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Tempo Session Intent for HTTP Payment Authentication

Abstract

This document defines the "session" intent for the "tempo" payment method in the Payment HTTP Authentication Scheme. It specifies unidirectional streaming payment channels for incremental, voucher-based payments suitable for low-cost metered services, including both legacy contract-backed channels and TIP-20 channel precompile-backed channels.

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1. Introduction

This document is published as Informational but contains normative requirements using BCP 14 keywords [RFC2119] [RFC8174] to ensure interoperability between implementations. Payment method specifications that reference this document inherit these requirements.

The session intent establishes a unidirectional streaming payment channel using on-chain escrow and off-chain [EIP-712] vouchers. This enables high- frequency, low-cost payments by batching many off-chain voucher signatures into periodic on-chain settlements.

Unlike the charge intent which requires the full payment amount upfront, the session intent allows clients to pay incrementally as they consume services, paying exactly for resources received.

1.1. Use Case: LLM Token Streaming

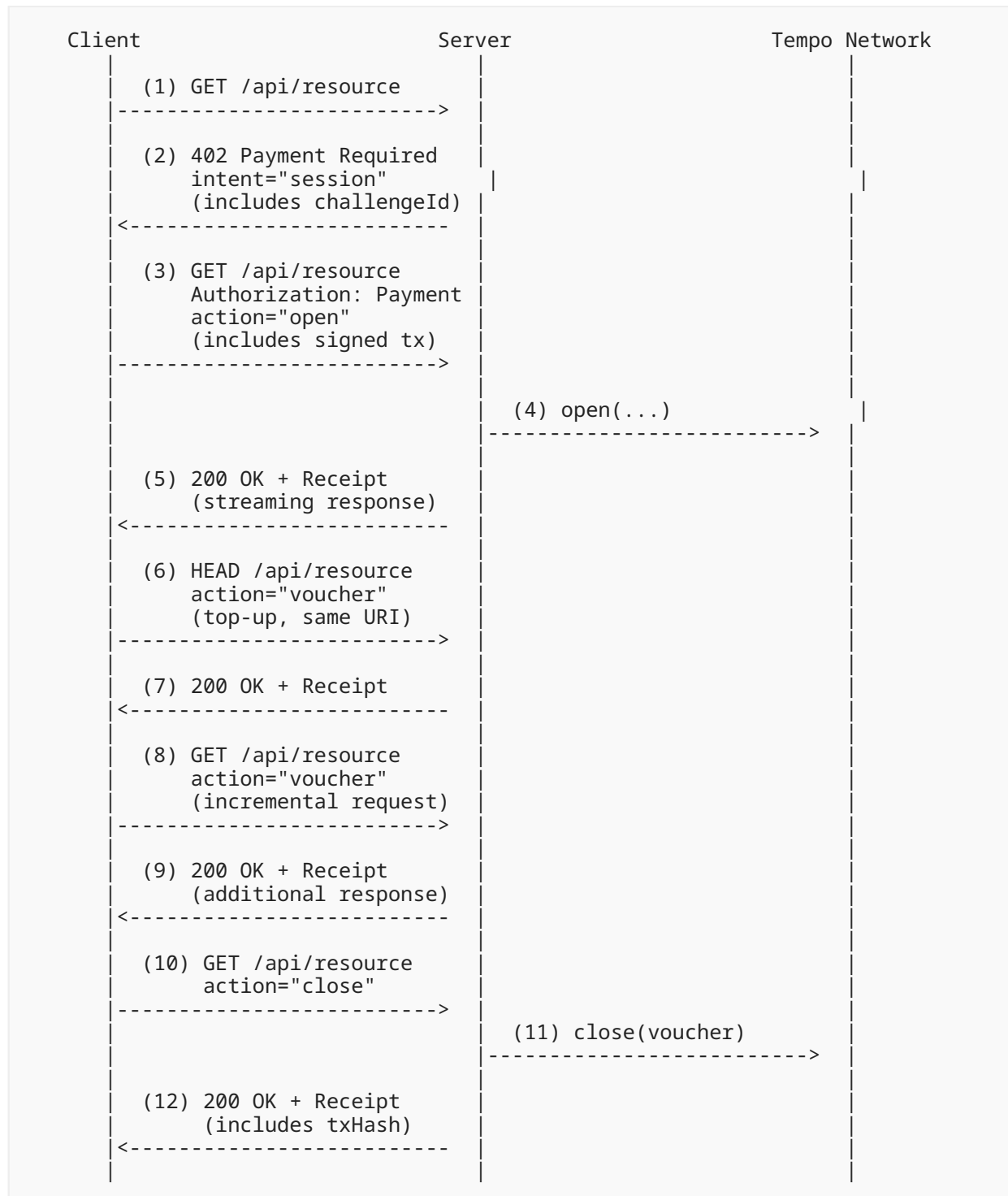
Consider an LLM inference API that charges per output token:

1. Client requests a streaming completion (SSE response)
2. Server returns 402 with a session challenge
3. Client opens a payment channel on-chain, depositing funds
4. Server begins streaming response
5. As response streams, or over incremental requests, client signs vouchers with increasing amounts
6. Server settles periodically or at stream completion

The client pays exactly for tokens received, with no worst-case reservation.

1.2. Session Flow

The following diagram illustrates the Tempo session flow:



Voucher updates and close requests are submitted to the **same resource URI** that requires payment. This allows sessions to work on any endpoint without dedicated payment control plane routes. Servers **SHOULD** support voucher updates via any HTTP method; clients **MAY** use HEAD for pure voucher top-ups when no response body is needed.

1.3. Concurrency Model

A channel supports one active session at a time. The cumulative voucher semantics ensure correctness—each voucher advances a single monotonic counter. The channel is the unit of concurrency; no additional session locking is required.

When a client sends a new streaming request on a channel that already has an active session, servers **SHOULD** terminate the previous session and start a new one. Voucher updates **MAY** arrive on separate HTTP connections (including HTTP/2 streams) and **MUST** be processed atomically with respect to balance updates.

Servers **MUST** ensure that voucher acceptance and balance deduction are serialized per channel to prevent race conditions.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Terminology

Streaming Payment Channel A unidirectional off-chain payment mechanism where the payer deposits funds into an escrow contract and signs cumulative vouchers authorizing increasing payment amounts.

Voucher An [EIP-712] signed message authorizing a cumulative payment amount for a specific channel. Vouchers are monotonically increasing in amount.

Channel A payment relationship between a payer and payee, identified by a unique `channelId`. The channel holds deposited funds and tracks cumulative settlements.

Settlement The on-chain [TIP-20] transfer that converts off-chain voucher authorizations into actual token movement.

Authorized Signer An address delegated to sign vouchers on behalf of the payer. Defaults to the payer if not specified.

Base Units The smallest indivisible unit of a TIP-20 token. TIP-20 tokens use 6 decimal places; one million base units equals 1.00 tokens.

4. Protocol Versions

Tempo session challenges can identify the channel backend through `methodDetails.sessionProtocol`:

Value	Channel backend	Description
v1	Contract-backed escrow	The legacy <code>TempoStreamChannel</code> contract interface described in Section 6.1 .
v2	TIP-20 channel precompile	The TIP-20 channel escrow precompile described in Section 6.2 .

Table 1

If `methodDetails.sessionProtocol` is absent, clients **MAY** treat the challenge as v1 for backwards compatibility. New servers **SHOULD** emit `"sessionProtocol": "v2"` when using the TIP-20 channel precompile. A client **MUST NOT** answer a challenge using a different session protocol than the one indicated by the challenge.

5. Encoding Conventions

This section defines normative encoding rules for interoperability.

5.1. Hexadecimal Values

All byte arrays (addresses, hashes, signatures, `channelId`) use:

- Lowercase hexadecimal encoding
- `0x` prefix
- No padding or truncation

Type	Length	Example
address	42 chars (0x + 40 hex)	<code>0x742d35cc6634c0532925a3b844bc9e7595f8fe00</code>
bytes32	66 chars (0x + 64 hex)	<code>0x6d0f4fdf1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f</code>

Type	Length	Example
signature	130-132 chars (0x + 128-130 hex)	65-byte (r s v) or 64-byte EIP-2098 compact

Table 2

Implementations **MUST** use lowercase hex. Implementations **SHOULD** accept mixed-case input but normalize to lowercase before comparison.

5.2. Numeric Values

Integer values (amounts, timestamps) are encoded as decimal strings in JSON to avoid precision loss with large numbers:

Field	Encoding	Example
cumulativeAmount	Decimal string	"250000"
requestedAt	Decimal string (Unix seconds)	"1736165100"
chainId	JSON number	4217

Table 3

The chainId uses JSON number encoding as values are small enough to avoid precision issues.

5.3. Timestamp Format

HTTP headers and receipt fields use [\[RFC3339\]](#) formatted timestamps: 2025-01-06T12:05:00Z. Timestamps in EIP-712 signed data use Unix seconds as decimal strings.

6. Channel Escrow Contract

Streaming payment channels require an on-chain escrow contract that holds user deposits and enforces voucher-based withdrawals.

6.1. Contract-Backed Channel State

For sessionProtocol: "v1", each channel is identified by a unique channelId and stores:

Field	Type	Description
payer	address	User who deposited funds

Field	Type	Description
payee	address	Server authorized to withdraw
token	address	[TIP-20] token address
authorizedSigner	address	Authorized signer (0 = payer)
deposit	uint128	Total amount deposited
settled	uint128	Cumulative amount already withdrawn by payee
closeRequestedAt	uint64	Timestamp when close was requested (0 if not)
finalized	bool	Whether channel is closed

Table 4

The `channelId` **MUST** be computed deterministically using the escrow contract's `computeChannelId()` function:

```
channelId = keccak256(abi.encode(
    payer,
    payee,
    token,
    salt,
    authorizedSigner,
    address(this),
    block.chainid
))
```

Note: The `channelId` includes `address(this)` (the escrow contract address) and `block.chainid`, explicitly binding the channel to a specific contract deployment and chain. Clients **MUST** use the contract's `computeChannelId()` function or equivalent logic to ensure interoperability.

