Journal of Mobile Multimedia, Vol. 9, No.3&4 (2014) 173-188
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USE OF TDM PSEUDO-WIRES FOR AN EFFICIENT NGN EMULATION OF ISDN MULTI-CHANNEL CIRCUIT-MODE BEARER SERVICES

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The specifications of the Next Generation Networks (NGN) agree on the need for migration mechanisms that enable the replacement of traditional networks, highlighting the ISDN networks. This requirement has a notable impact on NGN in terms of network design. Recent solutions proposed by ITU-T and ETSI for ISDN migration only include support for a subset of current ISDN services, not covering in detail the multi-channel circuit-mode bearer services. This paper examines the use of TDM pseudowires for NGN emulation of ISDN multi-channel calls between ISDN terminals, proposing new payload types.

Key words: Multi-channel service, ISDN bearer, NGN, Pseudo-wire

1 Introduction

The Next Generation Network Project aims to create a unique packet-switched network that integrates any existing or future service [1]. The progress of the NGN project is being driven by both economic and standardization reasons [2]. Thus, operators will benefit from an efficient and seamless integration between current user equipment and networks [3, 4], most notably Integrated Services Digital Network (ISDN) networks.

ISDN has been the last step in the evolution of the public switched telephone network. It was originally designed to support any type of voice or data service over a full-digital network. The broad range of services offered by ISDN is supported over three types of bearer services, namely the circuit-mode, frame-mode and packet-mode. These services are also classified into single and multi-channel as used on each call one or more B channels, respectively. The rigidity of the underlying channelized bit-rate structure and the lack of flexibility in building new, complex services have finally made ISDN unsuitable for the fast development and provision of rich multimedia services which conversely, have been rapidly developed on the Internet.

For backwards compatibility, the NGN must support potentially every ISDN bearer service (ITU-T I.230 series) with the same o higher QoS [5, 6]. Consequently, both the ITU-T and the ETSI have defined standardized mechanisms for the transparent integration of ISDN terminals (ISDN TEs).

This backwards compatibility is also required within the European normative [7]. The European directive on Universal Service [8] states that, at least one operator Electronic Communication Network (ECN) must ensure access to Publicly Available Telephone Service (PATS) at fixed locations such as

ISDN, PSTN, X.25, ... Furthermore, the specification [9] highlights the urgent need to articulate the necessary specifications that would meet those obligations. These regulations applied to ISDN require that the operator's network allows access for native ISDN terminals.

The solutions offered by ITU-T and ETSI to encapsulate ISDN signalling and user flows across the NGN network use transport or application-layer protocols. The proposal done by ITU-T [5, 10] is limited to ISDN circuit-mode bearer services whereas the ETSI proposal [11] adds partial support for frame and packet-mode services. For ISDN multi-channel circuit-mode bearer services, the ITU-T [6] recognizes that there are still large residual amount of ISDN user equipment that use these services, and therefore they must be supported. But, concerning these services, NGN specifications made only two comments, related to their transport on the NGN, as described below. On the one hand, the ITU-T [6] indicates that the transport of the "N" channels of the service must be performed on a single IP flow, to ensure equal conditions for all transmission channels. On the other hand, purely facultative, ITU-T Recommendations [5, 12, 13] propose to carry these services by using ITU-T TDMoIP interworking [13, 14], equivalent to UDP/IP-based TDM pseudo-wires (TDMPW) [15], what satisfies indicated by the Recommendation [6].

About these indications, we must make the following assessments. In the first place, ITU-T TDMoIP interworking is only defined for UDP/IP, while IETF defines TDMPWs for different tunneling mechanisms apart from UDP-IP, such as MPLS, L2TPv3/IP or Ethernet. So, TDMPWs are preferred.

In the second place, the ITU-T only mentions the use of TDMoIP interworking (or TDMPWs), but it is not detailed how to apply them. It is necessary to determine if each TDMPW must carry one or several ISDN calls, or the TDMPW type and payload more appropriate. After analysis, we conclude that as they are standardized, none of the TDMPWs fits the emulation of these multi-channel calls. It will be necessary to propose new types of TDMPW payload.

This paper proposes to transport ISDN multi-channel circuit-mode bearer services [17-21] between two ISDN terminals by AAL2 TDMPWs (UDP/IP-based or any other packet switched network) with new payload types we define.

The rest of this paper is organized as follows. Next section provides a shallow introduction to ISDN multi-channels calls, ISDN emulation on NGN and TDM pseudo-wires. Section III addresses an analysis of the TDMPWs to transport ISDN multi-channel services on the NGN. Finally, Section IV concludes the paper.

2 Background

2.1 ISDN Multi-channel Circuit-mode Bearer Services

ISDN transmission capacity is offered in a combination of several types of fixed-rate channels, one of which (B channel) was specially tailored to carry toll-quality digitalized voice. The ISDN also pioneered the concept of splitting user and control data flows, the latter were enclosed in D channels. The broad range of services offered by ISDN is supported over three types of bearer services, namely the circuit-mode, frame-mode and packet-mode. These services are also classified into single and multi-channel as used on each call one or more B channels, respectively.

Multi-channel ISDN services ("N" B-channels) require UDI (Unrestricted Digital Information) transport [22] and TSSI (Time Slot Sequence Integrity) structure. In particular, the service 2x64 [17] also requires RDTD (Restricted Differential Time Delay) structure.

