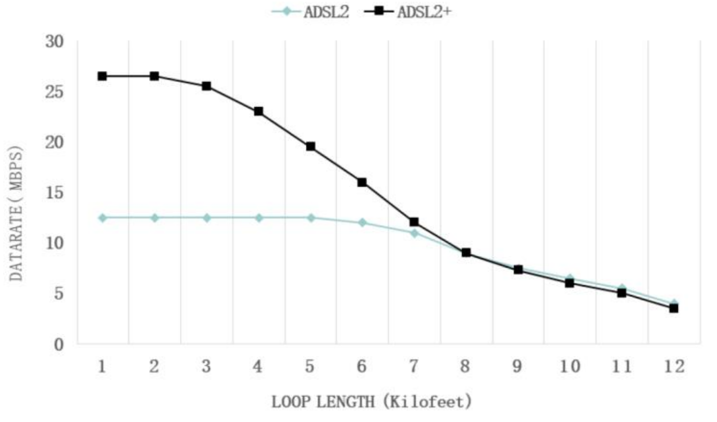
Main Features of ADSL2+ (4)

- Rate comparison between ADSL2 and ADSL2+



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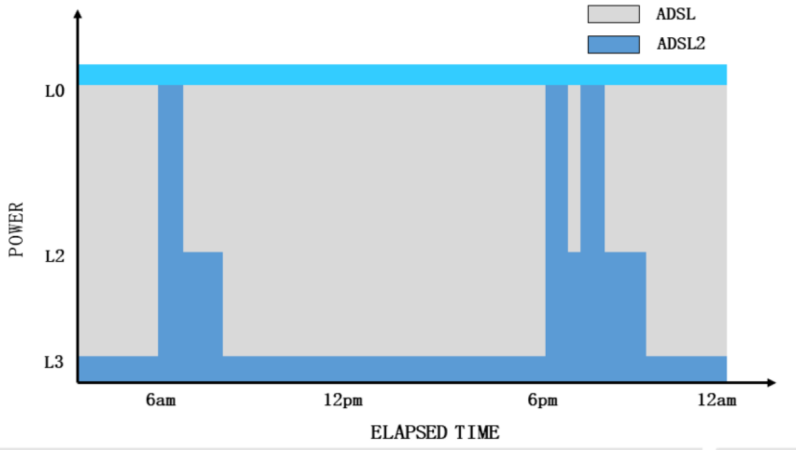
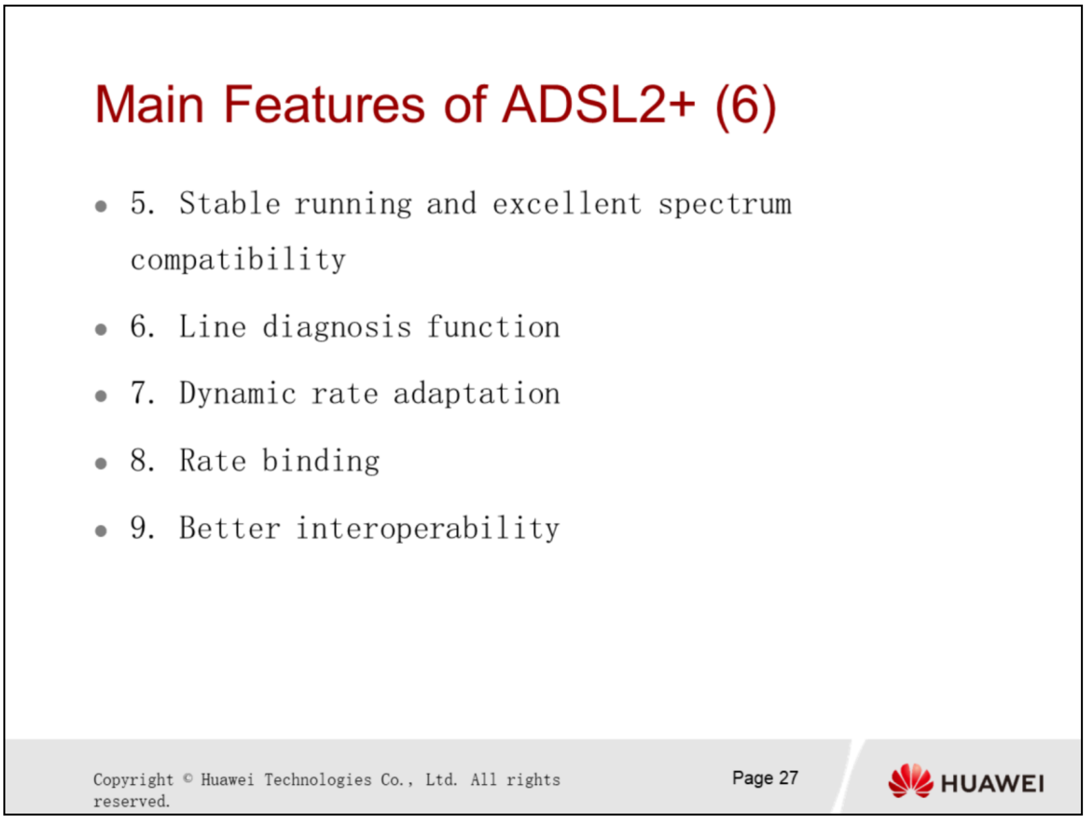
Main Features of ADSL2+ (5)

