Aggregation of Micro-Streams into one Common Stream

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Control Loops within Industrial Machines

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A typical industrial machine is build up of a huge amount of different physical actuators and sensors. They are connected to so called IO-Devices by different technologies, from electric wire to small busses (e.g. IO Link, PROFIBUS, CAN…). The IO-Devices in turn send/receive data in **a wide range of different rates** (e.g. typically between 1 kHz and 60 kHz) and **in a wide range of amount of real time data** according to the requirements of the control application and the type of sensors and actuators connected.

Industrial use cases:
Up to several hundred IO-Devices that are connected to thousands of actuators and sensors periodically exchange their real time data with one or several PLCs with

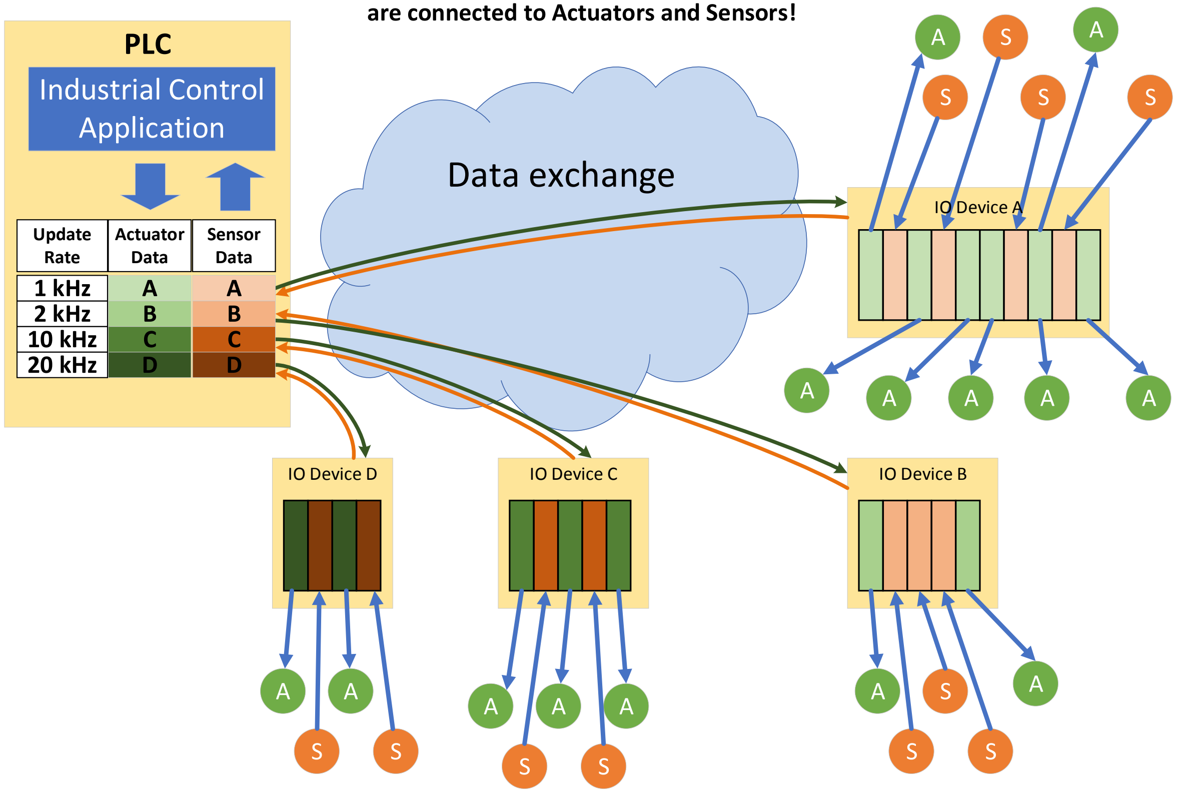
- **low data rates and small amount of real time data,**
- **low data rates and huge amount of real time data,**
- **high data rates and small amount of real time data,**
- **high data rates and huge amount of real time data,**

or with a mixture of all of them.