6.2. Precompile-Backed Channel State

For `sessionProtocol`: "v2", the channel is identified by a descriptor and the TIP-20 channel escrow precompile.

6.2.1. Channel Descriptor

The descriptor is carried in each v2 credential payload and contains:

Field	Type	Description
payer	address	Wallet that funds the channel and authorizes voucher spend

Field	Type	Description
payee	address	Wallet that receives settlement from the channel
operator	address	Optional payee-side operator authorized for channel operations; zero address if unset
token	address	TIP-20 token escrowed by the channel
salt	bytes32	Payer-selected entropy
authorizedSigner	address	Voucher signer; zero address delegates to payer
expiringNonceHash	bytes32	Hash of the sender-signed expiring-nonce open transaction

Table 5

The v2 channelId **MUST** be computed as:

```
channelId = keccak256(abi.encode(
    payer,
    payee,
    operator,
    token,
    salt,
    authorizedSigner,
    expiringNonceHash,
    escrow,
    chainId
))
```

The escrow value is the precompile or escrow address from `methodDetails.escrowContract`, and chainId is `methodDetails.chainId`. Servers **MUST** recompute this value from the descriptor and reject credentials whose channelId does not match.

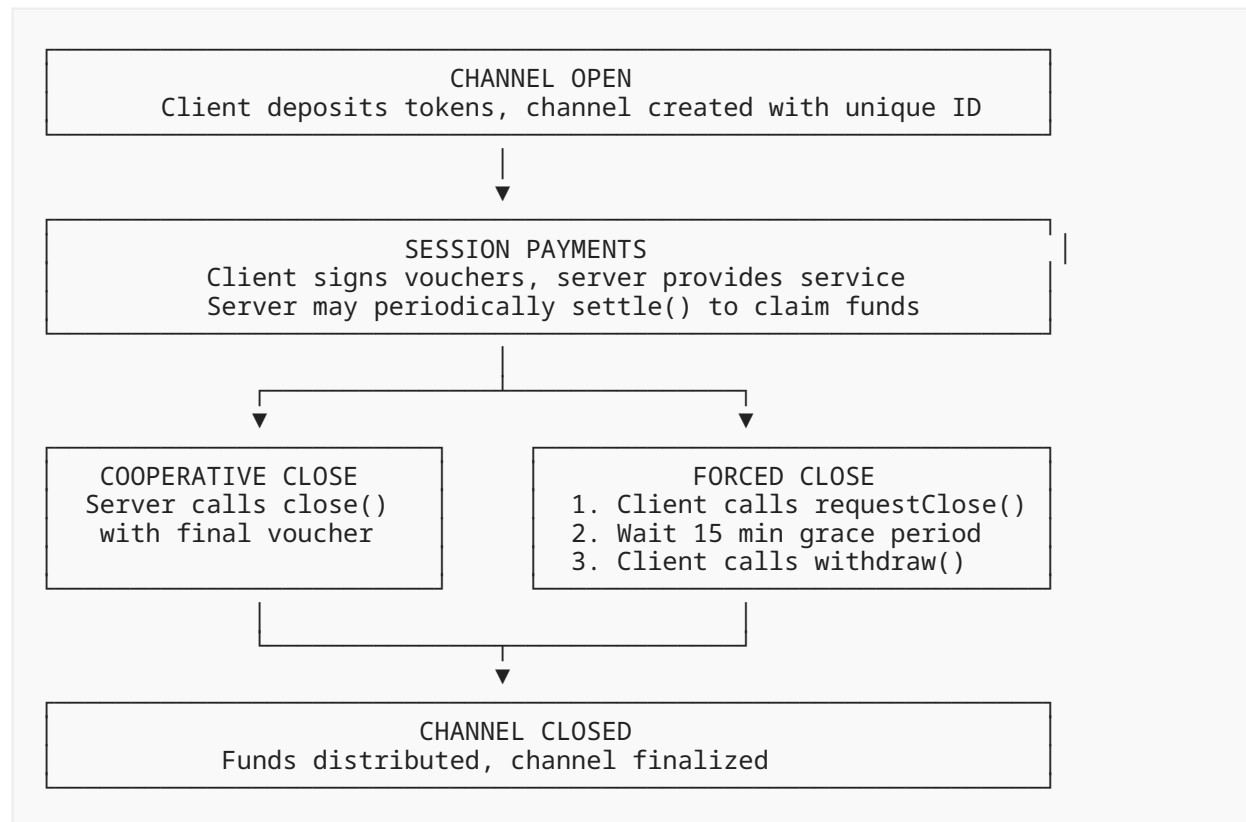
For v2, servers **MUST** verify that:

- `descriptor.payee` matches the challenge recipient
- `descriptor.token` matches the challenge currency
- `descriptor.operator` matches `methodDetails.operator` when present, or is the zero address when no operator is advertised
- `descriptor.expiringNonceHash` matches the open transaction being broadcast

V2 channel amounts use unsigned 96-bit integer semantics. Clients and servers **MUST** reject deposits, voucher amounts, settlement amounts, and close capture amounts that exceed $2^{96} - 1$.

6.3. Channel Lifecycle

Channels have no expiry—they remain open until explicitly closed.



6.4. Contract Functions

Compliant escrow contracts **MUST** implement the following functions. The signatures shown are a reference implementation; alternative implementations **MAY** use different parameter types (e.g., uint256 instead of uint128) as long as the semantics are preserved.

6.4.1. open

Opens a new channel with escrowed funds.

Parameter	Type	Description
payee	address	Server's address authorized to withdraw funds
token	address	[TIP-20] token contract address
deposit	uint128	Amount to deposit in base units (6 decimals)
salt	bytes32	Random value for deterministic channelId computation

Parameter	Type	Description
authorizedSigner	address	Delegated signer; use 0x0 to default to payer

Table 6

Returns the computed channelId.

```
function open(  
    address payee,  
    address token,  
    uint128 deposit,  
    bytes32 salt,  
    address authorizedSigner  
) external returns (bytes32 channelId);
```

6.4.2. settle

Server withdraws funds using a signed voucher without closing the channel.

Parameter	Type	Description
channelId	bytes32	Unique channel identifier
cumulativeAmount	uint128	Cumulative total authorized (not delta)
signature	bytes	EIP-712 signature from authorized signer

Table 7

The contract computes $\text{delta} = \text{cumulativeAmount} - \text{channel.settled}$ and transfers delta tokens to the payee.

```
function settle(  
    bytes32 channelId,  
    uint128 cumulativeAmount,  
    bytes calldata signature  
) external;
```

6.4.3. topUp

User adds more funds to an existing channel. If a close request is pending (`closeRequestedAt != 0`), calling `topUp()` **MUST** cancel it by resetting `closeRequestedAt` to zero and emitting a `CloseRequestCancelled` event.

Parameter	Type	Description
channelId	bytes32	Existing channel identifier

Parameter	Type	Description
additionalDeposit	uint128	Additional amount to deposit in base units

Table 8

```
function topUp(  
    bytes32 channelId,  
    uint128 additionalDeposit  
) external;
```

6.4.4. close

Server closes the channel, settling any outstanding voucher and refunding the remainder to the payer. Only callable by the payee.

Parameter	Type	Description
channelId	bytes32	Channel to close
cumulativeAmount	uint128	Final cumulative amount for settlement
signature	bytes	EIP-712 signature from authorized signer

Table 9

Transfers `cumulativeAmount - channel.settled` to payee, refunds `channel.deposit - cumulativeAmount` to payer, and marks channel finalized.

```
function close(  
    bytes32 channelId,  
    uint128 cumulativeAmount,  
    bytes calldata signature  
) external;
```

6.4.5. requestClose

User requests channel closure, starting a grace period of at least 15 minutes.

Parameter	Type	Description
channelId	bytes32	Channel for which to request closure

Table 10

Sets `channel.closeRequestedAt` to current block timestamp. The grace period allows the payee time to submit any outstanding vouchers before forced closure.

```
function requestClose(bytes32 channelId) external;
```

6.4.6. withdraw

User withdraws remaining funds after the grace period expires.

Parameter	Type	Description
channelId	bytes32	Channel to withdraw from

Table 11

Requires `block.timestamp >= channel.closeRequestedAt + CLOSE_GRACE_PERIOD`. Refunds all remaining deposit to payer and marks channel finalized.

```
function withdraw(bytes32 channelId) external;
```

6.5. Access Control

The escrow contract **MUST** enforce the following access control:

Function	Caller	Description
open	Anyone	Creates channel; caller becomes payer
settle	Payee only	Withdraws funds using voucher
topUp	Payer only	Adds funds to existing channel
close	Payee only	Closes channel with final voucher
requestClose	Payer only	Initiates forced close
withdraw	Payer only	Withdraws after grace period

Table 12

6.6. Signature Verification

The escrow contract **MUST** perform the following signature verification for all functions that accept voucher signatures (`settle`, `close`):

1. **Canonical signatures:** The contract **MUST** reject ECDSA signatures with non-canonical (high-`s`) values. Signatures **MUST** have `s <= secp256k1_order / 2` where the half-order is `0x7FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF5D576E7357A4501DDFE92F46681B20A0`. See [Section 14.8](#) for rationale.

2. **Authorized signer verification:** The contract **MUST** recover the signer address from the EIP-712 signature and verify it matches the expected signer for the channel:
 - If `channel.authorizedSigner` is non-zero, the recovered signer **MUST** equal `channel.authorizedSigner`
 - Otherwise, the recovered signer **MUST** equal `channel.payer`
3. **Domain binding:** The contract **MUST** use its own address as the `verifyingContract` in the EIP-712 domain separator, ensuring vouchers cannot be replayed across different escrow deployments.

