

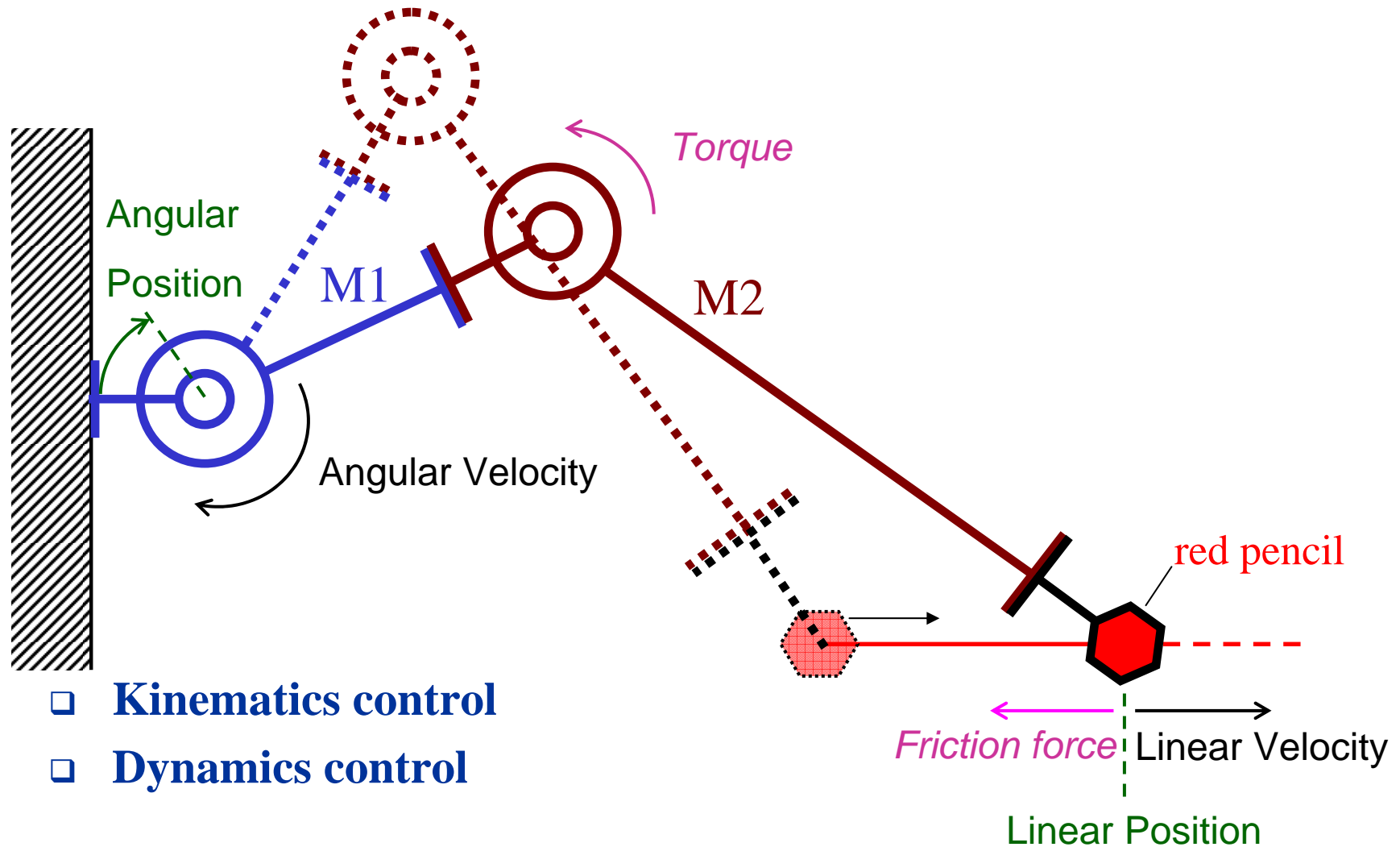
SpW-SnP-MR

SpaceWire networking Protocol for Modular Robotics

Agenda

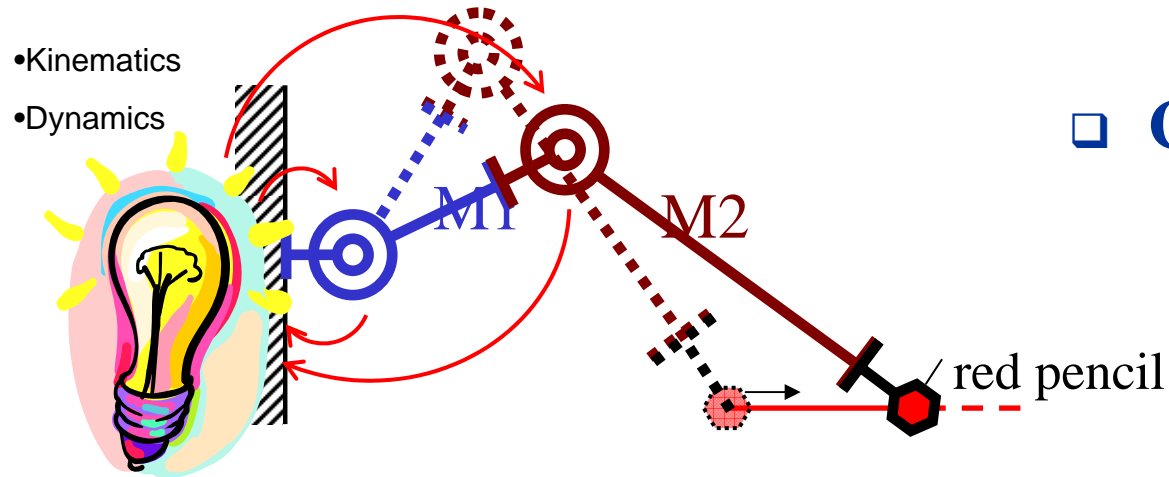
- ❑ **Background (robotics)**
- ❑ **Do we need a dedicated transport layer ?**
- ❑ **Conclusion**
- ❑ **Prerequisite (Time Synchronisation Protocol)**
- ❑ **Partial description of the MrT protocol layer**
- ❑ **Demonstrator**