In contrast, Audio / Video applications typically have high data rates with huge amount of data.

A typical Industrial Automation Use Case for Connectivity

Programmable Logic Control (PLC) exchange periodically real time data with Input/Output(IO)-Devices which are connected to Actuators and Sensors!



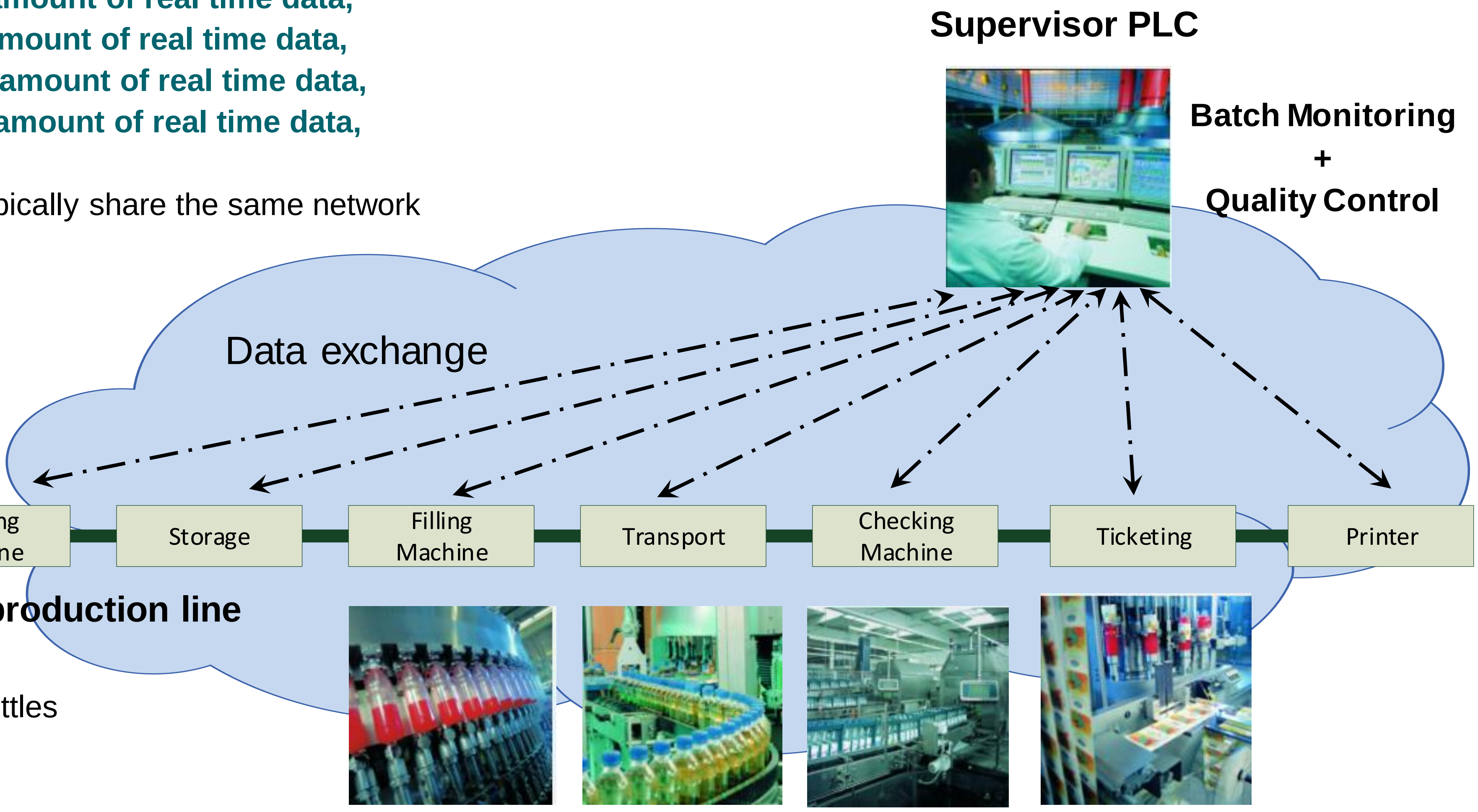
Supervisor PLC <-> PLCs Use Case:
Quality Control at Real Time in a Bottling Plant

