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Communication Overhead Description Schema for Multi Core Processor in Model-based Development

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Abstract: Autonomous driving systems require a wider range of functionalities than traditional embedded systems, making Model-based Development (MBD) with MATLAB/Simulink essential. This approach allows early simulation and validation, enhancing safety and reducing development time. At the same time, the real-time requirements of multi-tasking for autonomous driving cannot be ignored. Many core processors with computing performance and low power consumption have been developed to satisfy these requirements. However, due to their complexity, developing with many core processors takes time. In MBD, MATLAB/Simulink's automatic code generation is not tailored for many-core systems, leading to the development of a model-based parallelization tool that generates parallelized C code. This tool leverages the software-hardware interface for multi-many-core (SHIM) information—a standard that details the structure of many-core processors and performance metrics. However, SHIM cannot fully demonstrate communication overhead as it describes overhead in instruction units. With this, we propose a new schema to describe communication overhead in API units and an XML split specification to enhance SHIM's reusability. Experimental results show at least a 97.9% improvement in accuracy for estimating communication overhead, over 90% reduction in schema description, and a significant reduction in execution time with our schema.

Keywords: Embedded Systems, Model-based Development, Multi/Many-core

1. Introduction

In recent years, autonomous driving systems [1, 2] have attracted attention for reducing traffic accidents. However, real-time performance is essential for automated driving systems, and high computational power is required. In development of these systems, Model-based Development (MBD) has raised for its functionalities such as early simulation, and validation [3,4]. Furthermore, low power consumption is also required to enable installation in automobiles. Thus, more comprehensive functions are required than those of conventional embedded systems [5]. To meet these requirements, many-core processors are being adopted. Many-core processors offer high computational performance and energy efficiency [6–8]. Efficient utilization of these processors, however, necessitates understanding their complex specifications, which can extend development times.

In MBD, MATLAB/Simulink is noted for its automatic C code generation from models, but it does not support parallelized code generation [9]. Addressing this, the Embedded Multicore Consortium's Model-based Parallelizer (MBP) facilitates the automatic generation of parallelized C code. This integration streamlines simulation and code generation for multi-many-core processors, enhancing development efficiency. Utilizing SHIM (Software-Hardware Interface for Multi-Many-Core) to abstract essential processor information minimizes the reliance on physical hardware [10–13].

The latest version of SHIM [14] currently still lacks an efficient method to describe inter-core communication latency, which poses significant challenges. This deficiency leads to substantial inaccuracies in time predictions within the Model-based Parallelizer (MBP) due to the omission of inter-core communication latency calculations. Furthermore, the lack of a concise communication description necessitates extensive documentation of latency between cores, resulting in increased number of lines for the communication overhead description to more than ten thousand lines.

To address these issues, a revised schema is proposed that measures communication overhead in per-API units for more precise estimates and also simplifies the schema's structure to reduce its volume. This enhancement facilitates ease of use and construction, allowing for a more accurate and comprehensive representation of communication overhead. Additionally, it improves the reliability and efficiency of performance evaluations in multi-core environments.

The main contributions of this paper are as follows:

- This paper proposes a communication overhead schema that is independent of communication libraries and can account for changes in message size.
- This paper shows improvement in results by generating a communication overhead description file with an appropriate message size and using it in existing estimation methods. It