Failure to enforce these requirements on-chain would allow attackers to bypass server-side validation by submitting transactions directly to the contract.

7. Request Schema

The `request` parameter in the `WWW-Authenticate` challenge contains a base64url-encoded JSON object.

7.1. Fields

Field	Type	Required	Description
<code>amount</code>	string	REQUIRED	Price per unit in base units (see note below)
<code>unitType</code>	string	OPTIONAL	Unit being priced (e.g., "llm_token", "byte", "request")
<code>suggestedDeposit</code>	string	OPTIONAL	Suggested channel deposit amount in base units
<code>currency</code>	string	REQUIRED	[TIP-20] token address (e.g., "0x20c0...")
<code>recipient</code>	string	REQUIRED	Payee address (server's withdrawal address)—equivalent to the on-chain payee

Table 13

For the session intent, `amount` specifies the price per unit of service in base units (6 decimals), not a total charge. When `unitType` is present, clients can use it together with `amount` to estimate costs before streaming begins. The total cost depends on consumption: `total = amount × units_consumed`.

The optional `suggestedDeposit` indicates the server's recommended channel deposit for typical usage. Clients **MAY** deposit less (if they expect limited usage) or more (for extended sessions). The minimum viable deposit is implementation-defined but **SHOULD** be at least amount to cover one unit of service.

Challenge expiry is specified via the expires auth-param in the WWW-Authenticate header per [I-D.httpauth-payment], using [RFC3339] timestamp format. Unlike the charge intent, the session request JSON does not include an expires field—expiry is conveyed solely via the HTTP header.

7.2. Method Details

As of version 00, session-specific request fields are placed in methodDetails. A future high-level "session" intent definition may promote common fields to the core schema.

Field	Type	Required	Description
methodDetails.escrowContract	string	REQUIRED	Address of the channel escrow contract
methodDetails.channelId	string	OPTIONAL	Channel ID if resuming an existing channel
methodDetails.minVoucherDelta	string	OPTIONAL	Minimum amount increase between vouchers (server policy hint)
methodDetails.chainId	number	OPTIONAL	Tempo chain ID (default: 4217)
methodDetails.operator	string	OPTIONAL	V2 payee-side operator address clients encode in new channel descriptors
methodDetails.sessionProtocol	string	OPTIONAL	Session protocol version, either "v1" or "v2"
methodDetails.sessionSnapshot	object	OPTIONAL	V2 reusable channel snapshot; see Section 7.3

Table 14

Channel reuse is **OPTIONAL**. Servers **MAY** include channelId to suggest resuming an existing channel:

- **New channel** (no channelId): Client generates a random salt locally, computes channelId using the formula in [Section 6.1](#), opens the channel on-chain, and returns the channelId in the credential.
- **Existing channel** (channelId provided): Client **MUST** verify `channel.deposit - channel.settled >= amount` before resuming. If insufficient, client **SHOULD** either call `topUp()` with the difference or open a new channel.

Servers **MAY** cache (payer address, payee address, token) → channelId mappings to suggest channel reuse, reducing on-chain transactions.

When `methodDetails.sessionProtocol` is "v2", servers **MUST** include `methodDetails.chainId` and `methodDetails.escrowContract` in the challenge after applying defaults. The `escrowContract` value identifies the TIP-20 channel escrow precompile or compatible deployment. Servers **MAY** include `methodDetails.operator`; if omitted, clients **MUST** use the zero address for the descriptor operator.

7.3. Session Snapshot

For v2 reusable channels, servers **MAY** include a snapshot of channel state in `methodDetails.sessionSnapshot` and **MAY** also send it in the `Payment-Session-Snapshot` response header. The header value is a base64url-encoded JSON object without padding. Servers **MAY** also send a `Payment-Session` header containing the reusable `channelId`.

A session snapshot contains:

Field	Type	Required	Description
<code>acceptedCumulative</code>	string	REQUIRED	Highest cumulative voucher amount accepted by the server
<code>chainId</code>	number	REQUIRED	Tempo chain ID
<code>channelId</code>	string	REQUIRED	V2 channel identifier
<code>closeRequestedAt</code>	string	OPTIONAL	Close-request timestamp if the channel is closing
<code>deposit</code>	string	REQUIRED	Current on-chain deposit
<code>descriptor</code>	object	REQUIRED	Channel descriptor from Section 6.2
<code>escrow</code>	string	REQUIRED	Escrow precompile or contract address
<code>requiredCumulative</code>	string	REQUIRED	Minimum cumulative amount required for the challenged request
<code>settled</code>	string	REQUIRED	Amount already settled on-chain
<code>spent</code>	string	REQUIRED	Amount consumed according to server accounting
<code>units</code>	number	OPTIONAL	Units delivered according to server accounting

Table 15

Clients **MAY** use a valid snapshot to avoid local channel lookup. Clients **MUST** verify that the snapshot `channelId`, `descriptor`, `escrow`, and `chainId` are consistent with the v2 channel ID derivation before using it to construct a credential.

7.3.1. Bootstrap Preflight

Servers **MAY** support same-resource bootstrap for reusable v2 channels. A client sends a HEAD request to the protected resource. If the server needs payer identity before it can resolve a channel, it **MAY** challenge with a zero-amount tempo charge request. After the client proves the zero-amount challenge, the server returns 204 No Content and **MAY** include Payment-Session and Payment-Session-Snapshot headers.

Example (new channel):

```
{
  "amount": "25",
  "unitType": "llm_token",
  "suggestedDeposit": "10000000",
  "currency": "0x20c000000000000000000000000000000000000000000000",
  "recipient": "0x742d35cc6634c0532925a3b844bc9e7595f8fe00",
  "methodDetails": {
    "escrowContract": "0x1234567890abcdef1234567890abcdef12345678",
    "chainId": 4217,
    "sessionProtocol": "v2"
  }
}
```

This requests a price of 0.000025 tokens per LLM token, with a suggested deposit of 10.00 tokens. The client generates a random salt locally.

Example (existing channel):

```
{
  "amount": "25",
  "unitType": "llm_token",
  "currency": "0x20c00000000000000000000000000000000000000000000",
  "recipient": "0x742d35cc6634c0532925a3b844bc9e7595f8fe00",
  "methodDetails": {
    "escrowContract": "0x1234567890abcdef1234567890abcdef12345678",
    "channelId":
"0x6d0f4fdf1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f",
    "chainId": 4217,
    "sessionProtocol": "v2"
  }
}
```

For existing channels, suggestedDeposit is omitted since the channel already has funds. The channelId tells the client to resume this channel.

8. Fee Payment

When a challenge includes `methodDetails.feePayer: true`, the server commits to paying transaction fees on behalf of the client. In the session intent, `feePayer` affects only the client-originated channel funding transactions (open and topUp).

8.1. Server-Paid Fees

When `feePayer: true` for open or topUp:

1. **Client signs with placeholder:** The client signs the Tempo Transaction [TEMPO-TX-SPEC] with `fee_payer_signature` set to a placeholder value (`0x00`) and `fee_token` left empty. The client uses signature domain `0x76`.
2. **Server receives credential:** The server extracts the client-signed transaction from the credential payload.
3. **Server adds fee payment signature:** The server selects a `fee_token` (any USD-denominated TIP-20 stablecoin) and signs the transaction using signature domain `0x78`. This signature commits to the transaction including the `fee_token` and client's address.
4. **Server broadcasts:** The final transaction contains both signatures:
 - Client's signature (authorizing the channel operation)
 - Server's `fee_payer_signature` (committing to pay fees)

8.2. Client-Paid Fees

When `feePayer: false` or omitted, the client **MUST** set `fee_token` to a valid USD TIP-20 token address and include valid fee payment fields so the transaction is executable without server fee sponsorship. The server broadcasts the transaction as-is.

8.3. Server-Initiated Operations

The `settle` and `close` contract functions are server-originated on-chain transactions. The server pays transaction fees for these operations regardless of the `feePayer` setting:

- **Voucher updates** (`action="voucher"`) are off-chain and incur no transaction fees.
- **Settlement** (`settle()`) and channel **close** (`close` invocation) are initiated by the server using the highest valid voucher. The server covers the fees for these transactions.
- Servers **MAY** recover settlement costs through pricing or other business logic.

The `feePayer` field applies only to open and topUp operations where the client provides a signed transaction.

8.4. Server Requirements

When acting as fee payer for `open` or `topUp`:

- Servers **MUST** maintain sufficient balance of a USD TIP-20 token to pay transaction fees
- Servers **MAY** use any USD-denominated TIP-20 token with sufficient AMM liquidity as the fee token
- Servers **MUST** validate the transaction matches challenge and channel parameters before adding fee payer signature
- Servers **MUST** reject credentials with unknown action values

8.5. Client Requirements

- When `feePayer: true`: Clients **MUST** sign with `fee_payer_signature` set to `0x00` and `fee_token` empty or `0x80` (RLP null)
- When `feePayer: false` or omitted: Clients **MUST** set `fee_token` to a valid USD TIP-20 token and have sufficient balance to pay fees

9. Credential Schema

The credential in the Authorization header contains a base64url-encoded JSON object per [I-D.httpauth-payment].

9.1. Credential Structure

Field	Type	Required	Description
challenge	object	REQUIRED	Echo of the challenge parameters from the server's WWW-Authenticate header
payload	object	REQUIRED	Session-specific payload object

Table 16

Implementations **MUST** ignore unknown fields in credential payloads, request objects, and receipts to allow forward-compatible extensions.