Industial use cases:

- ❑ Up to tens of PLCs periodically exchange real-time data with one supervisor PLC with
  - **low data rates and small amount of real time data,**
  - **low data rates and huge amount of real time data,**
  - **high data rates and small amount of real time data,**
  - **high data rates and huge amount of real time data,**

  or with a mixture of all of them.
- ❑ Many applications of such kind typically share the same network

PLC(s) per machine



Example for throughput per hour:

- Blowing Machine: 81 000 PET bottles
- Filling Machine: 40 500 liter

Example for Stream Reservation based on MSRP without Micro-Stream (µStream) aggregation

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Example:

- 1 PLC ←→ 50 IO-Devices (bidirectional, ~ 50 µStreams per direction)
  - IO-Device with real time data rate of 1 kHz (µStream transmission rate)
  - Max e2e latency: 1ms
  - Max hop count: 16
  - ➔ Max per hop latency: 62,5µs

- Stream reservation based on MSRP
  - a SR-Class with class measurement interval 62,5µs ~ 16 kHz to fulfill the max e2e latency requirement

➔ If making each µStream an individual Stream using the existing MSRP mechanisms without µStream-Aggregation, it will result in an overprovisioning factor of **16** for reservation of such 50 µStreams per direction.

Proposal: µStream Aggregation using Interleaving

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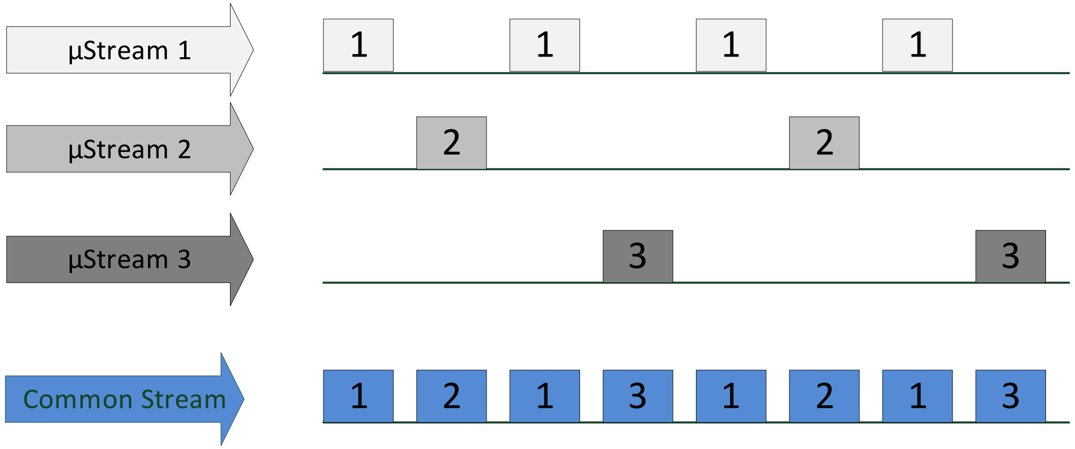
Definition

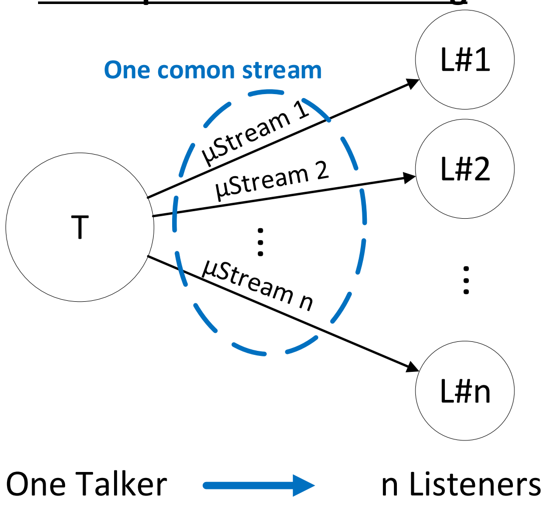
- ❑ **µStream Aggregation** combines multiple µStreams into one common Stream
  - forwarded in the network using one multicast destination MAC address
  - reserved in one stream reservation process by using a common Traffic Specification (TSpec)