- 3. Longer transmission distance
- 4. Lower power consumption



- 3. Longer transmission distance
  - ADSL2/ADSL plus supports a transmission distance no less than 6.5 km at rates of 192 Kbps/96 Kbps.
  - ADSL2 supports the 1-bit constellation while ADSL supports a minimum constellation of 2 bits.
  - ADSL2 annex L adopts new spectrum division. When the distance exceeds 4 km, the sub-bands above tone 128 are turned off, and the transmit power of sub-bands with lower tones are increased to extend the transmission distance.
  - The frame overhead can be flexibly configured to provide a 28 Kbps bandwidth, which is very important in long-distance transmission.
  - The tone ordering and pilot tones determined by a receiver can reduce the probability of activation failures due to ADSL pilot tones with an excessively low SNR. In addition, the 2 bits on the pilot tones can increase the bandwidth by 8 Kbps.
- 4. Lower power consumption
  - The noise margin is reduced by reducing the transmit power. In this way, unnecessary power consumption is saved while the system stability is ensured.
  - The new low-power mode L2 reduces the transmit power to 30% of the normal power when no data is transmitted. In L2 mode, the power is sufficient for transmitting only necessary management messages and synchronization signals (for example, 1-bit constellation). The power can be quickly restored when subscriber data is transmitted.
  - The CO and CPE of the ADSL2/ADSL plus provide the power cut back function in the range of 0 - 40 dB to effectively reduce the transmit power during normal operation. (In an ADSL system, only the CO has this

function in the range of 0 – 12 dB.)



- 5. More stable running and better spectrum compatibility
  - The receiver determines the tone ordering based on the channel analysis result and selects the best tone as the pilot tone, making ADSL connections more stable.
  - Tones are disabled during the training. The receive end tests the RF interference (RFI) signal distribution to avoid RFI and reduce the crosstalk to other line pairs.
  - Excellent dynamic adaptability: The enhanced bit swap dynamically changes the line rate.
  - Power cutback to a maximum of 40 dB in the receiver and transmitter reduces the near-end echo and crosstalk.
  - The receiver determines the pilot tone to prevent activation failures caused by line bridge connectors or AM interference.
  - The training process is shortened to quickly recover connection synchronization from errors.
- 6. Line diagnosis function
  - Supports the dual-end test function. The CO and CPE can be trained, and line parameters can be obtained through a dedicated line test process.
- 7. Dynamic rate adaptation
  - The Seamless Rate Adaptive (SRA) technology is used to resolve crosstalk and AM interference, and adjust the connection rate without

being perceived by subscribers to adapt to environment changes.

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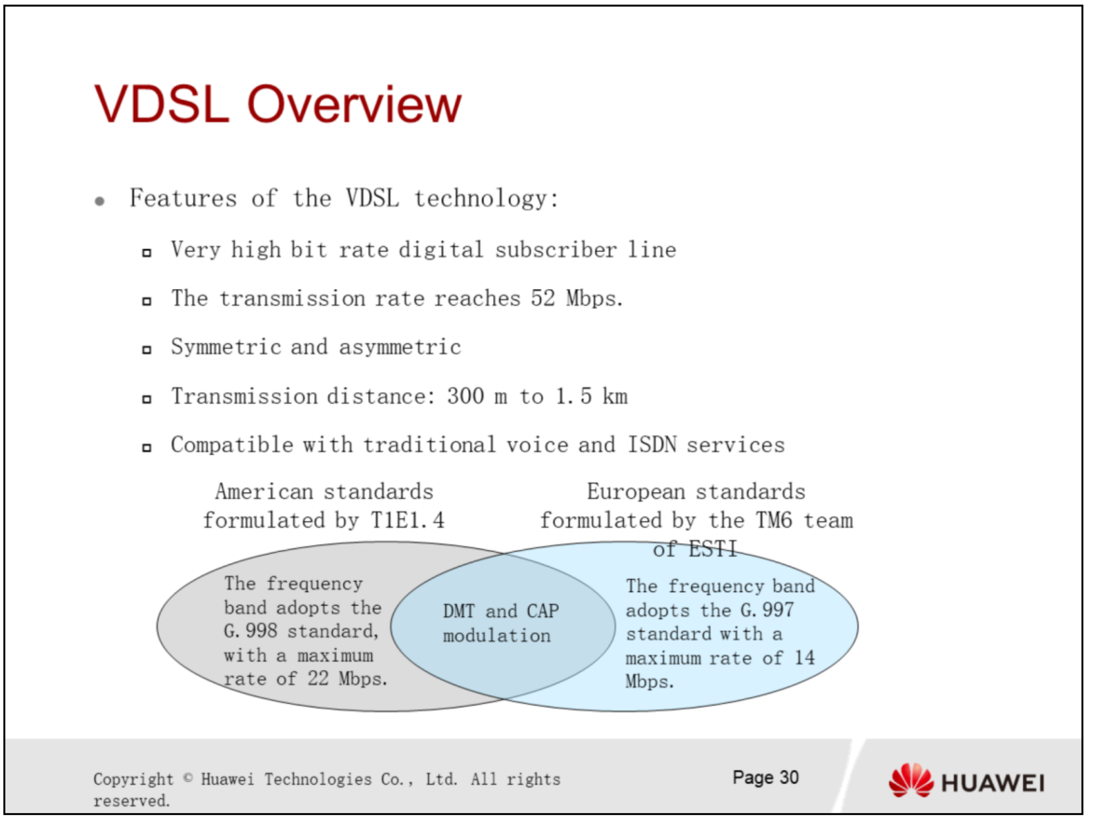