With UDI transport, terminals can exchange any information, negotiated between them, transparently to the network. RDTD service structure means that if two samples are transmitted at the same time (for any two different channels of service), they must reach the destination with a delay of no upper than "50 ms". TSSI structure means that information must be delivered to the destination in the same order between channels when it was sent.

2.2 ISDN Emulation in NGN

The ITU-T aims to define a world-wide network infrastructure capable of supporting current and future telecommunication services and network technology. The Next Generation Network model, as standardized by the ITU-T in [23], is the last step on that direction. Both the ITU-T and the ETSI have cooperated to develop the NGN architecture.

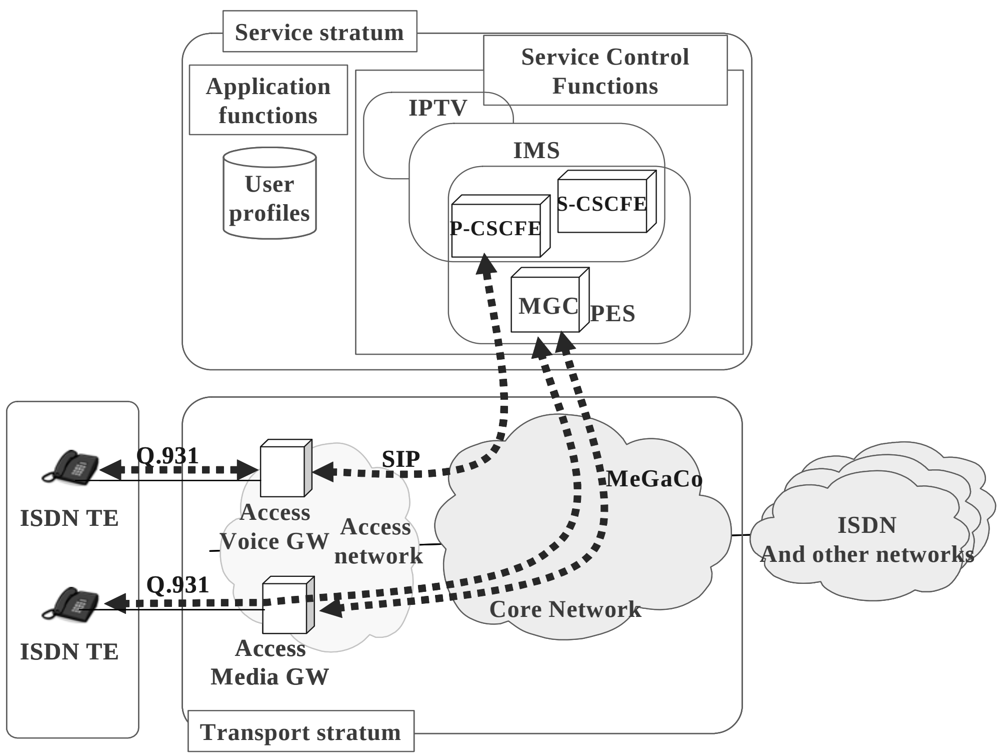

Figure 1 Simplified NGN architecture

The NGN functional architecture exhibits a transport stratum and a service stratum. The transport stratum provides IP connectivity, hiding the core and access networks' technologies. It also aggregates user traffic to be transported over the core network, controls, allocates network resources and provides support for network control and management. The service stratum resides above the IP layer, containing users' profiles, auxiliary applications and as many service-supporting control-functions as needed. These control functions operate the transport stratum to provide the desired service. Among the service-control functional components identified in the Service stratum are: the IPTV, which provides IP-based television services; the IMS, which provides SIP-controlled multimedia services; and the PTSN/ISDN Emulation Subsystem (PES).

There are two alternative architectures for implementing PES, depending on Access Gateways (AGW) be implemented either monolithically (Voice Gateway, A-VGW) or in a decomposed way (Gateway controller MGC and Media Gateway A-MGW) [10], as shown in Figure 1. The first one is based on a so-called call server (CS-PES) where a Media Gateway Controller (MGC) terminates the ISDN signaling and accordingly controls the Access Media Gateway via MeGaCo [24]. In the second choice, the ISDN signaling is terminated at an Access Voice Gateway which uses SIP signaling to communicate with the IMS's Call Session Control Functions (CSC-FE).

2.3 TDM Pseudo-wires

IETF defines pseudo-wires (PWs) [16, 25] as a mechanism to allow the emulation of telecommunications services over a Packet Switched Network (PSN) through virtual connections that, from the user's point of view, provides the same service than the original circuit or link. The emulation preserves the essential attributes of the original services such as voice quality, delay, timing and signaling features. Each pseudo-wire is established between an ingress and an egress PE (Provider Edge).

Depending on the tunneling mechanism, different types of pseudo-wires are defined: UDP/IP, L2TPv3/IP, MPLS, Ethernet. As a matter of fact, the UDP/IP PWs are equivalent to TDM over IP interworking defined by ITU-T [13]. This type of pseudo-wire, albeit simple, lacks of a control plane, able to negotiate connection parameters at connection-setup time, such as the payload type, jitter buffer's size, the timing recovery mechanism or the traffic type. So, other types of pseudo-wires may be more suitable for a practical implementation. In general, the choice of the type of PWs is dependent on the operator's network.