- ❑ **µStream Interleaving is a method to combine multiple µStreams into one common Stream using multiplexing.**
  - **Talker µStream-Interleaving** (for 1-to-n communication)
    A single Talker is responsible for organizing its µStreams for multiple Listeners into a common Stream.
  - **Listener µStream-Interleaving** (for n-to-1 communication)
    A single Listener is responsible for organizing the µStreams that are transmitted by multiple talkers to this Listener into a common Stream.

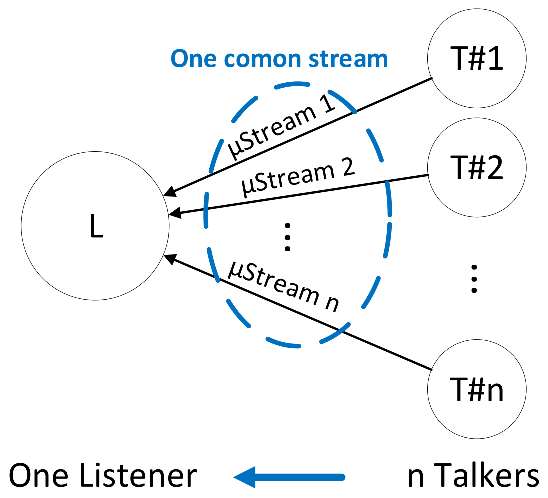
µStream Aggregation using Interleaving



Talker µStream-Interleaving



Listener µStream-Interleaving



Local Computation of Interleaved Schedule for µStream Aggregation

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An **Interleaved Schedule (IS)** for a common stream

- is locally computed either at the Talker or at the Listener, who knows the traffic specifications of all aggregated µStreams, but not required to have the knowledge of the network topology.
- specifies a repeating time schdule that allocates the time slots to transmission or reception of all aggregated µStreams in a certain way, e.g. distribute total bandwidth of all µStreams among slots as evenly as possible.

❑ For **Talker µStream-Interleaving** in 1-to-n communication, an **IS**

- is computed locally at the **Talker**, who intends to transmit n µStreams to multiple Listeners.
- **schedules interleaved µStream transmission at the Talker**
- is used by the Talk, not necessarily known to the Listeners

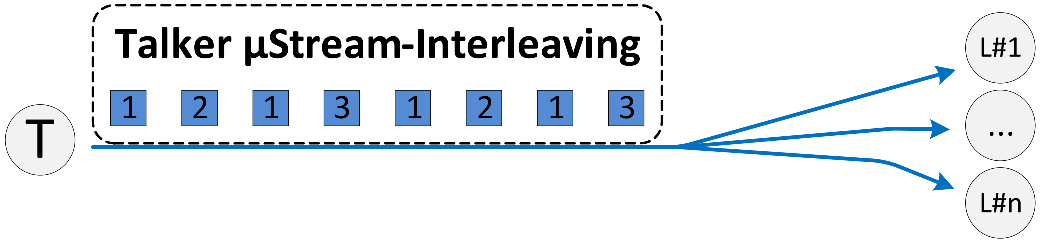
❑ For **Listener µStream-Interleaving** in n-to-1 communication, an **IS**