BACKGROUND - Robot control

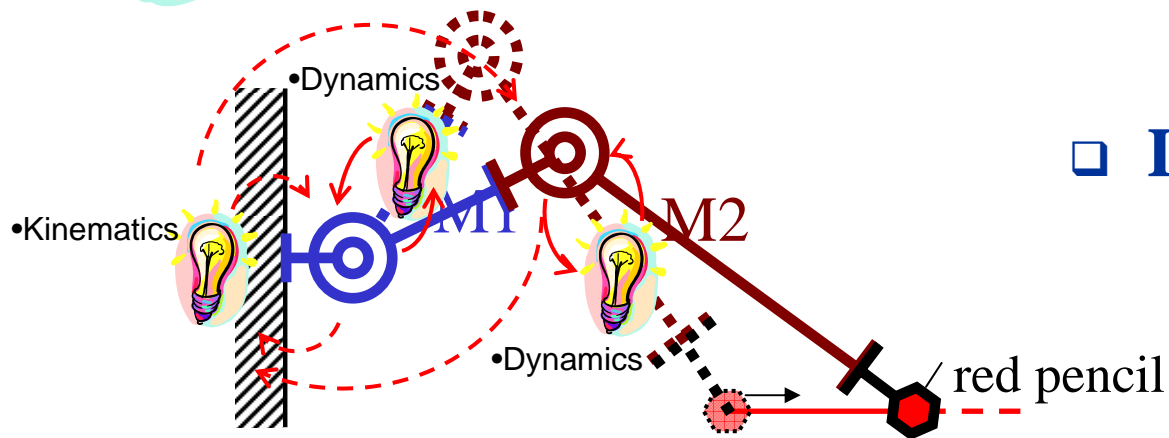


- Kinematics control
- Dynamics control

BACKGROUND - Robot control through Virtual Decomposition technique



□ Centralised control



□ Distributed control

BACKGROUND - Virtual Decomposition technique and distributed control protocol

- ❑ **Modular Robot = 1 master node and N slave nodes**
- ❑ **Communication scheme:**
 - ❑ **Message A :** Slave nodes 1 to N send data to master node: velocity + position.
 - ❑ **Message B :** Master node sends data to slaves nodes 1 to N: desired velocity + desired velocities in slave body frame.
 - ❑ **Message C :** Slave nodes 1 to N send data to master node: desired body-fixed net force/moment.
 - ❑ **Message D :** Master node sends data to slave nodes 1 to N: desired motor torque.
- ❑ **Time constraint : 0.3 ms**

BACKGROUND - Communication protocol for distributed control

- ❑ **Nodes implemented as processes**
- ❑ **Communication scheme:**
 - ❑ **Step A : Reliable transport of message A from Slave process to Master process.**
 - ❑ **Step B : Reliable transport of message B from Master process to Slave process.**
 - ❑ **Step C : Reliable transport of message C from Slave process to Master process.**
 - ❑ **Step D : Reliable transport of message D from Master process to Slave process.**
- ❑ **E.g.: 0.3 ms for a six-joint robot**
 - ⇒ [A, B, C, D] sequence in less than 0.05 ms, including recovery actions in case of transport failure.

Discussion on transport layer (1/2)

Reliable transport of A, B, C, and D messages (RMAP based)

- Write acknowledged RMAP command for each message + timeout + retry
- Trade-off
 - 👍 Protocol is ready for use
 - 👎 Timeout defined with fixed value
 - 👎 Expected minimum communication time for [A, B, C, D] cycle :
 $4 \times 2 \times T_M = 8T_M$ (T_M : expected communication time for one packet)
 - 👎 Expected communication time for [A, B, C, D] cycle including 1 retry: $4 \times 4 \times T_M = 16T_M$
 - 👎 Expected communication time for [A, B, C, D] cycle including FDIR: three or four times $8T_M$

Discussion on transport layer (2/2)

Reliable transport of the [A, B] and [C, D] message pairs (1/2)

□ Semantics:





- Message A : “Knowing that, at time T_1 , my position is Pos and my velocity is Vel, I need to know before time T_2 what should be the values for the desired velocity and for the desired velocities in slave body frame at time T_3 ? ($T_3 > T_2 > T_1$)
- Message B : answer (expected before T_2)
- Message C : “Knowing that , at time T_4 , the desired body-fixed net force/moment is DesBFNFM, I need to know before time T_5 what should be the values for the torque at time T_6 ? ($T_6 > T_5 > T_4$)
- Message D: answer (expected before T_5)

□ FDIR based on physical continuity (data obsolescence).

Discussion on transport layer (2/2)

Reliable transport of the [A, B] and [C, D] message pairs (2/2)

□ Trade-off:

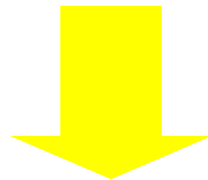
-  Protocol is to be specified
-  Timeout has variable value
-  No retry. FDIR = use a guessed value
-  Expected communication time for [A, B, C, D] cycle including FDIR: $4 \times T_M = 4T_M$

□ Potential for evolutions:

- Query [C,D] to be replaced with local computation or with query to a "neighbour" node
- Queries [A,B] and [C,D] may be replaced with different queries

Conclusion

- ❑ Need for query based communication scheme
- ❑ Need for variable real-time constraints (e.g. two queries and answers within 0.05 ms)



- ❑ Cannot be implemented with RMAP
- ❑ Need for SnP-MrT protocol and for a dedicated SnP protocol ID

Prerequisite : time synchronisation

- ❑ Non Modular Robotics specific
- ❑ Probably a very generic need
- ❑ A specific SpW-SnP (with its own protocol ID) should be designed : SpW-SnP-TSP
- ❑ Suggestions are welcome
- ❑ A proposal will be submitted before next SpW WG meeting (master/slaves, variable time precision and frequency)