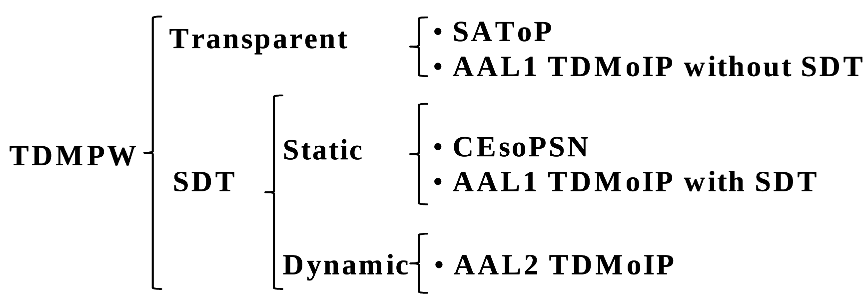

Figure 2 TDMPW taxonomy

TDM pseudo-wires (TDMPWs) [15] can emulate the main features of a time-division multiplexed link: frame and multi-frame synchronization (when needed), timing recovery at the output end, complying with the path MTU, and simultaneous transport of several TDM flows. Depending on the format of the payload, jointly defined by IETF and ITU-T, there are two types of TDMPWs (Figure 2).

The transparent or structure-independent TDMPWs take the TDM signal as a continuous stream of bits (without interpreting any frame structure that it may have) transporting it completely, including overhead and data/signalling channels for channelized circuits, so that each TDMPW emulates a full TDM circuit. Two TDMPWs of this type are defined: SAToP [13, 26] and transparent AAL.1 TDMoIP [14, 27].

In the structure-aware or SDT (Structured Data Transport) TDMPWs, the ingress PE must understand and interpret the frame structure of the TDM signal, and can read/manipulate TDM overheads and signalling, which ensures the alignment and integrity of the TDM frame structure and provides more robustness to PSNs with higher packet loss rate. These TDMPWs are classified in two subtypes:

- Static: they provide CES (Circuit Emulation Service) [28]. Two TDMPWs of this type are defined: CESoPSN [13, 29] and AAL1 TDMoIP with SDT [14, 27].
- Dynamic: they provide LES (Loop Emulation Service) [30]. IETF only defines a TDMPW of this type, referred as AAL2 TDMoIP [14, 27, 31]. TDM channels may belong to different trunks, identifying each pair "interface, channel" through a CID (Channel Identifier). The TDMPW payload is filled by an integer number of AAL2 (ATM Adaptation Layer) minicells [32]. Each AAL2 minicell is filled with a SSCS PDU, built it from the bytes of the TDM channel identified by the CID assigned to that minicell.

The control plane of the AAL1/2 TDMoIP types has only been fully standardized for MPLS TDMPWs [31].

3 Transport of Multi-channel Calls between ISDN Terminals by using TDMPWS

ISDN multi-channel services can be transported on the NGN through TDMoIP interworking flows (as proposed by ITU-T) or, preferably, by TDMPWs, defined for several tunnelling mechanisms. This proposal only applies to calls between two ISDN terminals, establishing the TDMPW among their respective AGWs (Figure 3).

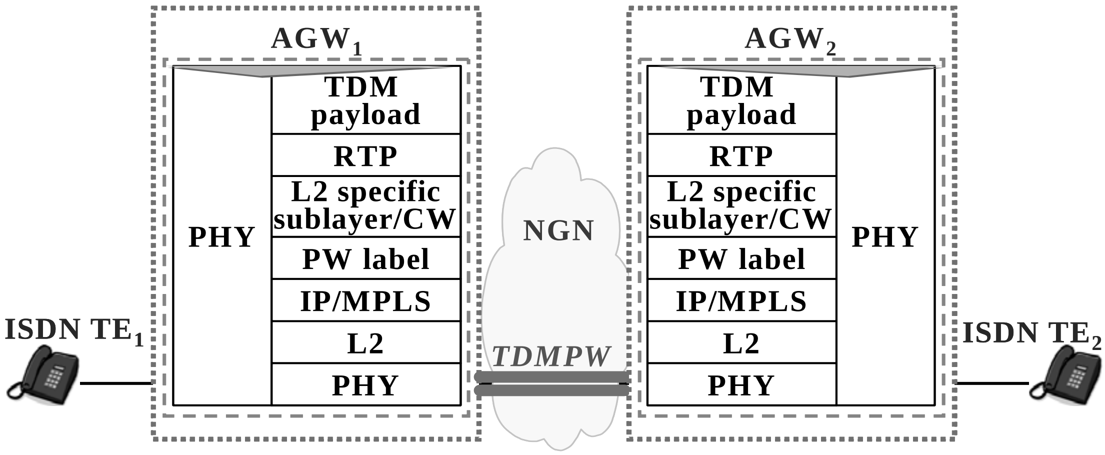

Figure 3 Multi-channel call between two ISDN terminals using TDMPWs

3.1 Multiplexing of Calls on each TDMPW

In all standard ISDN multi-channel bearer services (ITU-T I.230 series), various B channels involved in one call, belong to the same ISDN UNI (User-Network Interface). Consequently, the "N" B-channels of a multi-channel call must be transported on the same TDMPW, satisfying indicated by the Recommendation [6] (among different TDMPWs there is no sequencing or timing relationship).

Instead of using an independent TDMPW each ISDN call, it is more efficient to concentrate several calls (single or multi-channel, and permanent or switched) on the same TDMPW (Figure 4). Calls are multiplexed on the same TDMPW until complete its capacity, in which case another TDMPW be established. This provides a lower overhead in the data plane (the same IP and CW Control Word headers for multiple calls) and a lower number of messages in the control plane (fewer TDMPWs).