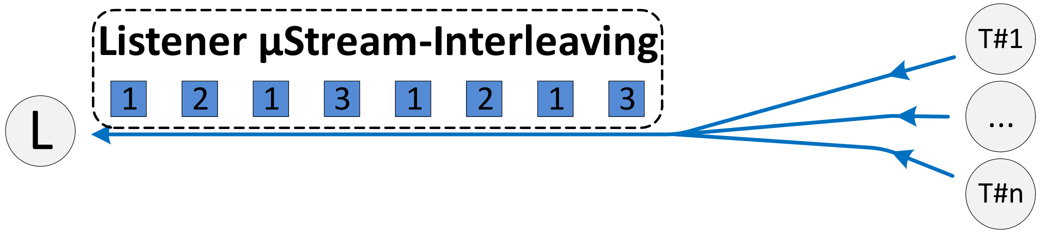
- is computed locally at the **Listener**, who intends to receive n µStreams from multiple Talkers.
- **schedules interleaved µStream reception at the Listener**
- **must be propagated to and converted for use by each Talker**

Example of an Interleaved Schedule

Traffic specification of µStream i given by application: $\mathbf{TS_i(M_i, N_i, L_i)}$
$\mathbf{M_i}$: max frame size; $\mathbf{N_i}$: number of frames; $\mathbf{L_i}$: trans. interval

	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	…	Slot m
µStream 1	M_1xN_1	-	M_1xN_1	-	M_1xN_1	-	-	M_1xN_1
µStream 2	-	M_2xN_2	-	-	-	M_2N_2	-	-
…	…	…	…	…	…	…	…	…
µStream n	-	-	-	M_nxN_n	-		-	M_nxN_n





Stream Reservation for Talker µStream-Interleaving

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Target application of Talker µStream-Interleaving:

- one talker to n listeners communcaiton, e.g. PLC to I/O devices, supervisor PLC to PLCs

Assumption:

- The talker has the information of all the µStreams to be aggregated, such as µStream TSpecs, application-level µStream identification, etc.

Workflow:

- The Talker computes the IS (*see previous slide*) and derives the TSpec for use in the reseravtion of the common stream (*see figure right above*)

- The Talker initiates the reservation process using TSpec of the common stream, which follows the conventional reservation procedures with **„Talker-Advertise / Listener-Join“**

  => Talker µStream-Interleaving is transparent to the network and can be applied with the exsiting reservation method.

- Upon successful reservation, the Talker starts stream transmission according to the locally computed IS and using the same stream DA for all aggregated µStreams.

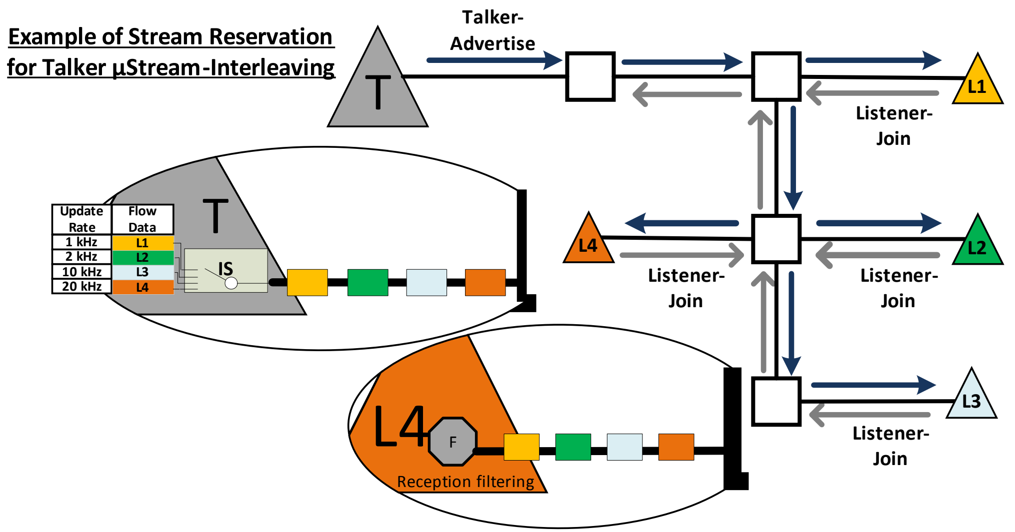
- Each Listener performs local filtering of received µStreams.