- The preceding two types of DSL technologies, ADSL and SHDSL, have a maximum transmission rate of 8 Mbps. VDSL which is short for very high speed digital subscriber line is a new generation of high-speed DSL technology.
- VDSL can reach a maximum transmission rate of 52 Mbps on common twisted pairs. It provides various transmission rates and multiple working modes, including symmetric and asymmetric transmission, to meet the requirements of different customers. Because the transmission rate of VDSL is high, the twisted pairs used in VDSL are shorter, usually from 300 m to 1 km. The length of the twisted pairs is inversely proportional to the transmission rate.
- Compared with ADSL, VDSL uses a higher frequency band than PSTN and ISDN frequencies on twisted pairs. Therefore, VDSL is compatible with existing traditional telephone services as well as ISDN services. VDSL also uses passive filters as signal splitters to support voice and ISDN transmission. The basic working principles of VDSL are similar to that of ADSL.
- VDSL is a video and data transmission technology over the voice frequency band. It provides multiple working modes and can transmit data at a high rate within a short distance. This technology enables telecom operators to use existing twisted pairs to transmit broadband services, such as VoD and high-speed Internet access.
- Currently, the internationally recognized VDSL system complies with the American standard formulated by T1E1.4 and European standard formulated by of ESTI TM6. Both standards adopt the G.998 standard and DMT/CAP modulation

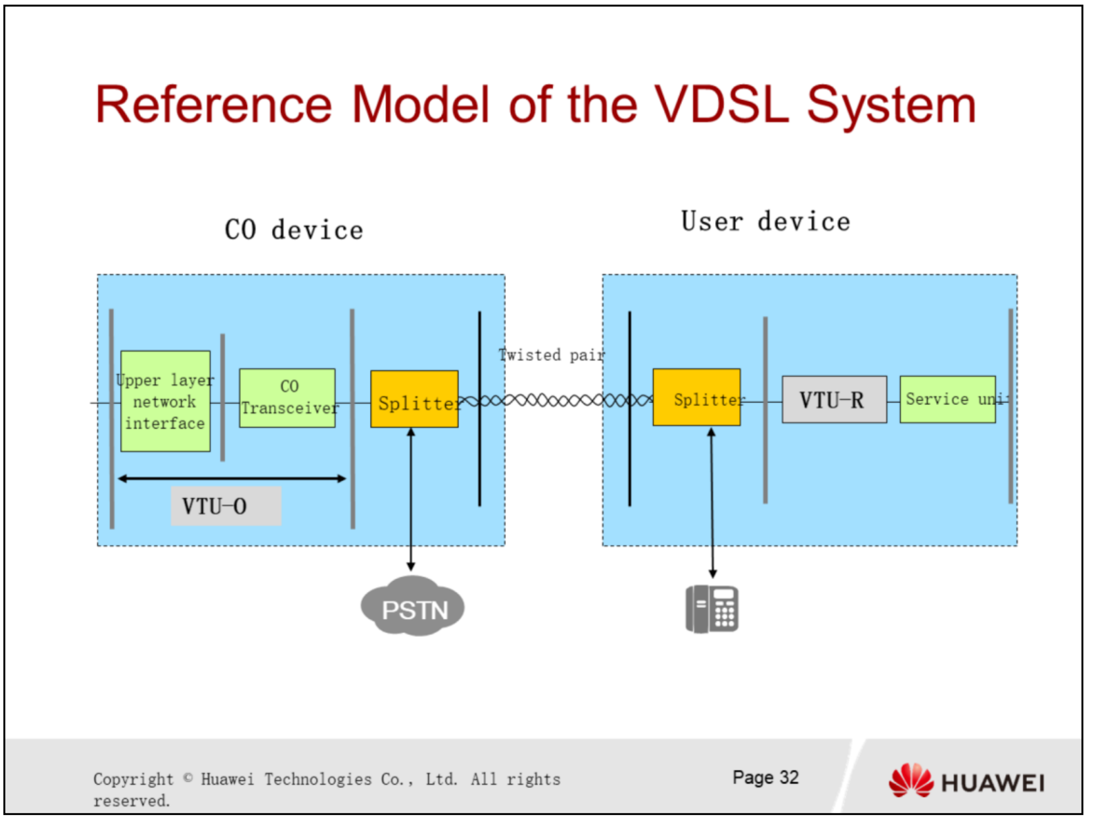
modes. The difference is that the American standard adopts the G.998 standard for baseband planning to provide a highest rate of 22 Mbps, while the European standard adopts the G.998 standard for baseband planning to provide a highest rate of 14 Mbps.