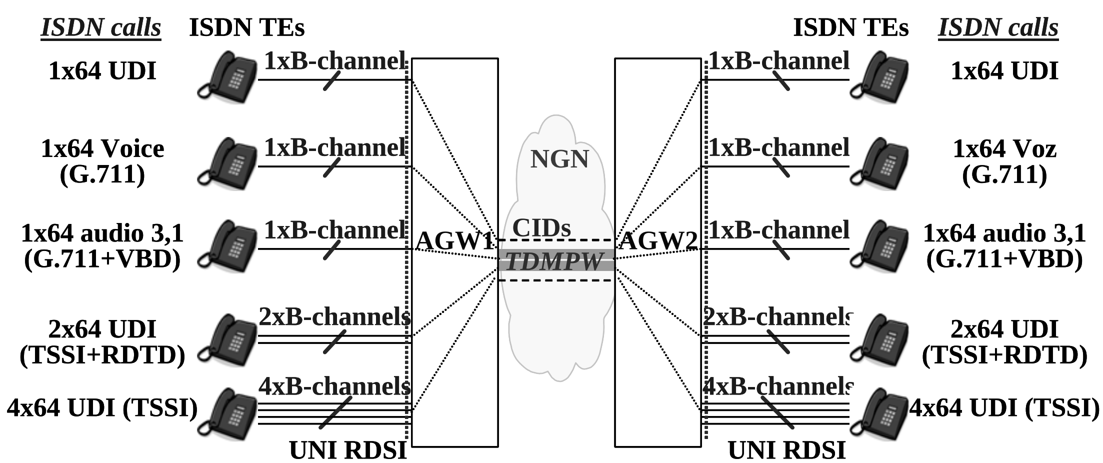

Figure 4 ISDN circuit-mode calls multiplexed on a TDMPW

Although TDMPWs are designed to be established prior to the establishment of calls (management plane), they can be established in call time (control plane) if it offers a significant advantage. For switched ISDN calls, the establishment of TDMPWs before calls requires the establishment of a mesh of TDMPWs between all the AGWs of operator, which is not feasible for reasons of scalability. Consequently, unless there are permanent calls, the establishment of the TDMPW will be based on the control signaling of switched calls.

For the multiplexing of calls, it should be noted that:

- Multi-channel or unrestricted single-channel [33] circuit-mode services: they require UDI transport over the IP network, and so RTP PT (Payload Type) CLEARMODE [34] without Voice Activity Detection (VAD).
- Voice single-channel circuit-mode services: they allow transcoding from G.711 to any other codec, as well as incorporating VAD at any codec. The former should be avoided in most cases, because of the involved transcoding delays [43]. For the latter, more desirable because it saves bandwidth, it is advisable that the egress PE generates comfort noise during silence periods. This requires that the ingress PE sends the proper comfort noise parameters using SID (Silence Insertion Descriptor) frames, identified by the PT Comfort Noise Generation (CNG) [35].

Note that the different calls multiplexed within the TDMPW may use different payload types, so the payload type indicator must travel along the samples.

3.2 Choosing the Type of TDMPW

When choosing the type of TDMPW, we have to discard the transparent ones, because they only allow to emulate complete interfaces, without identifying their elementary channels.

The structure-aware TDMPWs can only carry the "N" B-channels of a Nx64 multi-channel call. PEs (their Native Service Processors) will need to support the ISDN physical frame format, both primary and basic UNIs V [37] interfaces, according to each operator's preference. Since the PEs would be located on the AGWs responsible for the terminating ISDN interfaces, it seems reasonable to assume this condition satisfied.

Among the different types of structure-aware TDMPWs, the static (CESoPSN and AAL1 TDMoIP with SDT) are not suitable for the following reasons.

First, as they have no VAD (Voice Activity Detection) support, they carry even the idle channels, which represents an inefficient use of bandwidth.

Secondly, they do not adequately support the concentration of permanent or switched calls:

- Switched calls are dynamically set up and released, thus modifying the aggregated number of active channels. However, TDMPWs are usually set up at management time, before any call is established, making it impossible to follow the future variyng capacity demanded by the calls.

- Permanent calls are established in management time, as TDMPW are, however, when adding or deleting a new permanent call, it would be necessary to tear down and re-establish the TDMPW, interrupting the service for the existing calls.

As opposed to static TDMPWs, the dynamic structure-aware TDMPWs (AAL2 TDMoIP) can emulate services with channels from different interfaces, and can dynamically modify the number of carried channels. Moreover, its control plane may negotiate between both PEs the voice processing to apply to the transported channels, such as VAD.

From the above analysis, we may conclude that the only suitable way to emulate the ISDN multi-channel calls are the AAL2 TDMoIP TDMPWs.

3.3 AAL2 TDMPW Payload Format

According to the defined AAL2 TDMoIP payloads at [27, 30], each TDM channel is assigned a unique CID. An Nx64 multi-channel call will use “N” CIDs. This payload format is not valid for emulating multi-channel calls, as is discussed below.

In a multi-channel call, the ISDN source terminal generates a flow of “Nx64 Kb/s” rate. In the ISDN interface, the flow is conveyed on "N" 1x64 kbps B-channels, so that each TDM frame of the ISDN interface carries "N" samples of that flow (“N” channels virtually behave as a single channel of rate “Nx64”). The 2x64 service, with its distinctive RDTD structure, represents an exception to this rule: this service is designed to support stereo voice calls, so the two channels must be transported to the remote terminal in parallel, and samples from each channel at the source should always be delivered to the same channel at the destination.