$N_{s1} = \sum_{i=1}^{n} N_i$ in slot 1

	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	…	Slot m
µStream 1	$M_1 x N_1$	-	$M_1 x N_1$	-	$M_1 x N_1$	-	-	$M_1 x N_1$
µStream 2	-	$M_2 x N_2$	-	-	-	$M_2 N_2$	-	-
…	…	…	…	…	…	…	…	…
µStream n	-	-	-	$M_n x N_n$	-		-	$M_n x N_n$

Derive TSpec of the common stream: $\boldsymbol{TS}(\boldsymbol{M}, \boldsymbol{N}, \boldsymbol{L})$ from the TSepcs of n aggregated µStreams $TS_i(M_i, N_i, L_i)$ and the IS

$$\boldsymbol{M} = \max\{\boldsymbol{M_1}, \boldsymbol{M_2}, \boldsymbol{M_3}, \ldots, \boldsymbol{M_n}\} \rightarrow \boldsymbol{max.frame\ size}$$
$$\boldsymbol{N} = \max\{\boldsymbol{N_{s1}}, \boldsymbol{N_{s2}}, \boldsymbol{N_{s3}}, \ldots, \boldsymbol{N_{sm}}\} \rightarrow \boldsymbol{max.number\ of\ frames}$$
$$\boldsymbol{L} = \boldsymbol{slot\ length}$$



Stream Reservation for Listener µStream-Interleaving

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Target application of Listener µStream-Interleaving:

- n talkers to one listener communcaiton, e.g. I/O devices to PLC, PLCs to supervisor PLC

Assumption:

- The Listener has the information of all the µStreams to be aggregated, such as µStream TSpecs, application-level µStream identification.
- The **Cyclic Queuing and Forwarding** (CQF) is applied in the network for transmission of the aggregated µStreams, while the CQF cycle time is made equal to the time slot length of the IS

Workflow:

- The Listener computes the IS and derives the TSpec for use in the reseravtion of the common stream (*see previous slide*)
- The Listener initiates the reservation process, which follows a reverse reservation procedure (in contrast to the conventional one), called **„Listener-Advertise (LA) / Talker-Join (TJ)“**
  - The LA carries the TSpec of the common stream and other stream information as in the legacy Talker-Advertise.
  - In addition, the LA carries the IS computed by the Listener together with the timing information necessary for the Talkers to derive the beginning of each scheduling cycle.
  - The IS is adjusted at each hop during its porpagation along each path from the Listener to each Talker, which rotates the IS once in that each row in the IS is shifted back (to earlier time) by exactly one time slot. (This is feasible due to the use of CQF)
- Each Talker transmits its µStream according to the corresponding row in the received IS.

Example of Interleaved Schedule Rotation in Reservation for Listener µStream-Interleaving