Relationship Between the VDSL Rates and Distances Defined by the ITU

- Although the transmission rate of VDSL is high, the transmission distance is far less than that of ADSL.

Rate / Distance	Downstream Rate (Mbps)	Upstream Rate (Mbps)	Distance (m)
Asymmetric - short distance	52	6.4	300
Asymmetric - medium distance	26	3.2	1000
Asymmetric - long distance	13	1.6	1500
Symmetric - short distance	26	26	300
Symmetric - medium distance	13	13	1000
Symmetric - long distance	6.5	6.5	1500

- Although the transmission rate of VDSL is high, the transmission distance is far less than that of ADSL. This is because high-speed transmission requires complex modulation modes, dense constellation encoding, and outstanding channel characteristics, but the length of transmission lines can pose negative impacts on channel performances.
- At the early stage of VDSL design, the ITU divides VDSL transmission capabilities into long-, medium-, and short-distance transmissions in asymmetric and symmetric transmission modes.



- This is the reference model of the VDSL system. Basic modules include VDSL devices at the CO and subscriber sides. Devices at both sides are connected by twisted pairs through their own splitters. The other end of the CO device is connected to an ONU, and the other end of the subscriber device is connected to a network device or a small LAN.
- VTU-O is short for VDSL transceiver unit at the ONU, and has the same function as the CO-side modem ATU-C in ADSL. VTU-R is short for VDSL transceiver unit at the remote, and has the same function as the subscriber-side modem ATU-R in ADSL.
- Network interfaces defined by applications: Different data interfaces are used to aggregate data from upper-layer protocols to form unified data flows to be transmitted in fast and slow channels as required. Data flows are sent to the lower layer for framing. At the same time, application independent data frames from the lower layer are split and used by different application interfaces and protocols.
- In VDSL, a splitter similar to that in ADSL is used to separate data signals from traditional voice/ISDN signals.

Development History of VDSL2

- The International Telecommunication Union (ITU) recently completed the formulation of a new technical specification which enables global telecom operators to provide the "super" triple services integrating video, Internet, and voice services, with a rate 10 times faster than that of ordinary ADSL.
- ITU-T recommendations on VDSL2 enable telecom operators to provide high-definition television (HDTV), video-on-demand (VoD), videoconferencing, high-speed Internet access, and advanced VoIP voice services through standard copper telephone lines, giving telecom operators the capability to compete with cable providers and satellite operators.

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Advantages of VDSL2

- The rate can reach 10 times the average ADSL rate, and the maximum rate can reach 100 Mbps at 0 distance, effectively supporting triple play of video, Internet, and voice services.
- VDSL2 not only has the long-distance transmission capability of the ADSL2+ technology, but also increases the data transmission rate of the VDSL from 70 Mbps (downstream) /30 Mbps (upstream) to 100 Mbps (downstream) /100 Mbps (upstream). To achieve such a high transmission rate within 350 meters, the working frequency of VDSL2 is increased from 12 MHz to
30 MHz.
- To meet the access requirements of medium and long distance loops, the transmit power of VDSL2 is increased to 20 dBm, and the echo cancellation technology is also specified, so that the transmission performance is similar to that of ADSL in long-distance transmission scenarios.