Quick description of SnP-MrT

- ❑ **Modular robot initialisation queries**
 - Modular robot topological configuration exploration
 - Auto configuration of control parameters
 - Goal : plug-and-operate capability
- ❑ **Time bounded queries**
- ❑ **More to come...**

SnP-MrT - Generic packet

First byte transmitted

bytes	Destination Logical Address	Protocol Identifier	Nrab (# of return address bytes)	Return Address Byte #1
	Return Address Byte #2	...	Return Address Byte #(Nrab-1)	Return Address Byte #Nrab

32-bit words	Source Process Identifier	Destination Process Identifier	Header CRC	reserved	Packet Type	[SnP-MrT cargo]
	[SnP-MrT cargo]	[SnP-MrT cargo]		[SnP-MrT cargo]		[SnP-MrT cargo]
	[SnP-MrT cargo]	[SnP-MrT cargo]		[SnP-MrT cargo]		[SnP-MrT cargo]
	[SnP-MrT cargo]	[SnP-MrT cargo]		[SnP-MrT cargo]		[SnP-MrT cargo]
	[SnP-MrT cargo]	[SnP-MrT cargo]		...		[SnP-MrT cargo]

bytes	Data CRC	EOP
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Last byte transmitted

❑ Possible answers:

- Error messages
 - Unknown protocol ID reply
 - Unknown packet type reply
 - Invalid data CRC reply
- Appropriate reply

❑ Packet type:

- UNKNOWN_PROTOCOL_ID
- UNKNOWN_PACKET_TYPE
- INVALID_DATA_CRC
- TIME_BOUNDED_QUERY
- TIME_BOUNDED_QUERY_CANCELLATION
- TIME_BOUNDED_QUERY_REPLY
- TIME_BOUNDED_QUERY_DENIAL
- ... more TBD

SnP-MrT - Time-bounded query

First byte transmitted

bytes	Destination Logical Address	Protocol Identifier	Nraw (# of return address words)	Return Address Word #1
	Return Address Word #2	...	Return Address Word #(Nraw-1)	Return Address Word #Nraw

32-bit words	Source Process Identifier	Destination Process Identifier	Header CRC	reserved	Packet Type	Query identifier
	Deadline for reply (MSW)	Deadline for reply (LSW)	Number of input items		Input item #1 identifier	
	Input item #1 value	Input item #1 timestamp (MSW)	Input item #1 timestamp (LSW)		...	
	Number of Output items		Output item #1 identifier	
	Output item #1 timestamp (MSW)	Output item #1 timestamp (LSW)	

bytes	Data CRC	EOP
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Last byte transmitted

❑ Possible answers:

- Time bounded query reply
- Time bounded query denial
- Error messages

❑ Packet type:

- TIME_BOUNDED_QUERY

SnP-MrT - Time-bounded query reply

First byte transmitted

bytes	Destination Logical Address	Protocol Identifier	Nraw (# of return address words)	Return Address Word #1
	Return Address Word #2	...	Return Address Word #(Nraw-1)	Return Address Word #Nraw

32-bit words	Source Process Identifier	Destination Process Identifier	Header CRC	reserved	Packet Type	Query identifier
	Number of input items	Input item #1 identifier	Input item #1 value		Input item #1 timestamp (MSW)	
	Input item #1 timestamp (LSW)	Input item #1 timestamp (MSW)	Input item #1 timestamp (LSW)		Input item #2 timestamp (MSW)	
	Input item #2 timestamp (LSW)	Input item #2 timestamp (MSW)	Input item #2 timestamp (LSW)		...	

bytes	Data CRC	EOP
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Last byte transmitted

