Integrated Services Digital Network

- Some repetition
- ISDN principles and the structure of ISDN access
  - structure
  - interfaces
  - physical layer
- ISDN signaling
  - bearer and telecommunication services
  - layer 1
  - layer 2
  - layer 3
- Efficiency of signaling
- ISDN evaluation and summary

Some repetition

- Channel Associated Signaling (CAS) is tightly tied to the voice channel either in space, time or frequency -> no signaling unless voice channel is reserved.
- In in-band signaling, the voice path itself is used to carry signals.
- CAS has many limitations: in a PCM-frame one ts1 needs to be dedicated to signaling and a multi-frame of 16 frames needs to be maintained. The set of signals is limited.
- Channel Associated R2-signaling is the first widely adopted, standardized CAS signaling system (but was never used in every country).
- Call setup or register signaling vs. line signaling may use different representation of signals as well as different channels to carry the signals.
- Any CAS system provides only a limited set of signals, often their semantics is context dependent.

ISDN -access has a set of standardized interfaces

- ISDN-access provides a bus for connecting user terminals, the max of 8 terminals can be attached.
- Many interfaces are specified between logical entities in the access
- The rectangles are functions for the purpose of specifying the functioning and the interfaces.
- NT2 is optional – it represents a customer premises network or PBX or similar

ISDN Basic Interface provides 2 x 64kbit/s to the user

- D-channel: 16 kbit/s
  - B1-channel
  - B2-channel
- Two types of Interfaces:
  - Basic Rate Interface (BRI) (2B+D)
  - Primary Rate Interface (PRI) (30B+D)
- BRI provides two B-channels for information transfer and a signaling channel (D-channel):
  - Two independent terminals can use one B-channel each at a time.
  - The main purpose of the D-channel is transport of signaling between the terminals and the local ISDN exchange. Packet mode transfer is used on the D-channel.

Message based signaling systems

- Message based signaling has been developed to improve the control possibilities of the network by terminals.
- Message based signaling can be used only by Computer controlled, fully digital exchanges.
- Message based signaling is natural for computers - the signaling information is largely in the same format in which it is processed and stored.
- Message based signaling is based on ITU-T: SS6 (now CCS7 and ISDN) recommendations.
**ISDN Access and ISDN Interfaces**

- **S-interface**
  - Connects the network termination NT1 to the exchange line termination using the U-interface.
  - Bi-directional transfer uses two twisted pair copper cables (BRI), the bit rate is 160 kbit/s.
  - In Finland, multi-level code 2B1Q is used, with a baud rate of 80 kbaud.
  - Directional Full Duplex: Both parties send at the same time, receiver deducts what it has just sent, gets what the far end has sent.

- **V-interface**
  - Connects up to 8 ISDN terminals.
  - Bi-directional transfer uses four wires.

- **Network Termination (NT1)**
  - Connects to the exchange line termination using the U-interface.

**Examples of line codes**

- **AMI** (Alternate Mark Inversion)
- **HDB3** (High Density Bipolar 3)

**HDLC - High Level Data Link Control**

**HDLC - Transfers frames, delimited by 0111 1110 delimiters.**

**HDLC Sender**

- Data transfer takes place on a twisted pair copper cable (BRI), the bit rate is 160 kbit/s.
- In Finland, multi-level code 2B1Q is used, with a baud rate of 80 kbaud.
- Directional Full Duplex: Both parties send at the same time, receiver deducts what it has just sent, gets what the far end has sent.

**HDLC Receiver**

- Data transfer takes place on a twisted pair copper cable (BRI), the bit rate is 160 kbit/s.
- In Finland, multi-level code 2B1Q is used, with a baud rate of 80 kbaud.
- Directional Full Duplex: Both parties send at the same time, receiver deducts what it has just sent, gets what the far end has sent.

**S, T - Interfaces**

- **S-interface**
  - Connects to terminals.
  - Bus structure.
  - Up to 8 ISDN terminals can be connected.
  - Transfer in both directions uses 4 wires.

- **T-interface**
  - Connects to corporate PBXs.
  - Transfer rate is 2048 kbit/s.
  - T-interface has 32 channels with 64 kbit/s.
  - Other equipment such as Voice Mail and Voice response systems use ISDN primary rate as well.
R-interface

- R-interface separates the Terminal Adapter and a non-ISDN device from each other. It follows some existing specification understood by the non-ISDN device (e.g. V.24, V.35 or X.21 - protocol specification).