For the emulation of a multi-channel call to be correct, the destination terminal should be able to reconstruct the same flow as sent by the source terminal. However:

- To ensure a constant end to end delay, regardless of the bit rate of the emulated service, each AAL2 TDMPW packet includes the number of minicells that allows preserving this delay, depending on the channel activity. Consequently, at a multi-channel call, samples from two of its channels in the same TDM frame can be sent in several TDMPW packets.
- AAL2 TDMPWs does not provide any way to indicate the egress PE how to sort the samples from different CIDs when they belong to the same multi-channel call (the CW or RTP sequence number only guarantees the sequencing of TDMPW packets).

Thus, if a TDMPW packet is lost, the egress PE can misorder the samples, sending to the destination TE TDM frames that differ from those sent by the source TE. Note that the egress PE can still detect the missing TDMPW packet, by inspecting either the CW or RTP sequence numbers, but not which channels (CID) were carried by the minicells within that packet, or how many samples were contained at each minicell.

This misordering of the samples could destroy TSSI (Figure 5, samples “3” and “8”) and RDTD structures (Figure 5, samples “3” and “4” as “4” is lost and “3” does not, or between samples “10” and “12”, since there is no guarantee that TDM frames TDM2 and TDM3 are delivered to the destination TE spaced no more than 50 ms).

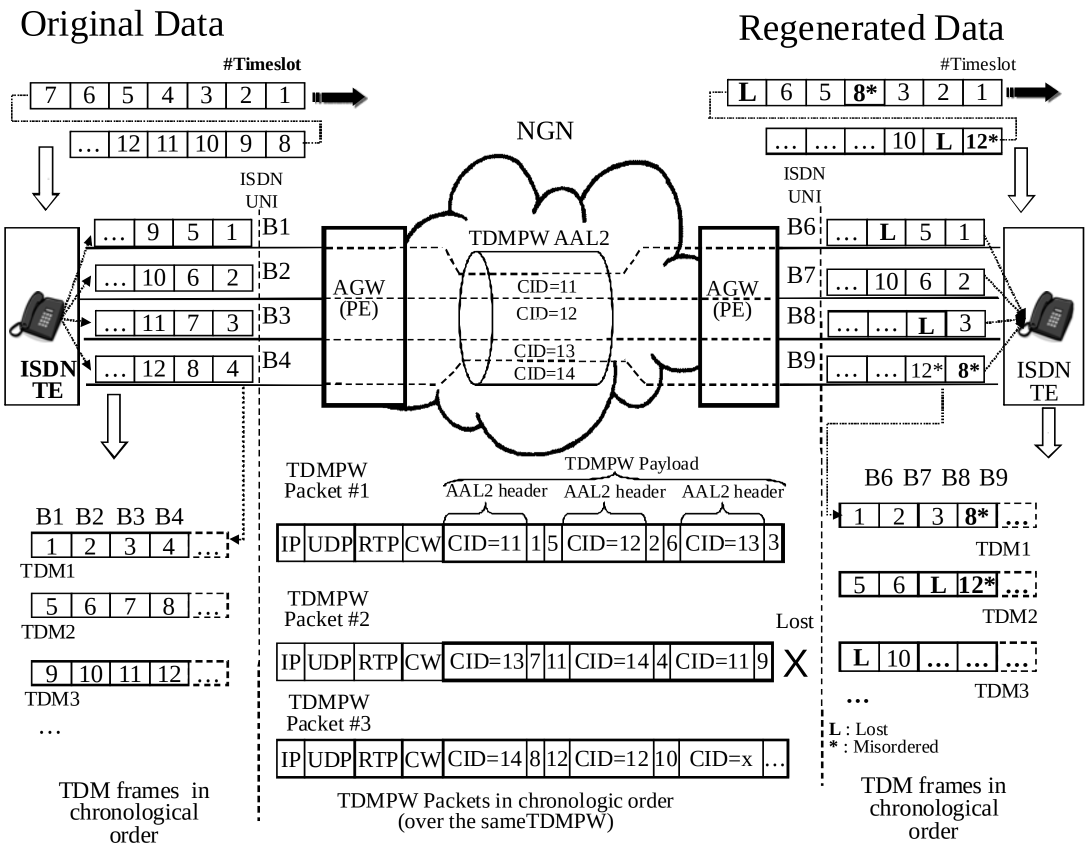

Figure 5 4x64 multi-channel ISDN call on standardized AAL2 TDMoIP PW with a CID per channel

To summarize, the standard AAL2 TDMPW payload format, which assigns a CID to each channel, can not properly carry ISDN multi-channel calls. To support that transport, including multiplexing several calls on the same TDMPW, we propose two options:

a) AAL2 TDMPWs with a CID per channel in VoIP mode: VoIP mode [14] proposes to insert a RTP header inside each AAL2 minicell AAL2 (eliminating the RTP header of the TDMPW), which would allow the egrees PE to know the time to play the first sample of each minicell. Thus, after the loss of a TDMPW packet, the egress PE can identify the affected TDM frames, properly placing the samples of the following TDMPW packets.

   This transport scheme guarantees that the sample order at the ingress is kept at the egress PE, which also ensures TSSI and RDTD structures (Figure 6). Also, the PT field of the RTP header of each minicell allows the egress PE to know the codec applied to each call in the IP network.