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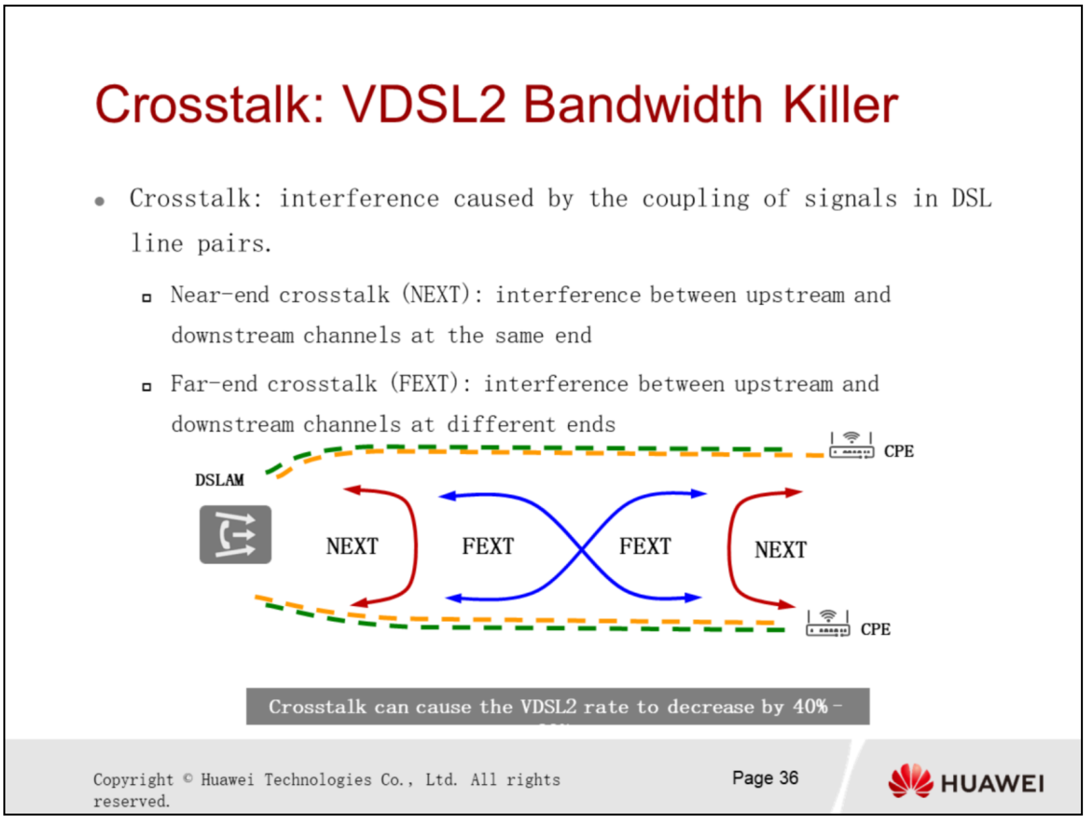
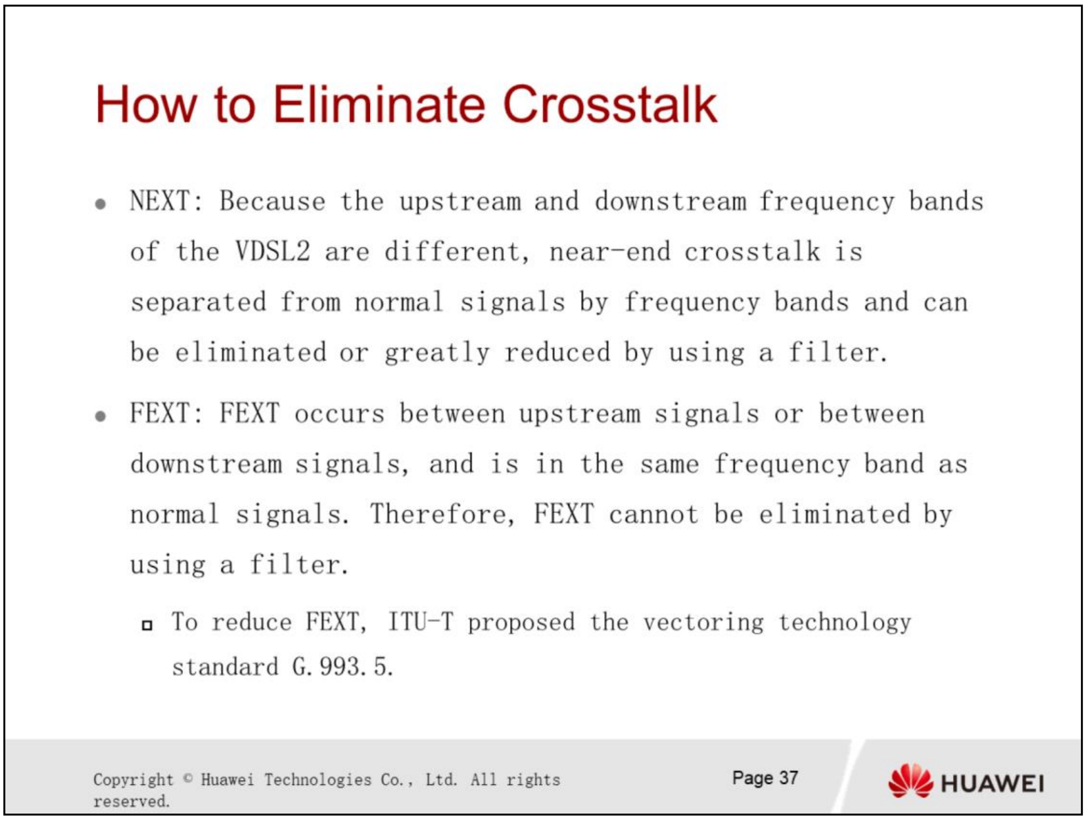


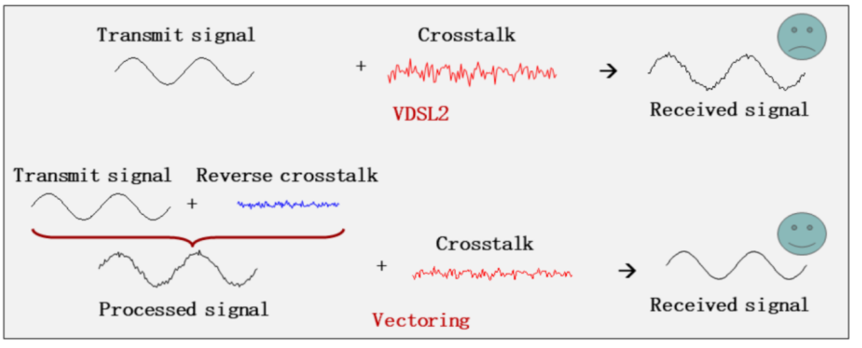
- VDSL2 can provide a higher bandwidth within 1 km (the theoretical rate can reach 100 Mbps), and has become the mainstream access mode of the last mile in an FTTx network. It makes high-speed Internet access possible and support abundant services. However, VDSL2 occupies a high frequency band, resulting in serious crosstalk between lines. As a result, the bandwidth of multi-wire interconnection decreases significantly compared with that of single-wire interconnection.
- VDSL2 crosstalk is classified into near-end crosstalk (NEXT) and far-end crosstalk (FEXT). Figure 1 shows a schematic diagram of the two types of crosstalk.
  - In NEXT, signals in a line pair are coupled and sent back to a near-end receiver. For example, in bundles of line pairs, the upstream transmission of one line pair interferes with the downstream transmission of another line pair.
  - In NEXT, signals in a line pair are coupled and sent to a far-end receiver. For example, in bundles of line pairs, the upstream transmission of one line pair interferes with the upstream transmission of another line pair.