![R-interface diagram]

In practice logical functions are grouped in the equipment

- U-interface (twisted pair)
- “Network Termination”
- Analogue interfaces
- Dip switches

Here physical “NT” = NT1 + TA (for analogue phones)

NB: Note the use of rj45 connectors instead of rj11 in Ethernet and also in telephones!

Communication between NT and a Terminal

- AMI-line code is used between a Terminal and the NT (AMI, Alternate Mark Inversion).
  - Start bit
  - AMI signal

<table>
<thead>
<tr>
<th>Bit</th>
<th>AMI signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Normally each other zero is up, each other down

- When there is no traffic over an ISDN interface, terminals are deactivated. A continuous INFO 0 signal is on the interface.

Activation and call setup

- Prior to activation there is no power in the interface and no bits are transferred.
- After activation there is a continuous stream of bits on the interface in both directions
  - This means that layer 1 is ready for requests from layer 2
  - In 2B+D interface also a limited power feed from the local exchange is available for emergency calling under a mains power failure.
  - Layer 2 works on the signaling channel only and transfers frames
  - Inside layer 2 frames, in their payload, Q.931 signaling messages are sent.
  - When layer 2 is ready (it has addresses for the endpoints etc), layer 3 can start a call setup procedure

Activation of the basic rate interface facilitates power saving while subscriber is not using the line

- Terminal starts activation by sending a continuous activation request: INFO 1. When the network detects the request, it starts sending synchronization frames INFO 2.
- When the network initiates activation, it starts sending INFO 2 directly.
- When the terminal detects a synchronization frame, it starts sending active state frames INFO 3. When the local exchange has received active state frames, it moves to INFO 4 state. The physical layer is now active and ready for information transfer.

Frame structure on the S-interface

- 48 bit frames 4000 times per second are used between a terminal and the NT1.
- The resulting bit rate is 192kbit/s
Frame synchronization on S-interface

- Frame synchronization is achieved by sending violation bits in the AMI code.
- The first (F) and the 14th bit (FA) equal to zero with a wrong polarity i.e. the same as the previous zero. To balance this for the sake of zero average voltage, the wrong zero is followed by DC balance bit (L).

NB: On S-interface the AMI code is inverted, i.e. logical zero is sent as a pulse with alternating polarity and a logical 1 is sent as zero voltage.

Overhead bits in the frame carry D-ch echo and control power consumption

- A Terminal can see that the NT has received its D-channel bits based on E(echo)-bits. NT copies a received D-bit to the next E-bit.
  - If two terminals are signaling at the same time on the S-interface, wrong E-bits tell that there was a collision and that the terminal should wait for a while prior to sending again.
- A-bit is used for power control. With A-bit, the network can command the terminals to deactivate themselves and to transfer to a low power mode in which they are only able to become active again either on network request or user action. The activation procedure uses the A bit.

Message based signaling can be functionally split following the OSI 7 layer model

Bearer services are transport services that are seen by the “user”

- Circuit switched bearer services include:
  - Speech
  - 3.1 kHz audio
  - 7 kHz audio
  - transparent 64 kbit/s.
- Packet switched bearer services include:
  - virtual call and permanent virtual connection,
  - connectionless packet switched service on the D-channel,
  - user-to-user signaling information.

Bearer services are transport services that are seen by the “user”

Telecommunication Services incorporate all OSI layers

- A Telecommunication service is a set of functions offered to a user and it is implemented using the capabilities of all OSI layers.
- Telecommunication services make use of the bearer services.
- Telecommunication services can by further divided into basic and supplementary services.
- Supplementary services can be used only in connection with a basic service.
- The term “feature” is more generic than “supplementary service”. In addition to supplementary services it refers to any functional properties of a system. Sales arguments and sales contract often list a lot of features...

Digital Subscriber Signaling System No 1 (DSS 1)

- DSS1 is based on a protocol stack that includes three OSI lower layers.
- DSS1 is fully message based and out-of-band offering the possibility of signaling while the voice channel is open end-to-end.
- DSS1 messages are sent on the D-channel.
  - NB: tones: dial-tone, ringing tone, busy tone are sent by exchanges on the audio channel.
- DSS1 layer 2 follows the HDLC principles and is called the LAPD-protocol (Q.920 - Q.921).
- DSS1 signaling overview is given in ITU-T Q.930 and detailed procedures are given in Q.931.
**Q.920/Q.921 - LAPD**

- **Connectivity over the link between a terminal and the Local exchange**
  - Inherits HDLC principles.
  - Corresponds to the OSI layer 2 requirements.