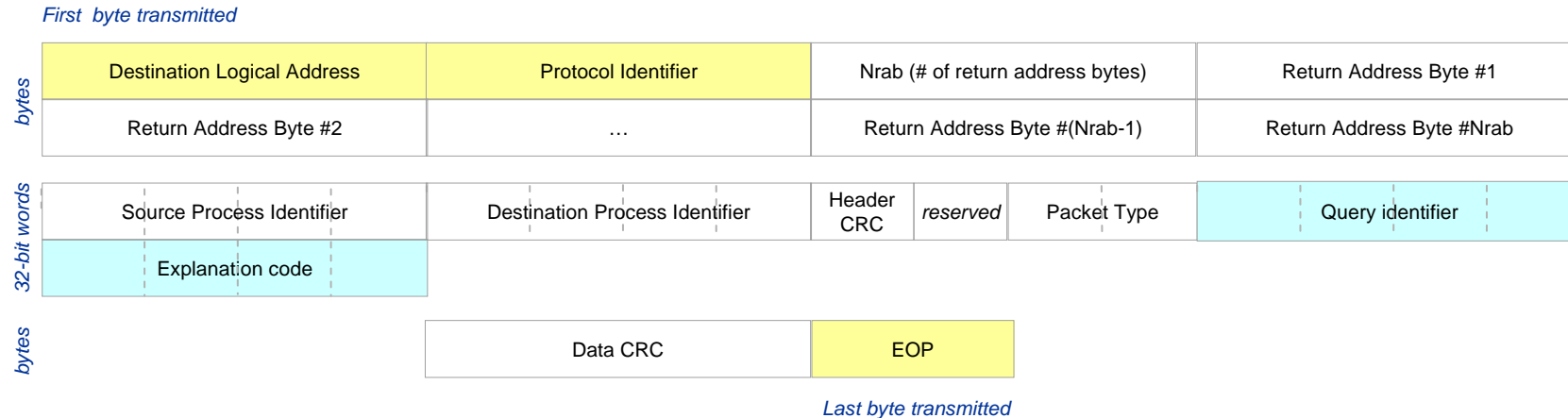
❑ Possible answers:

- Error messages

❑ Packet type:

- TIME_BOUNDED_QUERY_REPLY

SnP-MrT - Time-bounded query denial



❑ Possible answers:

- Error messages

❑ Packet type:

- TIME_BOUNDED_QUERY_CANCELLATION

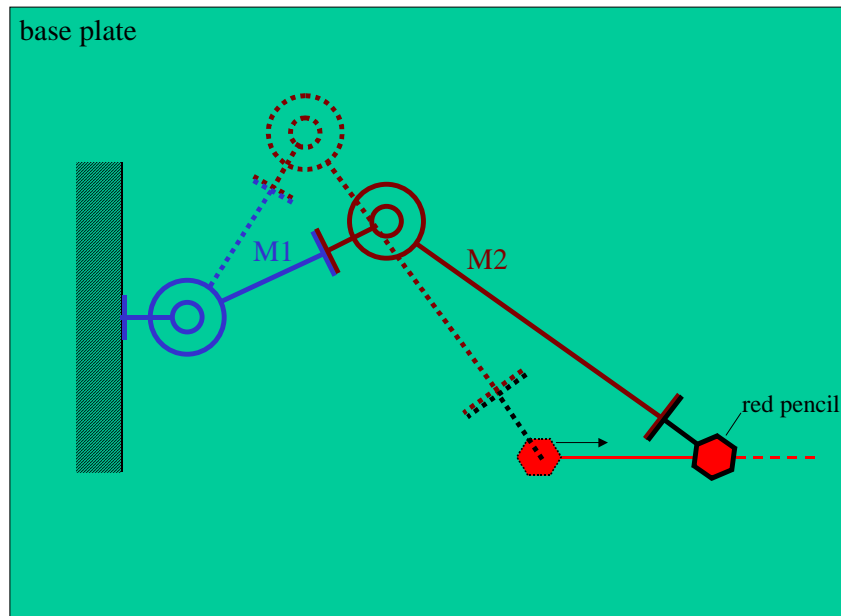
❑ Explanation code:

- DEADLINE_CANNOT_BE_MET
- UNKNOWN_OUTPUT_ITEM
- UNKNOWN_INTPUT_ITEM
- ...