- Because VDSL2 adopts frequency division multiplexing (FDM), signals sent in the interference line pair and signals received by interfered line pair in NEXT occupy different frequency bands. Therefore, the impact of the NEXT can be eliminated or greatly reduced by using a filter.
- However, signals sent in the interference line pair and signals received by interfered line pair in FEXT occupy the same frequency band. Therefore, FEXT cannot be eliminated by using a filter. In addition, VDSL2 transmits data within a short distance (generally no longer than 1 km) at a high frequency band (up to 30 MHz), resulting in more serious FEXT compared with other DSL technologies. Therefore, FEXT becomes the main factor affecting the performance of a VDSL2 system. FEXT decreases the SNR, reduces the line transmission rate, increases the bit error rate (BER), and even causes offline errors, severely affecting system stability and user experience.
- To eradicate the impact of FEXT on VDSL2, the ITU-T proposed the vectoring standard to resolve FEXT on VDSL2 lines and improve the multi-wire performance. In this standard, the crosstalk of one VDSL line is a vector in a set of crosstalk vectors for all other lines in the same bundle. The vectoring processing system performs matrix calculation based on the collected vector information and outputs vectorized crosstalk cancellation signals.

Vectoring Implementation Principle

- Vectoring improves the VDSL2 rate by eliminating crosstalk.
  - Obtain the crosstalk information on the line through the cooperation of CO devices and terminals, and calculate the crosstalk cancellation scheme accordingly.



Vectoring Acceleration Effect

- The highest rate supported by vectoring is the rate of VDSL2 single-wire pairs in an environment without crosstalk.

Copper Line Distance		Vectoring Downstream Rate	VDSL2 Downstream Rate
0. 5 mm Diameter	0. 4 mm Diameter		
300 m	250 m	120 Mbps	75 Mbps
600 m	500 m	100 Mbps	60 Mbps
1000 m	800 m	60 Mbps	40 Mbps
1200 m	1000 m	40 Mbps	30 Mbps

- The effective distance of vectoring is within 1. 5 km, and the rate improvement in the 300 – 800 m range is the most obvious.
- Vectoring can increase the rate by 50% – 90% on the basis of VDSL2, reaching 90% – 95% of the theoretical VDSL2 rate.