- **Transfers frames from many terminals to many layer 3 entities.**

**Properties:**

- DLCI - data link connection id identifies the link connections: DLCI = SAPI + TEI. SAPI = Service Access Point Id, TEI = Terminal Endpoint Id = (SAPI+CES).
  - Can guarantee frame order due to numbering.
  - Fault management - lighter than MTP in CCS#7.
  - Flow control based on windowing (windowing means that e.g. N=window size messages can be sent before an acknowledgement is required).

**LAPD frame format**

- **Address**
  - HO (Higher Order)
  - LO (Lower Order)
  - Control
  - Information
  - FSC

- **SAPI**
- **TEI**
- **N(S)**
- **N(R)**
- **P**

**DSS1 - Q.931 - signaling**

- **Corresponds to layer 3 - network layer:**
  - Understands end-to-end addresses: E.164 telephone numbers.
  - Can set up, control and release circuit switched calls.
  - Supports also packet switched on-demand connections.
  - Call identification is based on the call reference - and has nothing to do with e.g. the identity of the B-channel in use!
  - Supports the functional and the stimulus (keypad) modes of signaling.
  - User-to-user information transfer in signaling messages is also supported (charging is an issue).

**Functional and stimulus -modes**

- **Functional**
  - Information is encoded in service specific information elements.
  - As a result, signaling becomes service dependent. A new service requires new programs both in the CPE and the exchange.
  - Can be OK, if CPE = PBX.
  - For phones would really require a JAVA-like automatic software download function. There is no such thing in ISDN!

- **Stimulus -mode:**
  - Phone button pushes are carried in signaling as such (a field in a message tells which button was pushed).
  - Interpretation is the responsibility of the exchange.
  - A new service requires new programs only in the network.
  - The phone may have programmable soft keys to hide dialing sequences.

**Q.931 -signaling call setup procedure**

- **Terminal**
- **Setup**
- **Local Exchange**

- **Voice or data transfer**
  - Disconnect
  - Release
  - Release_comp

- **Call control**
  - Setup_ack
  - Call_proceeding
  - Alerting
  - Connect
  - Connect_ack

- **User data**
  - Info
  - Acknowledgement

- More digits/overlap sending
- Address complete, B-channel
- Ringing at the destination
- Answer, throunciong, charging
- Acknowledgement (B/mt-pt)

- Disconnection is symmetric
- Disconnection, changing ends
- Final tear down
- Release of B-channel

**NB:**

- LAPD is between TE and the local exchange. Its sole purpose is to carry frames between the two taking into account that many terminals can be connected to an S-interface.

- Unnumbered Information = UI -frames are not acknowledged also broadcast (e.g. SETUP to B subscriber).

- Acknowledged mode - I - numbered frames fault recovery and flow control procedures supported on layer 2.

- Initiation state - TEI values not yet chosen.
  - Before any higher level (Q.931) functions can be performed, each ISDN device must be assigned at least one unique TEI value. These numbers can be preassigned (TEIs 0-63), or dynamically assigned (TEIs 64-126). Most TEI assignment is done dynamically, using the TEI management protocol.

- Unnumbered Information = UI -frames are not acknowledged also broadcast (e.g. SETUP to B subscriber).

- Acknowledged mode - I - numbered frames fault recovery and flow control procedures supported on layer 2.

- NB: LAPD is between TE and the local exchange. Its sole purpose is to carry frames between the two taking into account that many terminals can be connected to an S-interface.