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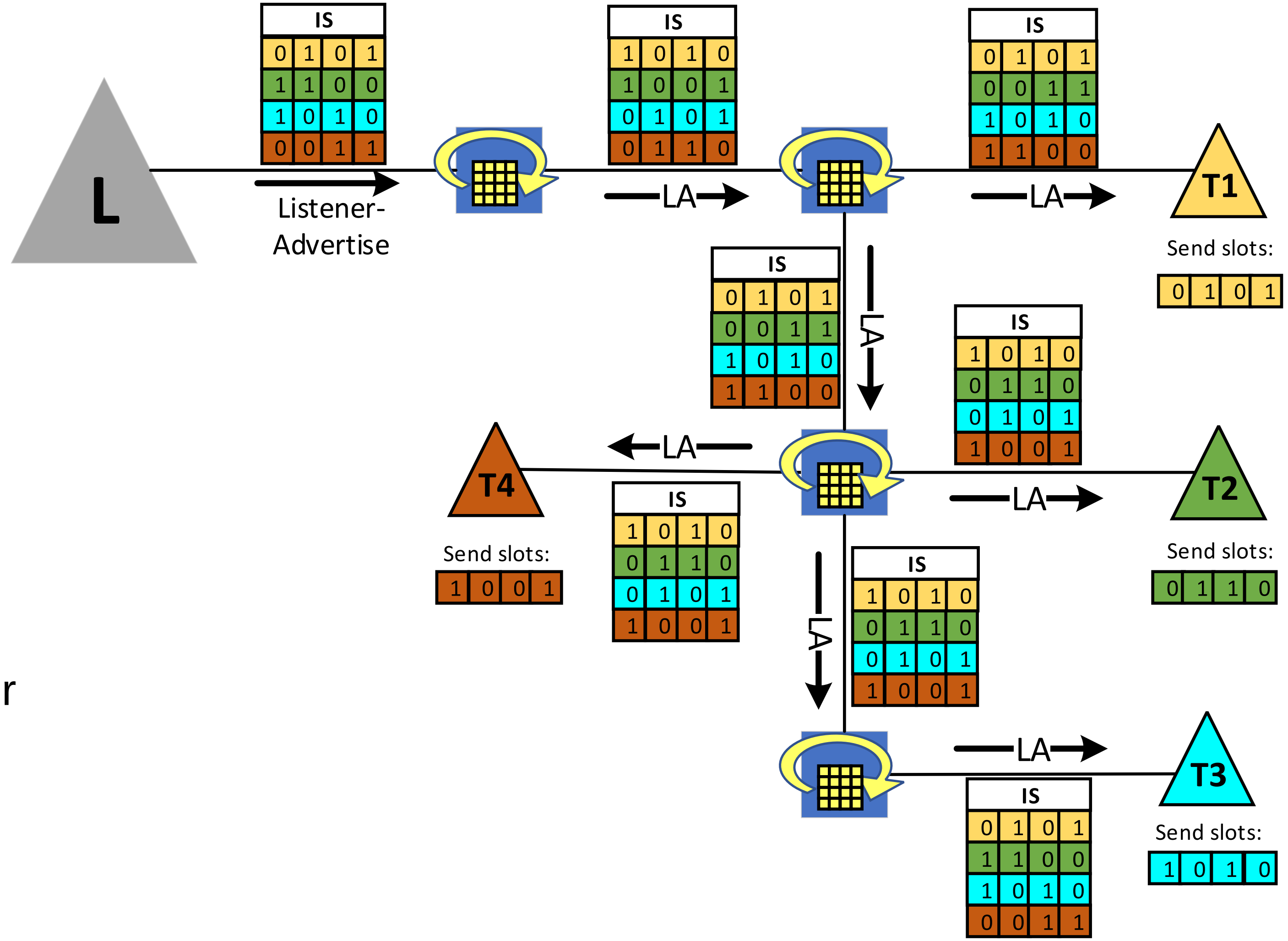
- An essential step in Listener µStream-interleaving is to convert a receiving schedule locally computed by the Listener to a sending schedule for use by each Talker within a distributed stream reservation process.

- Using CQF on the data plane and adding support for a new reservation µStream with "Listener-Advertise / Talker-Join" to the reservation protocol are two keys to applying µStream aggregation with listener µStream-interleaving for n-to-1 communication.



Summary and Outlook

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- ❑ Advantages of µStream-Aggregation to a common Stream (focus of this presentation)
  - Reduce bandwidth overprovisioning
  - Reduce the control plane overhead, e.g. the number of reservation data and Stream Das
  - Talker / Listener µStream-Interleaving is independent from topology
  - Locally computable by Talker / Listener, no need for a central controller
  - Streams / common Streams remain independent from each other
  - Dynamic given by a reservation protocol is still available to Streams / common Streams

- ❑ Outlook for aggregated Streams (upcoming)
  - Support for a large number of streams is required by industrial backbone networks.

Thank You!

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Discussion