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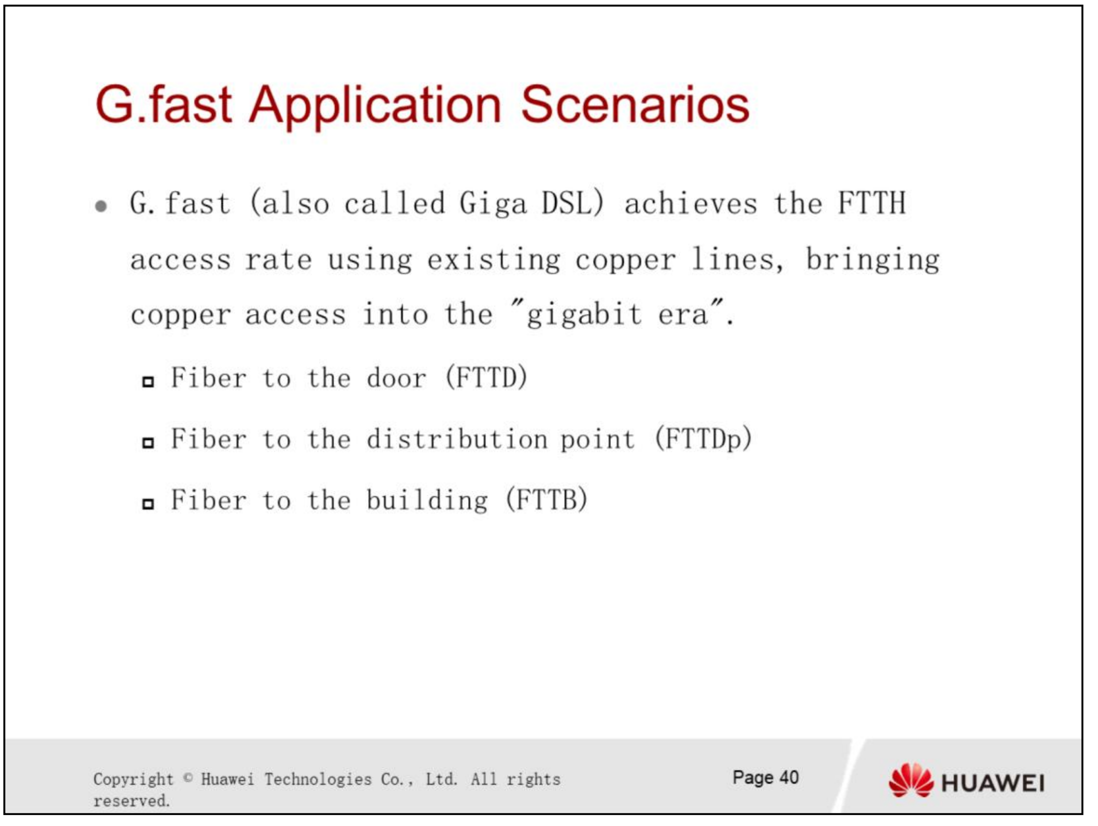
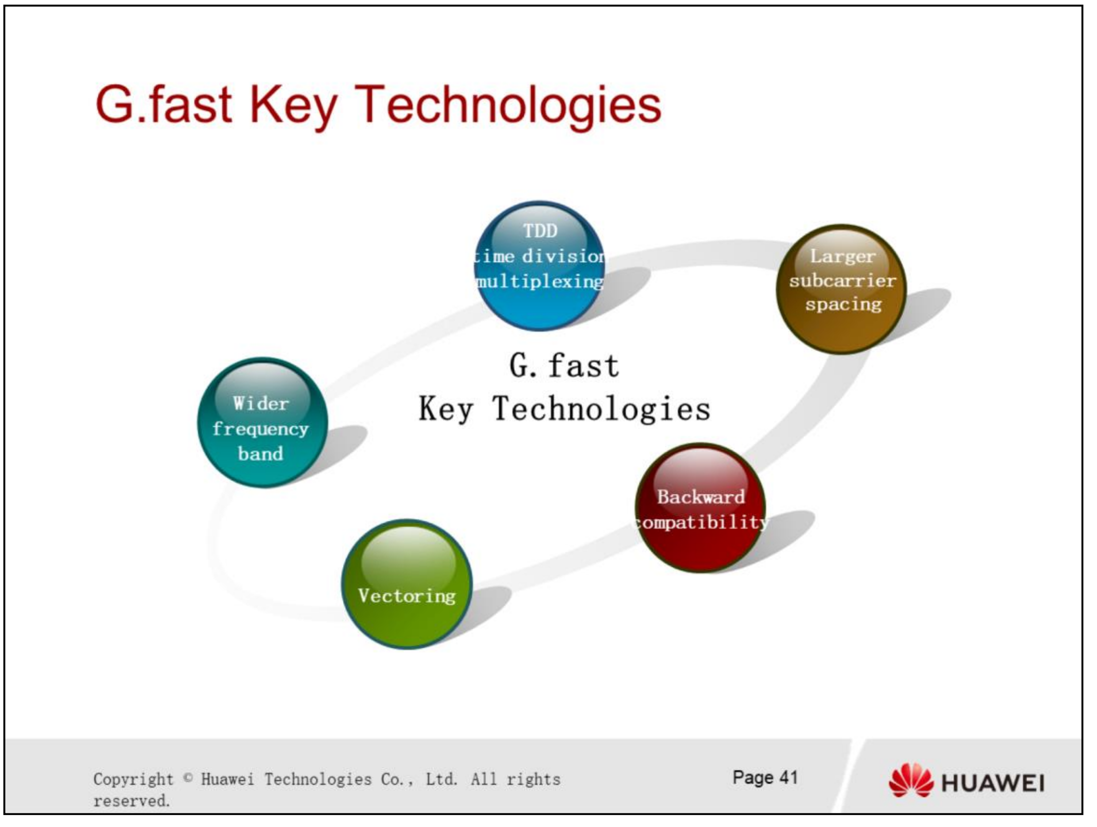


- FTTD: fiber to the door
  - Reverse power supply, 1-8 lines
- FTTDp: fiber to the Distribution point
  - Reverse power supply, 8-16 lines
- FTTB: fiber to the building
  - Local/remote power supply, 16-48 lines
- G. fast applies to the following scenarios:
  - FTTD, FTTDp, and FTTB where the fiber length to end subscribers is usually less than 200 m
  - The twisted pair at the drop cable section can be reused to avoid complex fiber routing and greatly reduce the network deployment cost.
  - Provides services for generally no more than 50 subscribers.
  - Device installation is complex, and onsite power supply is difficult to acquire, requiring low power consumption devices to support some special power modes, such as remote power supply or PoE.
  - The installation environment, such as electric poles, corridors, and manholes, demands high environment adaptability and less maintenance. Generally, remote maintenance needs to be supported.