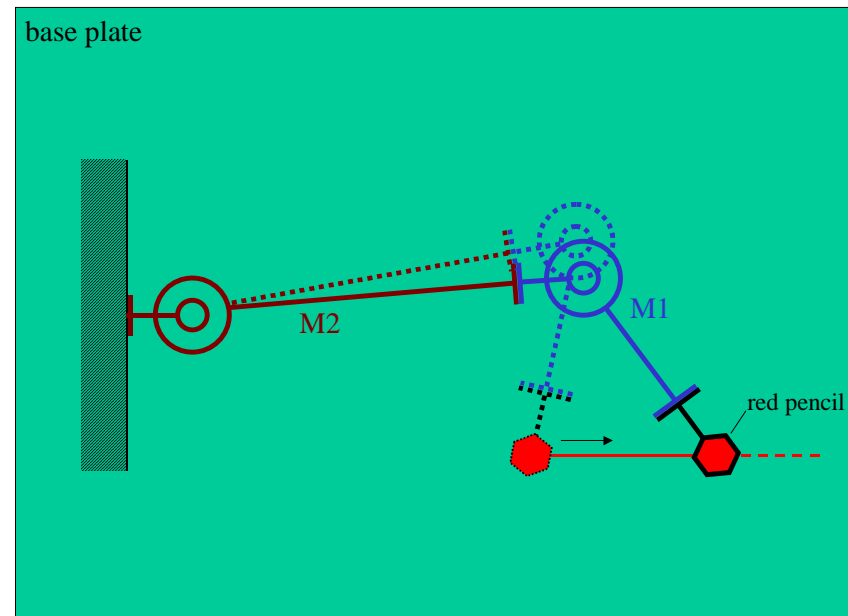
Suggestions

- ❑ **Better name (MRP, for SpW-SnP-MRP ?)**
- ❑ **SnP-PID management dedicated SpW-SnP**
 - "Do you support PID N? To what level (partial implementation)?"
 - "Give me the list of PIDs you support."
- ❑ **Other?**