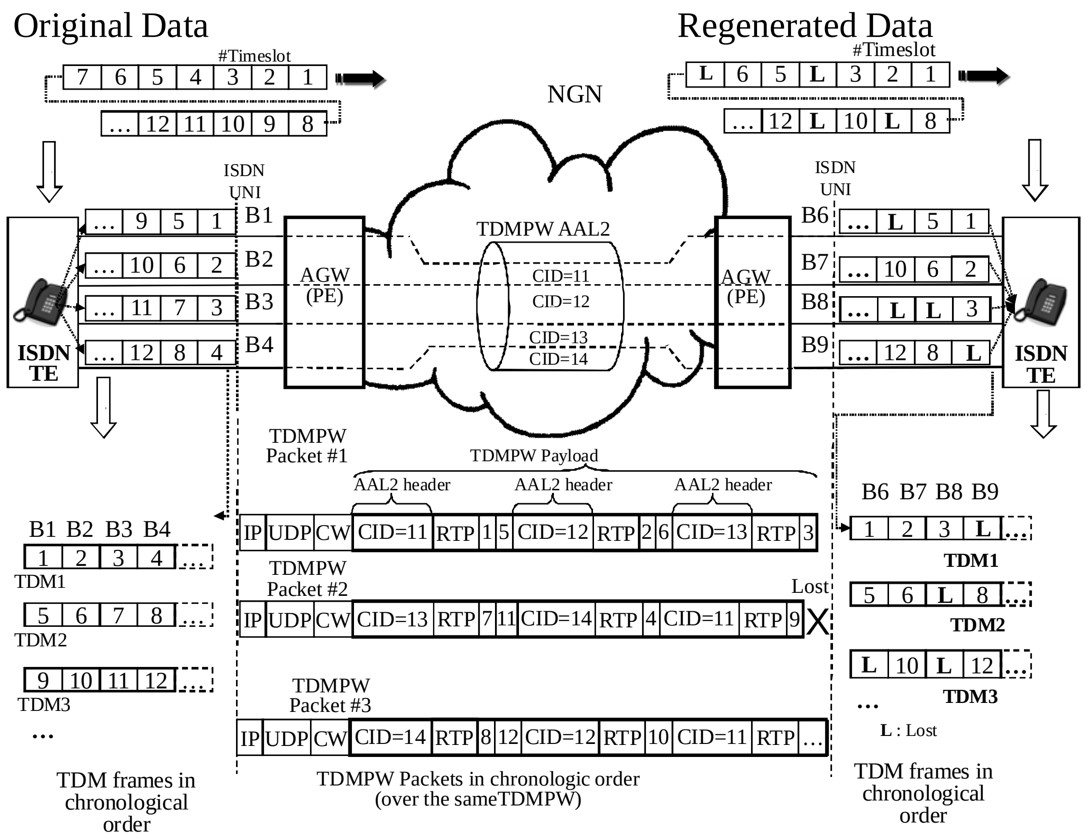

Figure 6 4x64 multi-channel ISDN call on AAL2 TDMoIP PW with a CID per channel and VoIP mode

b) AAL2 TDMPWs with a CID per call using basic structures: although the IETF specification [27] only provides for the allocation of a CID to each channel, the definition of AAL2 interworking flows by ITU-T Recommendations [14, 40] is much more general, allowing freedom for the nature of the flows identified by each CID (i.e., multiplexed flows of any kind and, even, RTP flows from any TDM interface). Taking advantage of this flexibility, we propose to associate a CID to each call carried by the TDMPW, either single or multi-channel (same CID to all its channels).

Samples will be transported by "basic structures" similar to those defined for the CESoPSN TDMPWs under basic Nx64 service [29]. Each basic structure consists of the sample of "N" channels of the call contained in a single TDM frame. The payload of each AAL2 minicell contains an integer number of basic structures (Figure 7).