9.2. Credential Lifecycle

A streaming payment session progresses through distinct phases, each corresponding to a payload action:

1. **Open**: Client deposits funds on-chain and presents the open action to begin the session. The server verifies the on-chain deposit and validates the initial zero-amount voucher.
2. **Streaming**: Client submits voucher actions with increasing cumulative amounts as service is consumed. The server may periodically settle vouchers on-chain.

3. **Close:** Client sends the `close` action with the final voucher. The server settles on-chain and returns a receipt.

Each action carries action-specific fields directly in the payload object, with the `action` field discriminating between phases.

9.3. Payload Actions

The payload object uses an `action` discriminator with action-specific fields at the same level:

Field	Type	Required	Description
<code>action</code>	string	REQUIRED	One of "open", "topUp", "voucher", "close"

Table 17

Action-specific fields are placed directly in the payload object alongside `action`. See each action's definition for required fields.

Action	Description
<code>open</code>	Confirms channel is open on-chain; begins streaming
<code>topUp</code>	Adds funds to an existing channel
<code>voucher</code>	Submits an updated cumulative voucher
<code>close</code>	Requests server to close the channel

Table 18

9.3.1. Open Payload

The `open` action confirms an on-chain channel opening and begins the streaming session. The client provides a signed transaction for the server to broadcast.

Payload fields (in addition to `action`):

Field	Type	Required	Description
<code>type</code>	string	REQUIRED	"transaction"
<code>channelId</code>	string	REQUIRED	Channel identifier (hex-encoded bytes32)
<code>transaction</code>	string	REQUIRED	Signed transaction bytes
<code>authorizedSigner</code>	string	OPTIONAL	Address delegated to sign vouchers
<code>descriptor</code>	object	REQUIRED for v2	Channel descriptor from Section 6.2

Field	Type	Required	Description
cumulativeAmount	string	REQUIRED	Initial cumulative amount (typically "0")
signature	string	REQUIRED	EIP-712 voucher signature for the initial amount

Table 19

The transaction field contains the complete signed Tempo Transaction (type 0x76) [TEMPO-TX-SPEC] serialized as RLP and hex-encoded. The server broadcasts the transaction, optionally adding a fee payer signature if `feePayer: true` was specified in the challenge (see [Section 8](#)).

For v1, the server recovers the payer address from the signed transaction and uses it to compute the `channelId` deterministically (see [Section 6.1](#)). The `authorizedSigner` is inferred from the `calldata` inside transaction and verified when the transaction is signed.

For v2, the client **MUST** include `descriptor`. The server **MUST** verify that the `descriptor` matches the signed open transaction, the challenge payment fields, and the `channelId` derivation in [Section 6.2](#). If `authorizedSigner` is present in the payload, it **MUST** match `descriptor.authorizedSigner`.

The initial voucher (`cumulativeAmount` and `signature`) proves the client controls the signing key and establishes the voucher chain.

Example:

[illegible]

Note: The transaction field contains RLP-encoded transaction bytes. When provided, the signature field is the EIP-712 voucher signature (65 bytes r||s||v or 64 bytes EIP-2098 compact).

The challenge object **MUST** echo the challenge parameters from the server's WWW-Authenticate header per [I-D.httpauth-payment].

9.3.2. TopUp Payload

The `topUp` action adds funds to an existing channel during a streaming session. Like `open`, the client provides a signed transaction for the server to broadcast.

Clients **MUST** include a challenge object in the Payment credential for topUp actions. To obtain a challenge for a top-up outside an active streaming response, clients **MAY** send a HEAD request to the protected resource; the server returns 402 with a WWW-Authenticate challenge (no body). Servers **MUST** reject topUp actions referencing an unknown or expired challenge id with problem type challenge-not-found.

Payload fields (in addition to `action`):

Field	Type	Required	Description
type	string	REQUIRED	"transaction"
channelId	string	REQUIRED	Channel ID
transaction	string	REQUIRED	Signed transaction bytes
descriptor	object	REQUIRED for v2	Channel descriptor from Section 6.2
additionalDeposit	string	REQUIRED	Additional amount to deposit in base units

Table 20

Example:

[illegible]

Upon successful verification, the server updates the channel's available balance. The new deposit is immediately available for voucher authorization.

9.3.3. Voucher Payload

The voucher action submits an updated cumulative voucher during streaming.

Payload fields (in addition to `action`):

Field	Type	Required	Description
channelId	string	REQUIRED	Channel identifier
descriptor	object	REQUIRED for v2	Channel descriptor from Section 6.2
cumulativeAmount	string	REQUIRED	Cumulative amount authorized
signature	string	REQUIRED	EIP-712 voucher signature

Table 21

Example:

[illegible]

9.3.4. Close Payload

The `close` action requests the server to close the channel and settle on-chain.

Payload fields (in addition to action):

Field	Type	Required	Description
channelId	string	REQUIRED	Channel identifier
descriptor	object	REQUIRED for v2	Channel descriptor from Section 6.2
cumulativeAmount	string	REQUIRED	Final cumulative amount for settlement
signature	string	REQUIRED	EIP-712 voucher signature

Table 22

The server uses the voucher fields (channelId, cumulativeAmount, signature) to close the channel on-chain. For v2, the server **MUST** use the descriptor to identify the channel and **MUST** reject a close credential whose descriptor does not match the stored channel.

Example:

[illegible]

10. Voucher Signing Format

Vouchers use typed structured data signing compatible with [EIP-712]. This section normatively defines the signing procedure; [EIP-712] is referenced for background only.

10.1. Wire Format

Voucher fields are placed directly in the credential payload object (alongside action) rather than in a nested structure:

Field	Type	Required	Description
channelId	string	REQUIRED	Channel identifier (hex-encoded bytes32)
cumulativeAmount	string	REQUIRED	Cumulative amount authorized (decimal string)
signature	string	REQUIRED	EIP-712 signature (hex-encoded)

Table 23

The EIP-712 domain and type definitions are fixed by this specification. Implementations **MUST** reconstruct the full typed data structure using the domain parameters from the challenge (chainId, escrowContract) before signature verification.

10.2. Type Definitions

The types object **MUST** contain exactly:

```
{
  "Voucher": [
    { "name": "channelId", "type": "bytes32" },
    { "name": "cumulativeAmount", "type": "uint128" }
  ]
}
```

For sessionProtocol: "v2", cumulativeAmount is encoded as uint96 instead of uint128.

Note: The EIP712Domain type is implicit per EIP-712 and **SHOULD NOT** be included in the types object. The domain separator is computed from the domain object using the canonical type string EIP712Domain(string name,string version,uint256 chainId,address verifyingContract).

10.3. Domain Separator

The domain object **MUST** contain:

Field	Type	Value
name	string	"Tempo Stream Channel" for v1; "TIP20 Channel Reserve" for v2
version	string	"1"
chainId	number	Tempo chain ID (e.g., 4217)
verifyingContract	string	Escrow contract address from challenge

Table 24

10.4. Signing Procedure

To sign a voucher, implementations **MUST**:

1. Construct the domain separator hash:

```
domainSeparator = keccak256(  
    abi.encode(  
        keccak256("EIP712Domain(string name,string version,uint256  
chainId,address verifyingContract)"),  
        keccak256(bytes(name)),  
        keccak256(bytes(version)),  
        chainId,  
        verifyingContract  
    )  
)
```

2. Construct the struct hash:

```
structHash = keccak256(  
    abi.encode(  
        keccak256("Voucher(bytes32 channelId,uint128 cumulativeAmount)"),  
        channelId,  
        cumulativeAmount  
    )  
)
```

For v2, the struct type string is `Voucher(bytes32 channelId,uint96 cumulativeAmount)`.

3. Compute the signing hash:

```
signingHash = keccak256("\x19\x01" || domainSeparator || structHash)
```

4. Sign with ECDSA using secp256k1 curve
5. Encode signature as 65-byte `r || s || v` where `v` is 27 or 28

10.5. Cumulative Semantics

Vouchers specify cumulative totals, not incremental deltas:

- Voucher #1: `cumulativeAmount = 100` (authorizes 100 total)
- Voucher #2: `cumulativeAmount = 250` (authorizes 250 total)
- Voucher #3: `cumulativeAmount = 400` (authorizes 400 total)

When settling, the contract computes: `delta = cumulativeAmount - settled`

11. Verification Procedure

11.1. Open Verification

On `action="open"`, servers **MUST**:

1. **Transaction verification:** Decode the signed transaction from `transaction`, verify it calls `open()` on the expected escrow contract with correct parameters. Recover the payer address from the transaction, infer `authorizedSigner` from the `calldata`, and compute `channelId` deterministically (see [Section 6.1](#)). If `feePayer: true`, add fee payer signature using domain `0x78` (see [Section 8](#)) and broadcast. Otherwise, broadcast as-is. For v2, servers **MUST** also verify the payload descriptor, the computed `channelId`, the descriptor `expiringNonceHash`, and the emitted channel open receipt before accepting the credential.
2. Query the escrow contract to verify channel state:
 - Channel exists with the computed `channelId`
 - `channel.payee` matches server's address
 - `channel.token` matches `request.currency`
 - `channel.deposit - channel.settled >= amount` (sufficient available balance)
 - Channel is not finalized
 - `channel.closeRequestedAt == 0` (no pending close request)
3. If `cumulativeAmount` and `signature` are provided, verify the initial voucher:
 - Recover signer from EIP-712 signature
 - Verify signature uses canonical low-s values (see [Section 14.8](#))
 - Signer matches `channel.payer` or `channel.authorizedSigner`
 - `voucher.channelId` matches
 - `voucher.cumulativeAmount >= channel.settled` (at or above current settlement)
4. Initialize server-side channel state

11.2. TopUp Verification

On `action="topUp"`, servers **MUST**:

1. **Transaction verification:** Decode the signed transaction from `transaction`, verify it calls `topUp()` on the expected escrow contract with the specified `additionalDeposit` amount. If `feePayer: true`, add fee payer signature using domain `0x78` (see [Section 8](#)) and broadcast. Otherwise, broadcast as-is. For v2, servers **MUST** verify that the payload descriptor matches the stored channel and that the top-up receipt references the credential `channelId`.
2. Query the escrow contract to verify updated channel state:
 - `channel.deposit` increased by `additionalDeposit`
 - Channel is not finalized
3. Update server-side accounting:
 - Increase available balance by `additionalDeposit`

11.3. Voucher Verification

On `action="voucher"`, servers **MUST**:

1. Verify the credential descriptor for v2, including channel ID, payee, token, operator, escrow address, and chain ID binding.
2. Verify voucher signature using EIP-712 recovery
3. Verify signature uses canonical low-s values (see [Section 14.8](#))
4. Recover signer and **MUST** verify it matches expected signer from on-chain state
5. Verify `channel.closeRequestedAt == 0` (no pending close request). Servers **MUST** reject vouchers on channels with a pending forced close to prevent service delivery that cannot be settled.
6. Verify monotonicity:
 - `cumulativeAmount >= highestVoucherAmount`
 - if `cumulativeAmount == highestVoucherAmount`, treat the request as an idempotent retry and do not change voucher state
 - if `cumulativeAmount > highestVoucherAmount`, `(cumulativeAmount - highestVoucherAmount) >= minVoucherDelta`
7. Verify `cumulativeAmount <= channel.deposit`
8. Persist voucher to durable storage before providing service
9. Update `highestVoucherAmount = cumulativeAmount`

Servers **MUST** derive the expected signer from on-chain channel state by querying the escrow contract. The expected signer is `channel.authorizedSigner` if non-zero, otherwise `channel.payer`. Servers **MUST NOT** trust signer claims in HTTP payloads.

Servers **MUST** persist the highest voucher to durable storage before providing the corresponding service. Failure to do so may result in unrecoverable fund loss if the server crashes after service delivery.

11.4. Idempotency

Servers **MUST** treat voucher submissions idempotently:

- Resubmitting a voucher with the same `cumulativeAmount` as the highest accepted **MUST** return 200 OK with the current `acceptedCumulative`
- Submitting a voucher with lower `cumulativeAmount` than highest accepted **MUST** be rejected
- Clients **MAY** safely retry voucher submissions after network failures

11.5. Rejection and Error Responses

If verification fails, servers **MUST** return an appropriate HTTP status code with a Problem Details [RFC9457] response body:

Status	When
400 Bad Request	Malformed payload or missing fields
402 Payment Required	Invalid signature or signer mismatch
410 Gone	Channel finalized or not found

Table 25

Error responses use Problem Details format:

```
{
  "type": "https://paymentauth.org/problems/session/invalid-signature",
  "title": "Invalid Signature",
  "status": 402,
  "detail": "Voucher signature could not be verified",
  "channelId": "0x6d0f4fdf..."
}
```

Problem type URIs:

Type URI	Description
<code>https://paymentauth.org/problems/session/invalid-signature</code>	Voucher or close request signature invalid
<code>https://paymentauth.org/problems/session/signer-mismatch</code>	Signer is not authorized for this channel

Type URI	Description
https://paymentauth.org/problems/session/amount-exceeds-deposit	Voucher amount exceeds channel deposit
https://paymentauth.org/problems/session/delta-too-small	Amount increase below minVoucherDelta
https://paymentauth.org/problems/session/channel-not-found	No channel with this ID exists
https://paymentauth.org/problems/session/channel-finalized	Channel has been closed
https://paymentauth.org/problems/session/challenge-not-found	Challenge ID unknown or expired
https://paymentauth.org/problems/session/insufficient-balance	Insufficient authorized balance for request

Table 26

For errors on the Payment Auth protected resource (the initial request carrying Authorization: Payment), servers **MUST** return 402 with a fresh WWW-Authenticate: Payment challenge per [I-D.httpauth-payment].

12. Server-Side Accounting

Servers **MUST** maintain per-session accounting state to track authorized funds versus consumed service. This section defines the normative requirements for balance tracking, crash safety, and idempotency.

12.1. Accounting State

For each active session identified by (challengeId, channelId), servers **MUST** maintain:

Field	Type	Description
acceptedCumulative	uint128	Highest valid voucher amount accepted (monotonically increasing)
spent	uint128	Cumulative amount charged for delivered service (monotonically increasing)
settledOnChain	uint128	Last cumulative amount settled on-chain (informational)

Field	Type	Description
deposit	uint128 or uint96	Latest verified on-chain deposit
closeRequestedAt	uint64	Latest verified close-request timestamp, or zero

Table 27

For v2 channels, `acceptedCumulative`, `spent`, `settledOnChain`, and `deposit` are uint96 values. Servers **MUST** key channel state by normalized lowercase `channelId`. Channel state updates **MUST** be linearizable per channel across concurrent requests.

The available balance is computed as:

```
available = acceptedCumulative - spent
```

12.2. Per-Request Processing

For each request carrying a Payment credential with `intent="session"`, servers **MUST** follow this procedure:

1. Voucher acceptance (if a voucher is provided in the credential):

- Verify signature and monotonicity per [Section 11.3](#)
- If valid, persist the new `acceptedCumulative` value to durable storage
- If invalid, return 402 with a fresh challenge

2. Balance check:

- Compute `available = acceptedCumulative - spent`
- Compute cost for this request (see [Section 12.5](#))
- If `available < cost`: return 402 with Problem Details including `requiredTopUp = cost - available`

3. Charge and deliver (if `available >= cost`):

- **MUST persist** `spent := spent + cost` to durable storage BEFORE or atomically with delivering the metered service
- Deliver the response (or next chunk/token window for streaming)
- Return Payment-Receipt header with current balance state

4. Receipt generation:

- Include balance state in receipt (see [Section 13.6](#))

12.3. Crash Safety

To prevent fund loss from server crashes:

- Servers **MUST** persist spent increments BEFORE delivering corresponding service. If the server crashes after persisting but before delivery, the client may retry and be charged again (see Idempotency below).
- Servers **MUST** persist acceptedCumulative BEFORE relying on the new balance for service authorization.
- Implementations **SHOULD** use transactional storage or write-ahead logging to ensure atomicity between state updates and service delivery.

12.4. Request Idempotency

To prevent double-charging on retries and network failures:

- Clients **SHOULD** include an Idempotency-Key header on paid requests
- Servers **SHOULD** track (challengeId, idempotencyKey) pairs and return the cached response (including receipt) for duplicate requests
- Servers **MUST NOT** increment spent for duplicate idempotent requests

If idempotency is not implemented, servers **MUST** document this limitation and warn clients that retries may incur additional charges.

Example idempotent request:

```
GET /api/chat HTTP/1.1
Host: api.example.com
Idempotency-Key: req_a1b2c3d4e5f6
Authorization: Payment eyJ...
```

12.5. Cost Calculation

The cost for a request depends on the pricing model declared in the challenge. Servers **MUST** support at least one of:

- **Fixed cost:** A predetermined amount per request
- **Usage-based fees:** Pricing proportional to resource consumption (e.g., tokens generated, bytes transferred, compute time)

For metered resources, servers compute cost during or after service delivery. For streaming responses (SSE, chunked), servers **SHOULD**:

1. Reserve an estimated cost before starting delivery
2. Adjust spent as actual consumption is measured

3. Pause delivery if available is exhausted (client must top-up)

12.6. Insufficient Balance During Streaming

When a streaming response exhausts available balance:

1. Server **MUST** stop delivering additional metered content
2. Server **MAY** hold the connection open awaiting a voucher top-up
3. Server **MAY** close the response; client then retries with higher voucher
4. If client submits a voucher update (request to same URI or any endpoint protected by the same payment handler), server **SHOULD** resume delivery on the original connection if still open

For SSE responses, servers **MUST** emit an `payment-need-voucher` event when available balance is exhausted:

```
event: payment-need-voucher
data:
{"channelId":"0x6d0f4fdf...", "requiredCumulative":"250025", "acceptedCumulative":"250000", "deposit":"500000"}
```

The `payment-need-voucher` event data **MUST** be a JSON object containing:

Field	Type	Required	Description
acceptedCumulative	string	REQUIRED	Current highest accepted voucher amount (base units)
channelId	string	REQUIRED	Channel identifier (hex-encoded bytes32)
deposit	string	REQUIRED	Current on-chain deposit in the escrow contract (base units)
requiredCumulative	string	REQUIRED	Minimum cumulative amount the next voucher must authorize (base units)

Table 28

The `deposit` field allows the client to determine the correct recovery action. When `requiredCumulative` exceeds `deposit`, the client **MUST** submit `action="topUp"` to increase the on-chain deposit before sending a new voucher. When `requiredCumulative` is within `deposit`, the client can submit `action="voucher"` directly.

After emitting `payment-need-voucher`, the server **MUST** pause delivery until a valid voucher advancing `acceptedCumulative` is accepted. Servers **SHOULD** close the stream if no voucher is received within a reasonable timeout (for example, 60 seconds). Clients **SHOULD** respond by sending a voucher credential to any endpoint protected by the same payment handler.

Servers **SHOULD NOT** deliver service beyond the authorized balance under any circumstances. See [Section 14.3](#) for rate limiting requirements.

13. Settlement Procedure

13.1. Settlement Timing

Servers **MAY** settle at any time using their own criteria:

- Periodically (e.g., every N seconds or M base units accrued)
- When `action="close"` is received
- When accumulated unsettled amount exceeds a threshold
- Based on gas cost optimization

Settlement frequency is an implementation detail left to servers.

The `close()` function settles any delta between the provided `cumulativeAmount` and `channel.settled`. If the server has already settled the highest voucher via `settle()`, calling `close()` with the same amount will only refund the payer the remaining deposit.