Demonstrator – System level

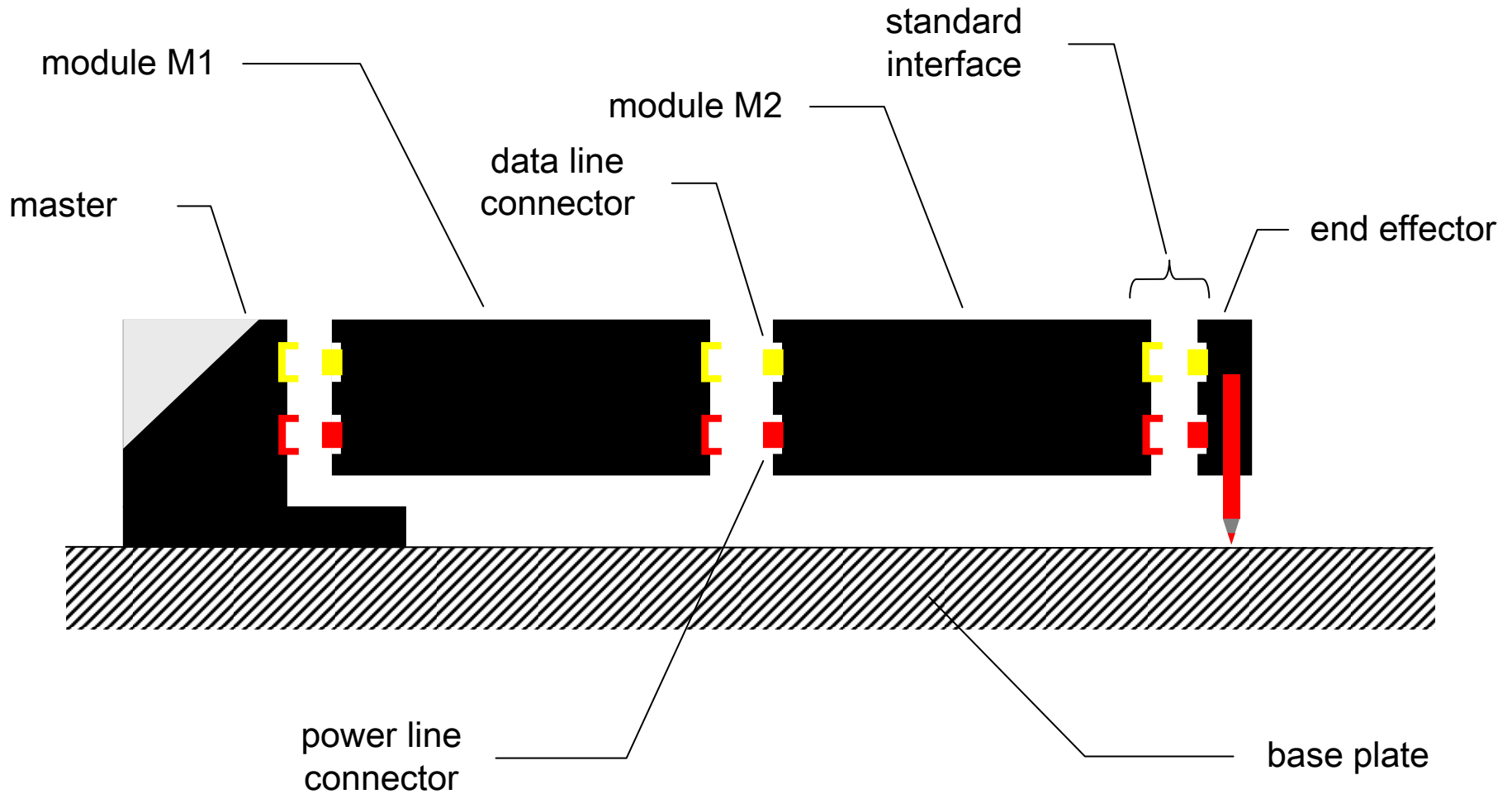


M2 is plugged to M1 which is plugged to the base plate



M1 is plugged to M2 which is plugged to the base plate

Demonstrator – Mechanics



Demonstrator – First module integrated



SnP-MrT – Unknown PID reply

First byte transmitted

bytes	Destination Logical Address	Protocol Identifier	Nrab (# of return address bytes)	Return Address Byte #1
	Return Address Byte #2	...	Return Address Byte #(Nrab-1)	Return Address Byte #Nrab
	Source Process Identifier (MSB)	Source Process Identifier	Source Process Identifier	Source Process Identifier (LSB)
	Destination Process Identifier (MSB)	Destination Process Identifier	Destination Process Identifier	Destination Process Identifier (LSB)
	Header CRC	reserved	Packet Type (MSB)	Packet Type (LSB)
	Data CRC	EOP		

Last byte transmitted

❑ Possible answers:

- Error messages

❑ Packet type:

- UNKNOWN_PID_REPLY

SnP-MrT – Unknown packet type reply

First byte transmitted

bytes	Destination Logical Address	Protocol Identifier	Nrab (# of return address bytes)	Return Address Byte #1
	Return Address Byte #2	...	Return Address Byte #(Nrab-1)	Return Address Byte #Nrab
	Source Process Identifier (MSB)	Source Process Identifier	Source Process Identifier	Source Process Identifier (LSB)
	Destination Process Identifier (MSB)	Destination Process Identifier	Destination Process Identifier	Destination Process Identifier (LSB)
	Header CRC	reserved	Packet Type (MSB)	Packet Type (LSB)
	Data CRC	EOP		

Last byte transmitted

❑ Possible answers:

- Error messages

❑ Packet type:

- UNKNOWN_PACKET_TYPE_REPLY

SnP-MrT – Invalid data CRC reply

First byte transmitted

bytes	Destination Logical Address	Protocol Identifier	Nrab (# of return address bytes)	Return Address Byte #1
	Return Address Byte #2	...	Return Address Byte #(Nrab-1)	Return Address Byte #Nrab
	Source Process Identifier (MSB)	Source Process Identifier	Source Process Identifier	Source Process Identifier (LSB)
	Destination Process Identifier (MSB)	Destination Process Identifier	Destination Process Identifier	Destination Process Identifier (LSB)
	Header CRC	reserved	Packet Type (MSB)	Packet Type (LSB)
	Data CRC	EOP		