- NB: gives only one signaling scenario.
**DSSI (Q.931) call signaling**

- **RELEASE** tells that **DISCONNECT** was received. **RELEASE COMPLETE** confirms the reception of **DISCONNECT** – charging stops and the B-channel is torn down.
- **CONNECT** message starts charging and all exchanges through connect the B-channel in both directions.
- **ALERTING** tells that the phone at B-subscriber (called party) is ringing. The D-channel message is **CALL_PROCEEDING** – tells that no more digits will be needed even at the terminating exchange, it also tells that at least the network is not busy (the B-subscribers can still be busy).
- **INFO** messages support overlap sending – the result is that the routeing can be done through the switchboard of the exchanges or not even look at the last digits. If NP is allowed in the number block, all digits are sent as **INFO** messages.
- **SETUP** message contains at least the bearer service (= is this a data call or audio call). In practice it is how to behave in a situation where DSS1 calls information retrieved based on earlier digits received for the call.
- **SETUP_ACK** acknowledges the reception of **SETUP**. It is more useful on the terminating side – tells that the kind of device that can support the telecommunication service requested has been found (e.g., a fax machine).
- **Directory numbers**
- **Also C-party number in case of Fall Forwarding**
- **The max 8 devices connected to one S-interface may have one or different telephone numbers**
- **If only one number is used Low Level Compatibility Information and High Level Compatibility Information in the SETUP message can be distinguished between a telephone, a fax machine, a computer etc.**
- **When the devices with the same telephone number all receive SETUP at the same time from the network, they look at the compatibility info and respond sharing the same audio channel from terminating exchange to A-subscriber.**
- **Connect shows which of the devices the user used to answer.**
- **Connect_ack shows which of the possible Connects won the race and was received first by the network.**
- **ISDN signaling duration on 16kbps (L2+L3)**

---

**Addressing of users in DSSI**

- **Called Party and Calling Party Number = E.164 telephone numbers**
- **Directory numbers**
- **Also C-party number in case of Fall Forwarding**
- **The max 8 devices connected to one S-interface may have one or different telephone numbers**
- **If only one number is used Low Level Compatibility Information and High Level Compatibility Information in the SETUP message can be distinguished between a telephone, a fax machine, a computer etc.**
- **When the devices with the same telephone number all receive SETUP at the same time from the network, they look at the compatibility info and respond sharing the same audio channel from terminating exchange to A-subscriber.**
- **Connect shows which of the devices the user used to answer.**
- **Connect_ack shows which of the possible Connects won the race and was received first by the network.**
- **Subaddress allows extending E.164 addressing**

---

**Use Case: Connecting PABXs to a Public Network**

- **Numbering and DDI**
- **A PABX can have a private numbering plan (i.e., a plan that is not visible in the public network).**
- In that case DDI – direct dialing in is not possible, instead all incoming calls are connected via the public network and the public network – even analogue subscriber signaling will do the job.
- **PABX numbering plan is a subset of the public network plan, DDI becomes possible and when an incoming call is delivered, some digits need to be sent from the public net to the PABX.**
- **An incoming call can be extended with public network extensions – in that case the hosting public exchange will start number analysis and routing when it has received the amount of digits in the shortest directory number in the dial plan.**
- **Signaling to private PABX networks.**
- **Typical signaling systems PABX to ISDN exchange are primary rate ISDN (Q.931), DASS (UK), in these cases all business services to PABX extensions are provided by the PABX.**
- **Private networking:**
- **PABXs can be connected to private PABX networks (multi-site companies).**
- Such networks can be sometimes extended with public network extensions – in that case the hosting public exchange can provide a private network signaling and route the call to the private PABX.**
- **In that case the public switch or switches need to support e.g., Q.931 – a private network signaling system, or H.248 – a UK private network signaling system.**
- **NB: many private network signaling systems are proprietary (vendor specific) although they may be based on DSSI.**

---

**A Signaling dump from an access line**

**SETUP** 08989600011398830800A1138184082000080208025322D829187E3A104
**CALL_PROC** 0299855001092010819A1
**Alerting** 029858200019010001
**Connect** 02985820001901000149020000920125150
**Release** 0898960001139883080008000008
**Release_Complete** 02998680001901000155A

- **Messages are presented in hexa code**
  - Hex code is 0, 1, 3, 4, 5, 6, 7, 9, A, B, C, D, E, F, where e.g. A = 1010 in binary
- **Bold characters are Layer 2 bits**
- **Normal characters are Layers 3 (Q.931) bits**
- **The setup message carries just two digits**

---

**Some details**

- **Overlap sending means that DSSI supports the traditional dialing procedure known from analogue phones.**
  - The origination exchange can start number analysis and routing when it has received enough digits. Usually it will make the first attempt of routing when it has received the amount of digits in this shortest directory number in the dial plan.
- **alternatively the GSM style dialing (select all digits first and then push the call button) can be used as well. In that case all digits are contained in the one and only MTP message.**

---

**Tones**

- **Ringing phase: alerting message is accompanied by alerting tone on the audio channel from terminating exchange to A-subscriber.**
- If call setup fails, busy tone can be sent in the backward direction from any exchange on the call path.
- **Windowing (in LAPD) means that the sender can send a max of say 5 messages without getting an acknowledgement.**
  - Even if the network deducts when all digits have been received at the public exchange, it may send no more digits and wait for an acknowledgement.
- **one acknowledgement can typically acknowledge all messages to a point in the stream of messages.**
- **NB: DSS 1 does not follow the client server model: it is based on the concept of communicating finite state machines.**
Message duration on 16kbit/s channel per message and per 8 message sequence

- Message duration in ms = message length in bits including all layers/signaling channel speed in kbit/s
- ISDN message lengths are usually around 20 octets: delay per msg is around 10 ms and for the whole sequence less than 100 milliseconds.