13.2. Cooperative Close

When the client sends `action="close"`:

1. Server receives the signed close request
2. Server verifies the close voucher covers at least the greater of server-recorded `spent` and current on-chain `settled`
3. Server closes on-chain, capturing only the amount actually owed to the payee and refunding the remainder to the payer
4. Server returns receipt with transaction hash

Servers **SHOULD** close promptly when clients request—the economic incentive is to claim earned funds immediately.

Servers **MUST NOT** capture more than the amount actually consumed by delivered service. A client can pre-authorize more funds than were spent; the server **MUST** use its accounting state to determine the close capture amount and **MUST NOT** treat `cumulativeAmount` alone as the amount to capture. For v2, the close capture amount is:

```
captureAmount = max(spent, settledOnChain)
```

and `captureAmount` **MUST** be less than or equal to both the close voucher `cumulativeAmount` and the on-chain `deposit`.

13.3. Forced Close

If the server does not respond to close requests:

1. Client calls `requestClose(channelId)` on-chain
2. 15-minute grace period begins (wall-clock time via `block.timestamp`)
3. Server can still `settle()` or `close()` during grace period
4. After grace period, client calls `withdraw(channelId)`
5. Client receives all remaining (unsettled) funds

Clients **SHOULD** wait at least 16 minutes after `requestClose()` before calling `withdraw()` to account for block time variance.

13.4. Sequential Sessions

A single channel supports sequential sessions. Each session uses the same cumulative voucher counter. When a new session begins on a channel, the previous session's spending state is irrelevant—the channel's `highestVoucherAmount` is the source of truth for the next voucher's minimum value.

13.5. Voucher Submission Transport

Vouchers are submitted via HTTP requests to the **same resource URI** that requires payment. There is no separate session endpoint. Clients **SHOULD** use HTTP/2 multiplexing or maintain separate connections for voucher updates and content streaming when topping up during a long-lived response.

For voucher-only updates (no response body needed), clients **MAY** use HEAD requests. Servers **SHOULD** support voucher credentials on HEAD requests for resources that require session payment.

13.6. Receipt Generation

Servers **MUST** return a `Payment-Receipt` header on **every successful paid request**. For streaming responses (SSE, chunked transfer), servers **MUST** include the receipt in the initial response headers AND in the final message of the stream. This ensures clients receive at least one receipt even if the stream is interrupted, while also providing accurate final state when the stream completes normally.

For SSE responses, the final receipt **SHOULD** be delivered as an event:

```
event: payment-receipt
data: {"method":"tempo","intent":"session","status":"success",...}
```

For chunked responses, the final receipt **MAY** be delivered as an HTTP trailer if the client advertises trailer support via TE: trailers.

The base Payment Auth spec defines core receipt fields. The session intent extends the receipt with balance tracking:

Field	Type	Description
method	string	"tempo"
intent	string	"session"
status	string	"success"
timestamp	string	[RFC3339] response time
reference	string	Payment reference; for session receipts, the channelId
challengeId	string	Challenge identifier for audit correlation
channelId	string	The channel identifier
acceptedCumulative	string	Highest voucher amount accepted
spent	string	Total amount charged so far
units	number	OPTIONAL : Units consumed this request (e.g., tokens, bytes)
txHash	string	OPTIONAL : On-chain transaction hash (present on settlement/close)

Table 29

The reference field serves as the core spec's payment reference and is the channel ID. The txHash field is **OPTIONAL** because not every response involves an on-chain settlement; voucher updates are off-chain.

The units field indicates what was consumed for **this specific request**. When the challenge includes unitType, clients can use it to interpret the unit of measure. Clients can compute cost as `units × amount` from the challenge.

Example receipt (per-request with metering):

```
{
  "method": "tempo",
  "intent": "session",
  "status": "success",
  "timestamp": "2025-01-06T12:08:30Z",
  "reference":
    "0x6d0f4fdf1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f",
  "challengeId": "c_8d0e3b5a9f2c1d4e",
  "channelId":
    "0x6d0f4fdf1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f",
  "acceptedCumulative": "250000",
  "spent": "237500",
  "units": 500
}
```

Example receipt (on close with settlement):

```
{
  "method": "tempo",
  "intent": "session",
  "status": "success",
  "timestamp": "2025-01-06T12:10:00Z",
  "reference":
    "0x6d0f4fdf1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f",
  "challengeId": "c_8d0e3b5a9f2c1d4e",
  "channelId":
    "0x6d0f4fdf1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f",
  "acceptedCumulative": "250000",
  "spent": "250000",
  "txHash":
    "0x1a2b3c4d5e6f7890abcdef1234567890abcdef1234567890abcdef1234567890"
}
```

14. Security Considerations

14.1. Replay Prevention

Vouchers are bound to a specific channel and contract via:

- `channelId` in the voucher message
- `verifyingContract` in EIP-712 domain
- `chainId` in EIP-712 domain
- Cumulative amount semantics (can only increase)

The escrow contract enforces:

- `cumulativeAmount > channel.settled` (monotonicity)
- `cumulativeAmount <= channel.deposit` (cap)

14.2. No Voucher Expiry

Vouchers have no `validUntil` field. This simplifies the protocol:

- Channels have no expiry—they are closed explicitly
- Vouchers remain valid until the channel closes
- The close grace period protects against clients disappearing

Operational guidance: Servers **SHOULD** settle and close channels that have been inactive for extended periods (e.g., 30+ days) to reduce storage requirements and operational liability. Servers **MAY** refuse to accept vouchers for channels with no activity exceeding a configured threshold.

14.3. Denial of Service

To mitigate voucher flooding, servers **MUST** implement rate limiting:

- Servers **SHOULD** limit voucher submissions to 10 per second per session
- Servers **MAY** implement additional IP-based rate limiting for unauthenticated requests
- Servers **MUST** enforce `minVoucherDelta` when present to prevent tiny increments
- Servers **MAY** skip expensive signature verification for vouchers whose `cumulativeAmount` is below the accepted cumulative amount, because such vouchers are rejected before they can advance state

Servers **SHOULD** perform format validation (field presence, hex encoding, length checks) before expensive ECDSA signature recovery to minimize computational cost of malformed requests.

To mitigate channel griefing via dust deposits:

- Servers **SHOULD** enforce a minimum deposit (e.g., 1 USD equivalent)
- Servers **MAY** reject channels below this threshold

14.4. Front-Running Protection

Cumulative voucher semantics prevent front-running attacks. If a client submits a higher voucher while a server's `settle()` transaction is pending, the settlement will still succeed—it merely leaves additional unsettled funds that the server can claim later.

14.5. Cross-Contract Replay Prevention

The EIP-712 domain includes `verifyingContract`, binding vouchers to a specific escrow contract address. This prevents replay of vouchers across different escrow contract deployments.

14.6. Escrow Guarantees

The escrow contract provides:

- **Payer protection:** Funds only withdrawn with valid voucher signature
- **Payee protection:** Deposited funds guaranteed (cannot be drained)
- **Forced close:** 15-minute grace period protects both parties

14.7. Authorized Signer

The `authorizedSigner` field allows delegation of signing authority to a hot wallet while the main wallet only deposits funds. This reduces exposure of the primary key during streaming sessions.

Security considerations for delegated signing:

- Clients using `authorizedSigner` delegation **SHOULD** limit channel deposits to acceptable loss amounts
- Clients **SHOULD** rotate authorized signers periodically
- Clients **SHOULD NOT** reuse signers across multiple high-value channels
- If the authorized signer key is compromised, an attacker can drain the entire channel deposit

14.8. Signature Malleability

ECDSA signatures are malleable: for any valid signature (r, s) , the signature $(r, -s \bmod n)$ is also valid for the same message. To prevent signature substitution attacks, implementations **MUST** enforce canonical signatures:

- Signatures **MUST** use "low-s" values with $s \leq \text{secp256k1_order} / 2$
- The secp256k1 half-order is:
`0x7FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF5D576E7357A4501DDFE92F46681B20A0`
- Servers **MUST** reject signatures with s values exceeding this threshold

Accepted signature formats:

- 65-byte (r, s, v) format where v is 27 or 28
- 64-byte EIP-2098 compact format

Implementations **SHOULD** use established libraries (e.g., OpenZeppelin ECDSA) that enforce these requirements.

14.9. Voucher Context and User Experience

The voucher message contains only `channelId` and `cumulativeAmount`. The `channelId` is derived from channel parameters including payer, payee, token, salt, and authorized signer, cryptographically binding these values.

However, wallet signing interfaces may only display the raw `channelId` bytes, making it difficult for users to verify payment details. Wallet implementations are encouraged to:

- Decode `channelId` components when the derivation formula is known
- Display the payee address and token in human-readable form
- Show cumulative vs. incremental amounts clearly

14.10. Session Attribution

Vouchers are bound to channels but not to specific HTTP sessions or API requests. When a payee operates multiple services using the same channel, voucher-to-service attribution is an implementation concern.

The `challengeId` in the challenge provides correlation across requests. Servers **MUST** implement challenge-to-voucher mapping for:

- Dispute resolution
- Usage accounting
- Audit trails

14.11. Cross-Session Replay Prevention

Vouchers use cumulative amount semantics: each voucher authorizes a total payment up to `cumulativeAmount`, and the on-chain contract enforces strict monotonicity (`cumulativeAmount > channel.settled`). This means a voucher can only ever advance the channel state forward -- it cannot be "replayed" to extract additional funds because the settlement watermark only moves in one direction.

A separate `sessionHash` binding is therefore unnecessary:

- **Cross-session replay is harmless:** If a voucher from session A is presented in session B, it can only authorize funds up to the amount already committed. The server tracks `highestVoucherAmount` per session and rejects vouchers that do not advance state.
- **Cross-resource replay:** Vouchers authorize cumulative payment on a channel, not access to specific resources. Resource authorization is handled at the application layer via `challengeId` correlation.