Last byte transmitted

❑ Possible answers:

- Error messages

❑ Packet type:

- INVALID_DATA_CRC_REPLY

Trade-off summary SnP-MrT/RMAP (1/2)

FDIR	SwB	SpW	RMAP	SnP-MrT (non robot ctrl)	SnP-MrT (robot ctrl)
no redundancy in communication path					
1 or more transient failure(s) on communication path					
link layer					
D	NO	NO	but EEP added to packet		
I (which packet?)	NO	NO	packet	SpW	SpW
R	NO	NO			SpW
S/NM	NO	NO			
network layer					
(non acknowledged)					
D	NO	NO	but destination gets EEP	NO	NO
I (which packet?)	NO	NO		NO	NO
R	NO	NO		NO	NO
S/NM	NO	NO		NO	NO
transport layer					
(acknowledged)					
D				NO	only timeout on ack.
I (which packet?)	N/A	N/A		NO	Is missing
R				NO	
S/NM				YES	feedback on failure
				YES	through timed ack.
				YES	through transaction ID
				YES	retry
				YES	feedback on failure
				YES	ack. through reply
				YES	ack. through reply
				YES	computed value
				YES	ack. through reply
1 or more permanent failure(s) on communication path					
link layer					
D	NO	NO	but EEP added to packet		
I (which packet?)	NO	NO	packet	SpW	SpW
R	NO	NO			SpW
S/NM	NO	NO			
network layer					
(non acknowledged)					
D	NO	NO	but destination gets EEP	NO	NO
I (which packet?)	NO	NO		NO	NO
R	NO	NO		NO	NO
S/NM	NO	NO		NO	NO
transport layer					
(acknowledged)					
D				NO	only timeout on ack.
I (which packet?)	N/A	N/A		NO	Is missing
R				NO	
S/NM				YES	feedback on failure
				YES	through timed ack.
				YES	through transaction ID
				NO	many cycles will fail
				YES	feedback on failure
				YES	ack. through reply
				YES	ack. through reply
				NO	many cycles will fail
				YES	ack. through reply

Trade-off summary SnP-MrT/RMAP

(2/2)

(FDIR continued)	SwB	SpW	RMAP	SnP-MrT (non robot ctrl)	SnP-MrT (robot ctrl)
single redundancy in communication path (two different paths per Sender-Destination pair)					
1 or more transient or permanent failure(s) on communication path					
link layer					
D	NO	NO	but EEP added to packet		
I (which packet?)	NO	NO	EEP	SpW	SpW
R	YES	byte broadcasting	NO	SpW	SpW
S/NM	NO	NO			
network layer					
D	NO	NO	but destination gets EEP	(non acknowledged)	
I (which packet?)	NO	NO	EEP	NO	NO
R	YES	byte broadcasting	NO	NO	NO
S/NM	NO	NO	NO	NO	NO
transport layer					
D				(acknowledged)	
I (which packet?)	N/A	N/A	NO	only timeout on ack.	YES
R			NO	ls missing	YES
S/NM			NO		YES
			YES	feedback on failure	YES
				through timed ack.	YES
				through transaction ID	YES
				retry	YES
				feedback on failure	YES
				ack. through reply	YES
				ack. through reply	YES
				computed value	YES
				ack. through reply	YES

Other layers

- ❑ **Session layer (SnP MrS) [TBA]**
- ❑ **Presentation layer (SnP MrP) [TBA]**
- ❑ **Application layer (SnP MrA) [TBA]**
- ❑ **SnP MR network management services [TBA]**
 - Support to network management in SnP MrT [TBA]
 - Support to network management in SnP MrS [TBA]
 - SnP MR network management services (SnP MrM) [TBA]

MR1 first module – front view