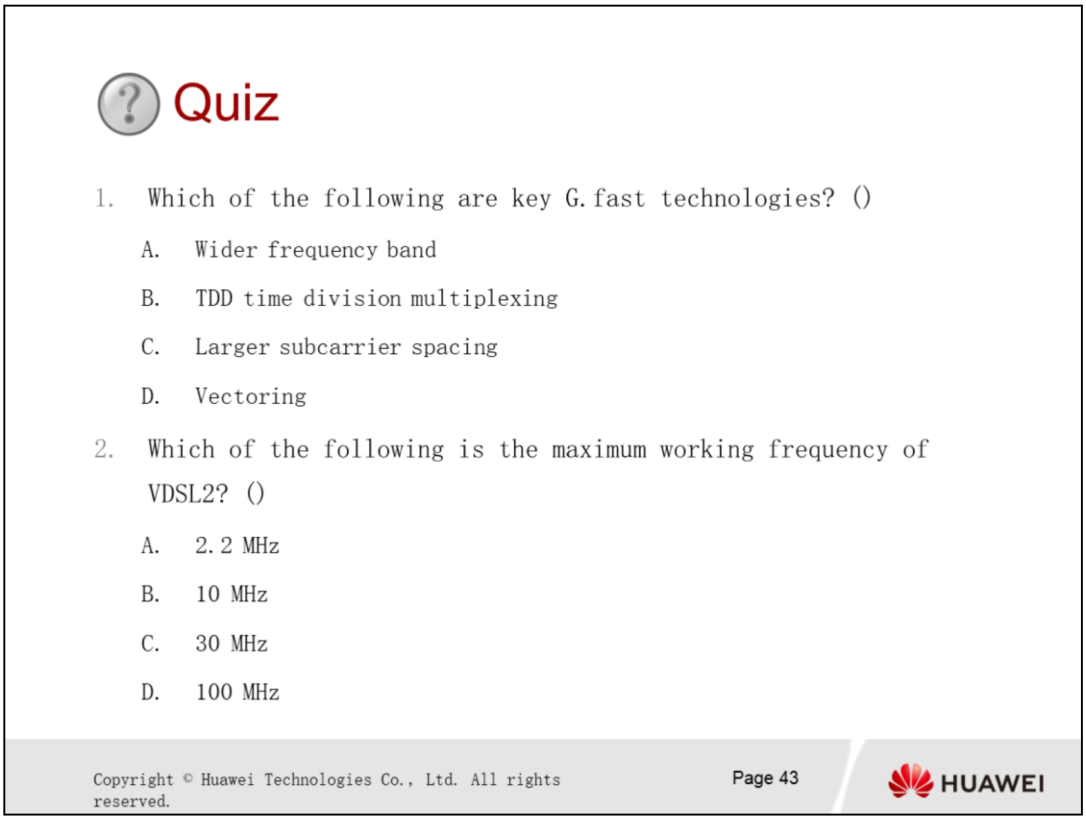


- Currently, the ADSL2+ uses the highest frequency of 2.2 MHz to provide a maximum downstream rate of 26 Mbps, while VDSL2 uses the highest frequency of 30 MHz to provide a maximum downstream rate of 100 Mbps. The G.fast technology must use a higher frequency band to provide a higher access rate. Therefore, the G.fast spectrum resources must be expanded. In the initial phase, the highest G.fast frequency is106 MHz, and can be extended to 212 MHz.
- ADSL/2/2+ and VDSL2 adopt the frequency division duplex (FDD) technology which uses different frequency bands to transmit data downstream and upstream at the same time. The disadvantage is that transmit signals generate echo which enters the receiver. When the frequency band is high, the impact is more obvious, and severely affects the performance of the receiver. In this case, the hybrid circuit needs to be used for echo suppression. G.fast does not distinguish the upstream and downstream frequency bands, and transmits data in the full frequency band in TDM mode in both directions. TDD allocates different timeslots for upstream and downstream data transmission. The transceiver sends and receives signals in different slots.
- As the frequency band width and number of subcarriers increase, the corresponding physical layers become more complex. To reduce complexity, the subcarrier spacing needs to be increased to reduce the number of subcarriers. To be compatible with the traditional DSL technology, the Giga DSL adopts a subcarrier spacing which is an integer multiple of 4.3125 kHz, where 4.3125 kHz is a subcarrier spacing used in traditional ADSL/2/2+/VDSL2 8a/12a/17a standards.
- During the upgrade from ADSL/VDSL2 to G.fast, some subscribers may want to retain the existing DSL services. To ensure smooth network upgrade, G.fast devices also support traditional VDSL2/ADSL.
- Similar to VDSL2, the G.fast performance is also affected by crosstalk between lines.

If the vectoring technology is not used, the G.fast rate will decrease severely.

Technical Application Comparison

VDSL2	Vectoring	G. fast
• Applies to large, medium, and small sites, such as CO DSLAM, and FTTC/B/D. • The technology is mature and the cost is low. • Provides 20–80 Mbps bandwidth for different distances.	• Applies to small and medium sites, such as FTTC/B/D. • Provides 50–100 Mbps bandwidth for different distances. • The cost is about 10–30% higher than that of the VDSL2 equipment.	• Applicable to small sites, such as FTTB/D. • Provides ultra-high bandwidth (500 Mbps to 1 Gbps), which is comparable to FTTH. • Devices are more expensive than FTTH devices, but the labor cost is lower than that of FTTH devices. • The cost is much higher than that of vectoring and VDSL2.



- Reference answer:
  1. ABCD
  2. C

Summary

- xDSL Technology Standards
- ADSL/ADSL2/ADSL2+ Technical Principles
- Introduction to VDSL/VDSL2
- Ultra-broadband Technology (Vectoring, G.fast)

Thank You

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