This simplification aligns the spec with the deployed `TempoStreamChannel` contract and the `@tempo/stream-channels` package, neither of which include a session hash in the voucher type.

14.12. Chain Reorganization

On Tempo networks, finality is achieved within approximately 500ms. However, for high-value channels, servers **SHOULD**:

1. Re-verify channel state periodically during long-lived sessions
2. Monitor for `ChannelClosed` or `CloseRequested` events

3. Cease service delivery if the channel becomes invalid

If a chain reorganization invalidates an accepted transaction, the server **SHOULD**:

1. Stop accepting vouchers for that channel
2. Return 410 Gone with problem type `channel-not-found`
3. Log the incident for investigation

14.13. Grace Period Rationale

The 15-minute forced close grace period balances competing concerns:

- **Payer protection:** Ensures timely fund recovery if the server becomes unresponsive
- **Payee protection:** Provides time to detect close requests and submit final settlements, even during network congestion or maintenance windows
- **Block time variance:** Allows margin for timestamp variations in on-chain enforcement

Implementations **MAY** use different grace periods in their escrow contracts, but **MUST** clearly document the value and ensure clients are aware.

15. IANA Considerations

15.1. Payment Intent Registration

This document registers the following payment intent in the "HTTP Payment Intents" registry established by [I-D.httpauth-payment]:

Intent	Applicable Methods	Description	Reference
session	tempo	Streaming payment channel	This document

Table 30

Contact: Tempo Labs (contact@tempo.xyz)

15.2. Problem Type Registration

This document registers the following problem types in the "HTTP Problem Types" registry established by [RFC9457]:

Type URI	Title	Status	Reference
https://paymentauth.org/problems/session/invalid-signature	Invalid Signature	402	This document
https://paymentauth.org/problems/session/signer-mismatch	Signer Mismatch	402	This document

Type URI	Title	Status	Reference
https://paymentauth.org/problems/session/amount-exceeds-deposit	Amount Exceeds Deposit	402	This document
https://paymentauth.org/problems/session/delta-too-small	Delta Too Small	402	This document
https://paymentauth.org/problems/session/channel-not-found	Channel Not Found	410	This document
https://paymentauth.org/problems/session/channel-finalized	Channel Finalized	410	This document
https://paymentauth.org/problems/session/challenge-not-found	Challenge Not Found	402	This document
https://paymentauth.org/problems/session/insufficient-balance	Insufficient Balance	402	This document

Table 31

Each problem type is defined in [Section 11.5](#).

16. References

16.1. Normative References

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- [RFC3339] Klyne, G. and C. Newman, "Date and Time on the Internet: Timestamps", RFC 3339, DOI 10.17487/RFC3339, July 2002, <<https://www.rfc-editor.org/info/rfc3339>>.
- [RFC4648] Josefsson, S., "The Base16, Base32, and Base64 Data Encodings", RFC 4648, DOI 10.17487/RFC4648, October 2006, <<https://www.rfc-editor.org/info/rfc4648>>.
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- [RFC8259] Bray, T., Ed., "The JavaScript Object Notation (JSON) Data Interchange Format", STD 90, RFC 8259, DOI 10.17487/RFC8259, December 2017, <<https://www.rfc-editor.org/info/rfc8259>>.

- [RFC9110] Fielding, R., Ed., Nottingham, M., Ed., and J. Reschke, Ed., "HTTP Semantics", STD 97, RFC 9110, DOI 10.17487/RFC9110, June 2022, <<https://www.rfc-editor.org/info/rfc9110>>.
- [RFC9111] Fielding, R., Ed., Nottingham, M., Ed., and J. Reschke, Ed., "HTTP Caching", STD 98, RFC 9111, DOI 10.17487/RFC9111, June 2022, <<https://www.rfc-editor.org/info/rfc9111>>.
- [RFC9457] Nottingham, M., Wilde, E., and S. Dalal, "Problem Details for HTTP APIs", RFC 9457, DOI 10.17487/RFC9457, July 2023, <<https://www.rfc-editor.org/info/rfc9457>>.
- [I-D.httpauth-payment] Moxey, J., "The 'Payment' HTTP Authentication Scheme", January 2026, <<https://datatracker.ietf.org/doc/draft-ryan-httpauth-payment/>>.

16.2. Informative References

- [RFC8610] Birkholz, H., Vigano, C., and C. Bormann, "Concise Data Definition Language (CDDL): A Notational Convention to Express Concise Binary Object Representation (CBOR) and JSON Data Structures", RFC 8610, DOI 10.17487/RFC8610, June 2019, <<https://www.rfc-editor.org/info/rfc8610>>.
- [EIP-712] Bloemen, R., "Typed structured data hashing and signing", September 2017, <<https://eips.ethereum.org/EIPS/eip-712>>.
- [SSE] WHATWG, "Server-Sent Events", n.d., <<https://html.spec.whatwg.org/multipage/server-sent-events.html>>.
- [TEMPO-TX-SPEC] Tempo Labs, "Tempo Transaction Specification", n.d., <<https://docs.tempo.xyz/protocol/transactions/spec-tempo-transaction>>.
- [TIP-20] Tempo Labs, "TIP-20 Token Standard", n.d., <<https://docs.tempo.xyz/protocol/tip20/spec>>.

Appendix A. Example

Note: In examples throughout this appendix, hex values shown with ... (e.g., "0x6d0f4fdf...") are abbreviated for readability. Actual values **MUST** be full-length as specified in [Section 5](#).

A.1. Challenge

```
HTTP/1.1 402 Payment Required
WWW-Authenticate: Payment id="kM9xPqWvT2nJrHsY4aDfEb",
  realm="api.llm-service.com",
  method="tempo",
  intent="session",
  expires="2025-01-06T12:05:00Z",
  request="<base64url-encoded JSON below>"
```

The request decodes to:

```
{
  "amount": "25",
  "unitType": "llm_token",
  "suggestedDeposit": "10000000",
  "currency": "0x20c0000000000000000000000000000000000000000000000000000000000000",
  "recipient": "0x742d35cc6634c0532925a3b844bc9e7595f8fe00",
  "methodDetails": {
    "escrowContract": "0x9d136eEa063eDE5418A6BC7bEafF009bBb6CFa70",
    "chainId": 4217,
    "sessionProtocol": "v2"
  }
}
```

Note: Challenge expiry is in the header expires auth-param, not in the request JSON. The client generates a random salt locally for new channels.

This requests a price of 0.000025 tokens per LLM token, with a suggested deposit of 10.00 pathUSD (10000000 base units).

A.2. Open Credential

The client retries the **same resource URI** with the open credential:

```
GET /api/chat HTTP/1.1
Host: api.llm-service.com
Authorization: Payment <base64url-encoded credential>
```

The credential payload for an open action:

```
{
  "challenge": {
    "id": "kM9xPqWvT2nJrHsY4aDfEb",
    "realm": "api.llm-service.com",
    "method": "tempo",
    "intent": "session",
    "request": "eyJ...",
    "expires": "2025-01-06T12:05:00Z"
  },
  "payload": {
    "action": "open",
    "type": "transaction",
    "channelId":
      "0x6d0f4fd1f2f6a1f6c1b0fbd6a7d5c2c0a8d3d7b1f6a9c1b3e2d4a5b6c7d8e9f",
    "transaction": "0x76f901...signed transaction bytes...",
    "cumulativeAmount": "0",
    "signature": "0xabcdef1234567890..."
  }
}
```

A.3. Voucher Top-Up (Same Resource URI)

During streaming, clients submit updated vouchers to the **same resource URI**. This can use any HTTP method; HEAD is recommended for pure top-ups when no response body is needed:

```
HEAD /api/chat HTTP/1.1
Host: api.llm-service.com
Authorization: Payment <base64url-encoded credential with action="voucher">
```

Or with a regular request that also retrieves content:

```
GET /api/chat HTTP/1.1
Host: api.llm-service.com
Authorization: Payment <base64url-encoded credential with action="voucher">
```

The credential payload for a voucher update:

```
{
  "challenge": {
    "id": "kM9xPqWvT2nJrHsY4aDfEb",
    "realm": "api.llm-service.com",
    "method": "tempo",
    "intent": "session",
    "request": "eyJ...",
    "expires": "2025-01-06T12:05:00Z"
  },
  "payload": {
    "action": "voucher",
    "channelId": "0x6d0f4fdf...",
    "cumulativeAmount": "250000",
    "signature": "0x1234567890abcdef..."
  }
}
```

A.4. Close Request (Same Resource URI)

Close requests are also sent to the same resource URI:

```
GET /api/chat HTTP/1.1
Host: api.llm-service.com
Authorization: Payment <base64url-encoded credential with action="close">
```

The credential payload for a close request:

```
{
  "challenge": {
    "id": "kM9xPqWvT2nJrHsY4aDfEb",
    "realm": "api.llm-service.com",
    "method": "tempo",
    "intent": "session",
    "request": "eyJ...",
    "expires": "2025-01-06T12:05:00Z"
  },
  "payload": {
    "action": "close",
    "channelId": "0x6d0f4fdf...",
    "cumulativeAmount": "500000",
    "signature": "0xabcdef1234567890..."
  }
}
```

The voucher fields contain the final cumulative amount for on-chain settlement.

Appendix B. Legacy Contract Reference Implementation

This appendix provides legacy v1 contract reference implementation details. These are informative and not normative.