Message transfer delay in previous slides

\[
\text{Msg transfer delay} = \frac{\text{Message length in bits}}{\text{Signaling channel speed}}
\]

Naturally the same formula applies to message flows.

Assume: message length = 1 000 bits and 16 kbit/s signaling channel

\[
\text{Msg transfer delay} = \frac{1000 \text{ bits}}{16000 \text{ Bits/s}} = 60 \text{ ms}
\]

DSS 1 strengths

- Cmp to analogue signaling:
  - Out of band: signaling can continue during a call. This gives flexibility in service implementation
  - Fast: signal delays in the order of tens of ms per signal. Low post dialing delay if network signaling is fast also (such as SS7)
  - Many symbols can support potentially a very wide range of services
  - Reliable: HDLC on layer 2 with msg numbers and checksums
  - Physically and logically separate from voice channel: flexibility for new services
  - "Native signaling" for digital exchanges and terminals: no AD conversions, information is sent pretty much in formats that can directly be processed by a program controlled device.
  - Historically or in hindsight
    - Provided digital signaling for PABXs, allows e.g. direct dialing in (which could also be provided by R2 but not all analogue signaling systems)
    - Became mother of many PABX signaling systems (QSIG and proprietary variants), mother of GSM signaling, etc. (also mother of V5 access signaling, mother of B-ISDN signaling but these are not successes)

DSS 1 weaknesses (all in hindsight)

- Technical
  - Functional mode requires new software both in terminals and exchanges when new services are introduced. However, DSS1 does not have software download from the network. Stimulus mode requires new software for new services at least for exchanges. We say that such signaling is service dependent.
  - A 2B+D line card could serve approximately half as many subscriber lines as an analogue subscriber line interface card. Therefore ISDN subscriber access was more expensive than analogue access.
  - NB: about 70% of local exchange cost is in line cards.

- Value
  - ISDN (2B+D) provides limited added value for subscribers, therefore penetration started to grow only when Internet and www became popular and higher bandwidth than modems could provide were needed.
  - Closed market solution: does not provide innovation opportunities for any users like the Internet. You are stuck with the services provided by your operator. Operators are stuck with the services provided by a small number of vendors. ISDN hw is always provided by equipment manufacturers for exchanges and for terminals. Neither does ISDN open particular opportunities for competitive operators.

Signalizing efficiency

- Delay per message, delay for the call setup flow, delay for a call flow including setup and release.
- Can be calculated directly from specification.
- Post dialing delay: from the moment last digit is pushed by the caller till the caller hears ringing tone.
- Modeling requires the knowledge of network structure.
- Close to user perception.
- Number of bits in a call flow
  - All in all calls create signaling traffic – the amount of signaling traffic should be significantly less than the signaling channel capacity
  - Users pay for the service: businesswise signaling is pure overhead – it follows that the following should apply: Amount of signaling bits in a call flow << amount of bits in the service
  - Amount of bits in the service is e.g. amount of voice bits in a call
  - If calling is a flat rate service, amount of signaling bits is not that important

ISDN Summary

- Signaling and voice channel are both physically and logically separated (out-of-band, common channel + call reference).
- Any signaling info needed for services is supported or can be added.
- Q.931 signaling is service dependent, contains really information that is relevant on OSI-layers 3 - 7. New services require new programs in CPEs in case of functional mode. There is no mechanism for automatic software download to CPEs.
- Multi-point structure complicated the implementation significantly.
- Major consumer value added is in 2 x 64kbit/s bit rate. ISDN adoption is determined by home Internet use.
- ISDN specified a digital PBX access signaling for the first time. This has been widely adopted! ISDN signaling has been reused in many new signaling applications (VS, private PBX networks, IP-Telephony, conferencing, GSM etc.) So, ISDN (DSS1) is the mother of many modern signaling systems.