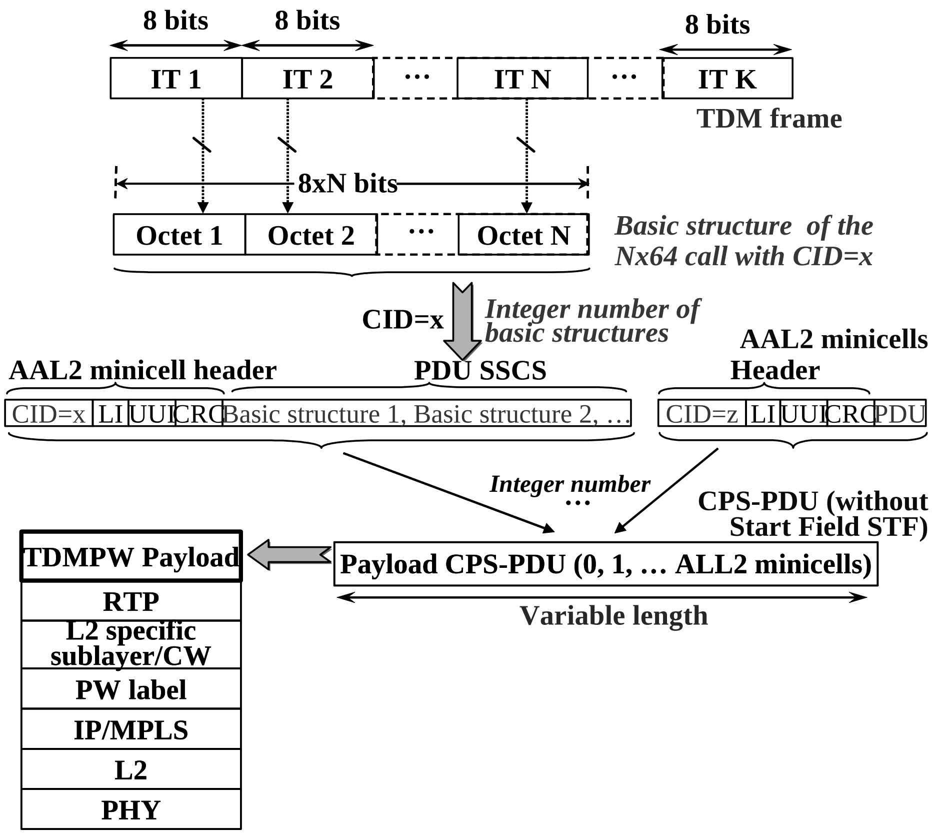

Figure 7 AAL2 TDMoIP payload with a CID per call based on basic structures

This scheme ensures that the flow regenerated at the output of the TDMPW matches the origin, which also ensures the TSSI structure. The RDTD structure is also guaranteed, since the “N = 2” samples from the same TDM frame will share the same minicell, shaping a “basic structure”.

At the destination, the egress PE needs to know the type of codec for each call, be it to transcode to the proper output codec or to insert comfort noise should VAD is used. To inform the PE, we propose two alternatives:

- VoIP mode, with an RTP header in each AAL2 minicell (Figure 8): the PT would be included in the RTP header.
- PT in the User-to-User Indication (UUI) of every AAL2 minicell (Figure 9): Annex A of the specification [30] outlines a possible use of UUI field to indicate the encoding of the media. This option has the same headers that AAL2 TDMPWs defined by [27], thus keeping the same TDMPW's RTP header.

For single- channel voice calls, with CNG PT, the ingress PE would sends two different AAL2 minicell types: one type for voice samples, and another type for the SID frames with CNG PT. In both cases the payload-type will be indicated in the PT RTP or UUI AAL2 field. The working-out of the noise-generation interval depends on the alternative:

- For the VoIP mode, with a CID per channel or call, the egress PE shall use the timestamps from the RTP header.
- For the PT in the UUI AAL2 field mode there are no timestamps, so the egress PE generates comfort noise until the next voice minicell is received.

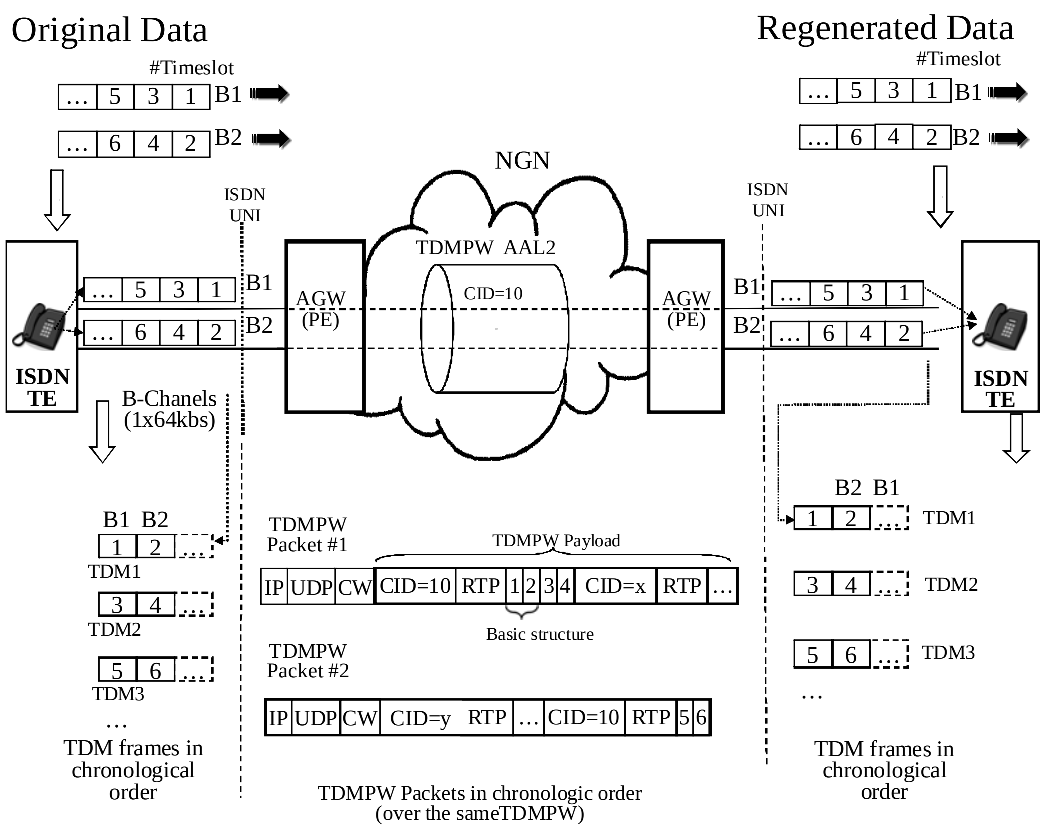

Figure 8 2x64 multi-channel ISDN call on AAL2 TDMoIP PW with a CID per call and VoIP mode