B.1. Solidity Interface

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.20;

interface ITempoStreamChannel {
    struct Channel {
        address payer;
        address payee;
        address token;
        address authorizedSigner;
        uint128 deposit;
        uint128 settled;
        uint64 closeRequestedAt;
        bool finalized;
    }

    function CLOSE_GRACE_PERIOD() external view returns (uint64);
    function VOUCHER_TYPEHASH() external view returns (bytes32);
    function CLOSE_REQUEST_TYPEHASH() external view returns (bytes32);

    function open(
        address payee,
        address token,
        uint128 deposit,
        bytes32 salt,
        address authorizedSigner
    ) external returns (bytes32 channelId);
```

```
function settle(
    bytes32 channelId,
    uint128 cumulativeAmount,
    bytes calldata signature
) external;

function topUp(
    bytes32 channelId,
    uint128 additionalDeposit
) external;

function close(
    bytes32 channelId,
    uint128 cumulativeAmount,
    bytes calldata signature
) external;

function requestClose(bytes32 channelId) external;

function withdraw(bytes32 channelId) external;

function getChannel(bytes32 channelId)
    external view returns (Channel memory);

function getChannelsBatch(bytes32[] calldata channelIds)
    external view returns (Channel[] memory);

function computeChannelId(
    address payer,
    address payee,
    address token,
    bytes32 salt,
    address authorizedSigner
) external view returns (bytes32);

function getVoucherDigest(
    bytes32 channelId,
    uint128 cumulativeAmount
) external view returns (bytes32);

function getCloseRequestDigest(
    bytes32 channelId,
    uint64 requestedAt
) external view returns (bytes32);

function domainSeparator() external view returns (bytes32);

event ChannelOpened(
    bytes32 indexed channelId,
    address indexed payer,
    address indexed payee,
    address token,
    address authorizedSigner,
    uint256 deposit
);

event Settled(
    bytes32 indexed channelId,
```

```

        address indexed payer,
        address indexed payee,
        uint256 cumulativeAmount,
        uint256 deltaPaid,
        uint256 newSettled
    );

    event CloseRequested(
        bytes32 indexed channelId,
        address indexed payer,
        address indexed payee,
        uint256 closeGraceEnd
    );

    event CloseRequestCancelled(
        bytes32 indexed channelId,
        address indexed payer,
        address indexed payee
    );

    event TopUp(
        bytes32 indexed channelId,
        address indexed payer,
        address indexed payee,
        uint256 additionalDeposit,
        uint256 newDeposit
    );

    event ChannelClosed(
        bytes32 indexed channelId,
        address indexed payer,
        address indexed payee,
        uint256 settledToPayee,
        uint256 refundedToPayer
    );

    error ChannelAlreadyExists();
    error ChannelNotFound();
    error ChannelFinalized();
    error InvalidSignature();
    error AmountExceedsDeposit();
    error AmountNotIncreasing();
    error NotPayer();
    error NotPayee();
    error TransferFailed();
    error CloseNotReady();
}

```

B.2. Deployed Contracts

Network	Chain ID	Contract Address
Moderato (Testnet)	42431	0x9d136eEa063eDE5418A6BC7bEaFF009bBb6CFa70

Table 32

B.3. Contract Source

The reference implementation is available at: <https://github.com/tempoxyz/tempo/tree/main/tips/ref-impls/src/TempoStreamChannel.sol>

Appendix C. Schema Definitions (JSON Schema)

This appendix provides JSON Schema definitions for implementations that prefer JSON Schema over CDDL.

C.1. Session Request Schema

```
{
  "$schema": "https://json-schema.org/draft/2020-12/schema",
  "$id": "https://paymentauth.org/schemas/session-request.json",
  "title": "Session Request",
  "type": "object",
  "required": ["amount", "currency", "recipient", "methodDetails"],
  "properties": {
    "amount": {
      "type": "string",
      "pattern": "^[0-9]+$",
      "description": "Price per unit in base units (decimal string)"
    },
    "unitType": {
      "type": "string",
      "description": "Unit type being priced (e.g., llm_token, byte)"
    },
    "suggestedDeposit": {
      "type": "string",
      "pattern": "^[0-9]+$",
      "description": "Suggested channel deposit in base units"
    },
    "currency": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{40}$",
      "description": "TIP-20 token address (mixed-case accepted, normalized to lowercase)"
    },
    "recipient": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{40}$",
      "description": "Payee address (mixed-case accepted, normalized to lowercase)"
    },
    "methodDetails": { "$ref": "#/$defs/methodDetails" }
  },
  "$defs": {
    "methodDetails": {
      "type": "object",
      "required": ["escrowContract"],
      "properties": {
        "escrowContract": {
```

```

        "type": "string",
        "pattern": "^0x[0-9a-fA-F]{40}$"
    },
    "channelId": {
        "type": "string",
        "pattern": "^0x[0-9a-fA-F]{64}$",
        "description": "OPTIONAL: for channel reuse"
    },
    "minVoucherDelta": {
        "type": "string",
        "pattern": "^[0-9]+$",
        "description": "OPTIONAL: server policy hint"
    },
    "feePayer": {
        "type": "boolean",
        "default": false,
        "description": "If true, server pays transaction fees"
    },
    "chainId": { "type": "integer" },
    "operator": {
        "type": "string",
        "pattern": "^0x[0-9a-fA-F]{40}$",
        "description": "OPTIONAL: v2 channel operator"
    },
    "sessionProtocol": {
        "enum": ["v1", "v2"],
        "description": "OPTIONAL: session protocol version"
    },
    "sessionSnapshot": { "$ref": "#/$defs/sessionSnapshot" }
},
"descriptor": {
    "type": "object",
    "required": ["payer", "payee", "operator", "token", "salt",
"authorizedSigner", "expiringNonceHash"],
    "properties": {
        "payer": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "payee": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "operator": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "token": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "salt": { "type": "string", "pattern": "^0x[0-9a-fA-F]{64}$" },
        "authorizedSigner": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "expiringNonceHash": { "type": "string", "pattern": "^0x[0-9a-fA-F]{64}$" }
    }
},
"sessionSnapshot": {
    "type": "object",
    "required": ["acceptedCumulative", "chainId", "channelId", "deposit",
"descriptor", "escrow", "requiredCumulative", "settled", "spent"],
    "properties": {
        "acceptedCumulative": { "type": "string", "pattern": "^[0-9]+$" },
        "chainId": { "type": "integer" },
        "channelId": { "type": "string", "pattern": "^0x[0-9a-fA-F]{64}$" },
        "closeRequestedAt": { "type": "string", "pattern": "^[0-9]+$" },
        "deposit": { "type": "string", "pattern": "^[0-9]+$" },
        "descriptor": { "$ref": "#/$defs/descriptor" },

```

```

        "escrow": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "requiredCumulative": { "type": "string", "pattern": "^([0-9]+)$" },
        "settled": { "type": "string", "pattern": "^([0-9]+)$" },
        "spent": { "type": "string", "pattern": "^([0-9]+)$" },
        "units": { "type": "integer" }
    }
}
}
}

```

C.2. Session Payload Schema

```

{
  "$schema": "https://json-schema.org/draft/2020-12/schema",
  "$id": "https://paymentauth.org/schemas/session-payload.json",
  "title": "Session Payload",
  "type": "object",
  "required": ["action"],
  "properties": {
    "action": { "enum": ["open", "topUp", "voucher", "close"] },
    "transaction": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]+$",
      "description": "Signed transaction bytes"
    },
    "channelId": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{64}$",
      "description": "Channel identifier"
    },
    "descriptor": {
      "$ref": "#/defs/descriptor",
      "description": "REQUIRED for v2"
    },
    "cumulativeAmount": {
      "type": "string",
      "pattern": "^([0-9]+)$",
      "description": "Cumulative amount authorized (decimal string)"
    },
    "signature": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{128,130}$",
      "description": "EIP-712 voucher signature"
    }
  },
  "$defs": {
    "descriptor": {
      "type": "object",
      "required": ["payer", "payee", "operator", "token", "salt",
        "authorizedSigner", "expiringNonceHash"],
      "properties": {
        "payer": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "payee": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "operator": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "token": { "type": "string", "pattern": "^0x[0-9a-fA-F]{40}$" },
        "salt": { "type": "string", "pattern": "^0x[0-9a-fA-F]{64}$" },

```

```
    "authorizedSigner": { "type": "string", "pattern": "^0x[0-9a-fA-F]
{40}$" },
    "expiringNonceHash": { "type": "string", "pattern": "^0x[0-9a-fA-F]
{64}$" }
  }
}
```

C.3. Session Receipt Schema

Servers **MUST** include Payment-Receipt only on successful processing of a session action (2xx responses). On error responses (4xx/5xx), servers **MUST** return Problem Details and **MUST NOT** include a Payment-Receipt header. The status field is always "success" because receipts represent successful acceptance; failures are communicated via HTTP status codes and Problem Details.

```

{
  "$schema": "https://json-schema.org/draft/2020-12/schema",
  "$id": "https://paymentauth.org/schemas/session-receipt.json",
  "title": "Session Receipt",
  "type": "object",
  "required": ["method", "intent", "status", "timestamp", "reference",
"challengeId", "channelId", "acceptedCumulative", "spent"],
  "properties": {
    "method": { "const": "tempo" },
    "intent": { "const": "session" },
    "status": { "const": "success" },
    "timestamp": {
      "type": "string",
      "format": "date-time"
    },
    "reference": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{64}$"
    },
    "challengeId": { "type": "string" },
    "channelId": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{64}$"
    },
    "acceptedCumulative": {
      "type": "string",
      "pattern": "^[0-9]+$",
      "description": "Highest voucher amount accepted"
    },
    "spent": {
      "type": "string",
      "pattern": "^[0-9]+$",
      "description": "Total amount charged so far"
    },
    "units": {
      "type": "integer",
      "description": "OPTIONAL: Units consumed this request"
    },
    "txHash": {
      "type": "string",
      "pattern": "^0x[0-9a-fA-F]{64}$",
      "description": "OPTIONAL: On-chain transaction hash (present on
settlement/close)"
    }
  }
}

```

Appendix D. Acknowledgements

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