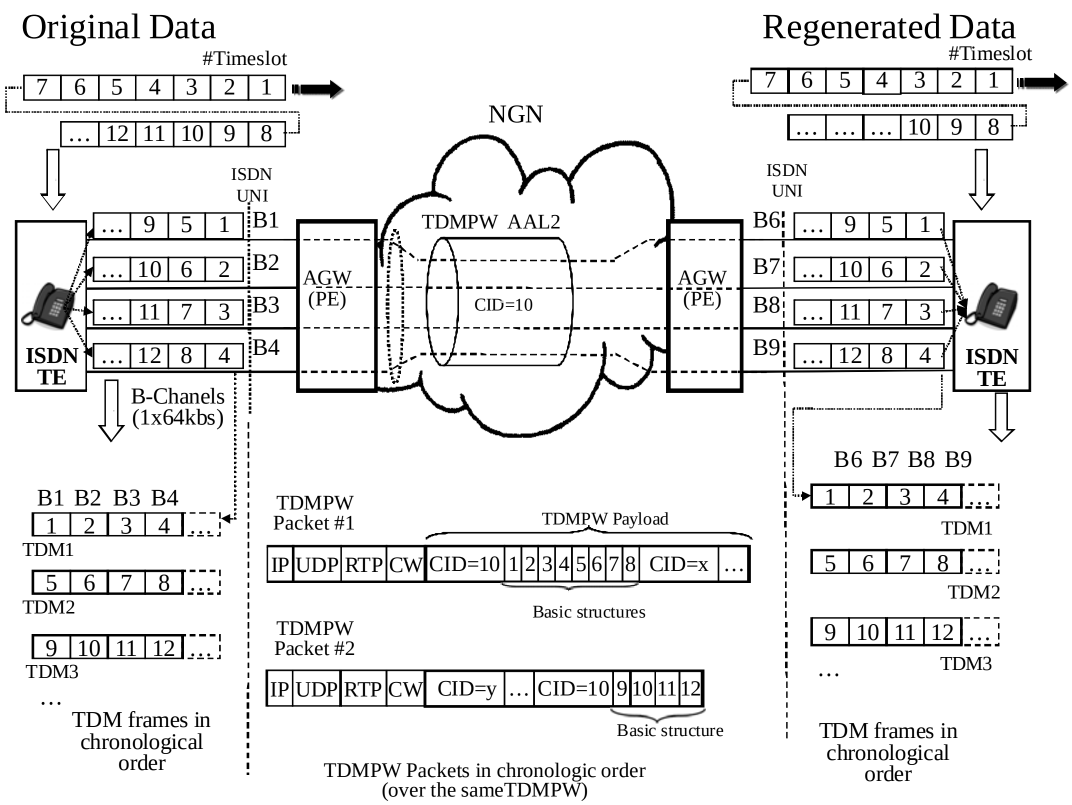

Figure 9 4x64 multi-channel ISDN call on AAL2 TDMoIP PW with a CID per call and PT in UUI field

3.4 Comparison of the Proposed TDMPW Payload Formats

The 3 types of proposed AAL2 TDMPW payloads can be compared in terms of bandwidth efficiency, attainable granularity and delay (Table I):

a) In the VoIP mode, the inclusion of an RTP header in every minicell wastes bandwidth. Given the great similarity that these headers may show, the problem could alleviated by applying RTP header compression mechanisms [41]. For the two options proposed under this mode, we can consider the following comments:

- When using one CID per channel samples of a call placed in the same TDM frame at the ingress PE can be sent in several TDMPW packets. The egress PE will have to wait for the arrival of all those packets to successfully build up the TDM frame, which may increase the delay.

- When using a CID per call all the samples from a call placed in the same TDM frame at the ingress PE are conveyed in the same TDMPW packet. Its disadvantage is a coarser packing granularity, because the payload of the minicells is forced to be a multiple of relatively larger basic structures. This reduces the margin to ensure a constant end to end delay between both PEs.

b) A CID per call with the PT in the UUI field: When compared to the VoIP mode, it is more bandwidth-efficient, as it does not require additional RTP headers. This solution also shows the coarse granularity feature described above.

Table 1 Comparison of the proposed AAL2 TMDOIP Payload Formates to Support ISDN Multichanel

	AAL2 TDMPW payload format standardized by [27]	**VoIP mode**		**CID per call and PT in the UIUI field**
		CID per channel	***CID per call***	
Guarantees TSSI and RDTD structures	No	Yes	Yes	Yes
Support ISDN multi-channel calls	No	Yes	Yes	Yes
AAL2 minicells' granularity	Octects	Octects	Basic structures	Basic structures
Transport of the PT of each call	No (it assumes the same codec for all calls)	PT RTP field in AAL2 minicells	PT RTP field in AAL2 minicells	UUI field of AAL2 minicell' header
Support call multiplexing	No (it assumes the same codec for all calls)	Yes	Yes	Yes
Determination of the noise-generation period for VAD-enabled single -channel calls	VAD not supported	By using RTP timestamp	By using RTP timestamp	Until the next voice minicell arrives
Overhead	Lower	High (RTP headers in AAL2 minicells)	High (RTP headers in AAL2 minicells)	Lower
Effect of delayed TDMPW packets	Egress PE should wait to last TDMPW with samples of the same frame TDM	Egress PE should wait to last TDMPW with samples of the same frame TDM	None (samples travel together in basic structures)	None (samples travel together in basic structures)

4 Conclusions

This paper addresses the transport of ISDN multi-channel circuit-mode bearer services for its NGN emulation.

First, we have evaluated the different TDMPWs, concluding that the AAL2 TDMPWs are the best choice, although its standard payload format does not guarantee the TSSI structure. To solve this, we have defined three new types for the TDMPW's payload format. Two of them are based on the inclusion of a header at the beginning of the RTP payload for each AAL2 minicell (VoIP mode), assigning a CID to every channel or call (in the latter, by organizing the samples from the channels of a call in basic structures.) The third type, which also assigns a CID to each call, uses the minicells' UUI field to indicate the type of processing applied to the samples, saving bandwidth.

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