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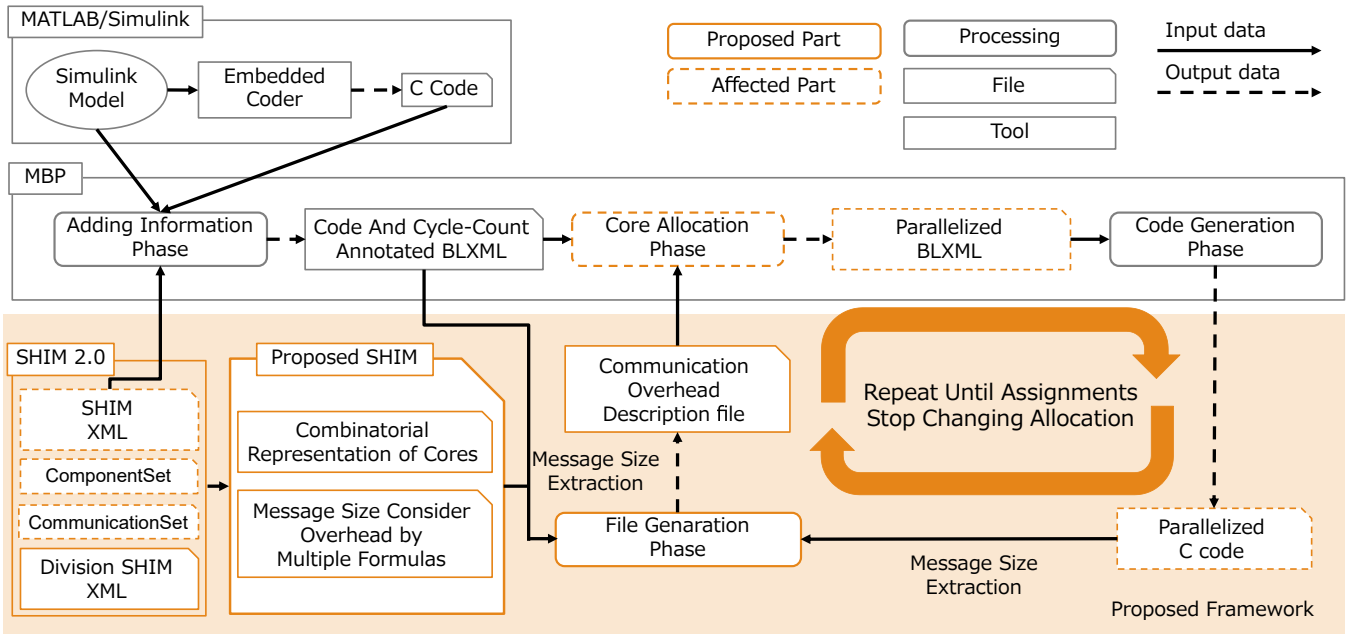

Fig. 1 System model.

demonstrates that the average improvement rate in the error of the estimated communication overhead is at least 97.9%.

- This paper proposes a new XML split specification to reduce the amount of description and the description of cores and combinations of cores by more than 90%, to reduce the burden on the users of SHIM.

The remainder of this paper is organized as follows. Section 2 describes the system model. Next, Section 3 shows the approach. Section 4 discusses the process of applying the proposal schema to MBP. Then, Section 5 shows the experimental results. Section 6 discusses related work. Finally, Section 7 concludes this paper.

2. System Model

This section introduces SHIM, MBP, and the system model shown in **Fig. 1**. The proposed framework is divided into two major parts. The first is a proposal for a schema that describes communication overhead based on per-API measurements. The second is to propose a method to generate a communication overhead description file from the proposed schema to apply the proposed schema to MBP.

2.1 SHIM

SHIM is an IEEE standard interface for describing hardware and software information of multi-many-core processors. SHIM is in XML format and has a tree structure consisting of five upper-level components. Two of the most important are described here. The current latest version is SHIM 2.0. The creation of SHIM XML by hardware providers is essential for software tool usage, yet not all providers supply this XML. This limitation could hinder hardware adoption. To address this, freely available Reference authoring tools, accompanied by specifications, allow users with access to technical manuals and hardware (such as simulators or evaluation boards) to generate SHIM XML for most multi-many-core systems, thus enhancing accessibility and integration.

2.1.1 ComponentSet

ComponentSet is a component representing complex processor core clusters and hardware boards. To represent them, three components are used: *MasterComponent* for processors and accelerators, *SlaveComponent* for the relationship among *MasterComponent*, memory blocks, and memory subsystems. Lastly, *Cache* denotes the cache.

2.1.2 CommunicationSet

This component defines the communication method and overhead between cores by describing the combination of cores and message size. All possible communications should be described in this component. The overhead described is the overhead of the communication only.

2.2 MBP

MBP is a model-based parallelization tool that can be used with MATLAB/Simulink. MBP takes a Simulink model and SHIM as input and can automatically generate parallelized C code and estimate execution time from the model.

2.2.1 Adding Information Phase

MBP extracts the block information from the Simulink model. Next, MBP splits the C code generated by the Embedded Coder into code blocks and generates BLXML with code annotations. Finally, MBP extracts hardware information from the SHIM XML and uses processor latency to estimate the performance of each Simulink block.

2.2.2 Core Allocation Phase

In this phase, MBP generates the mapping information using cycle count annotated BLXML generated in *Adding Information phase*. In addition, incorporating the communication overhead description file enables allocation that considers communication overhead.

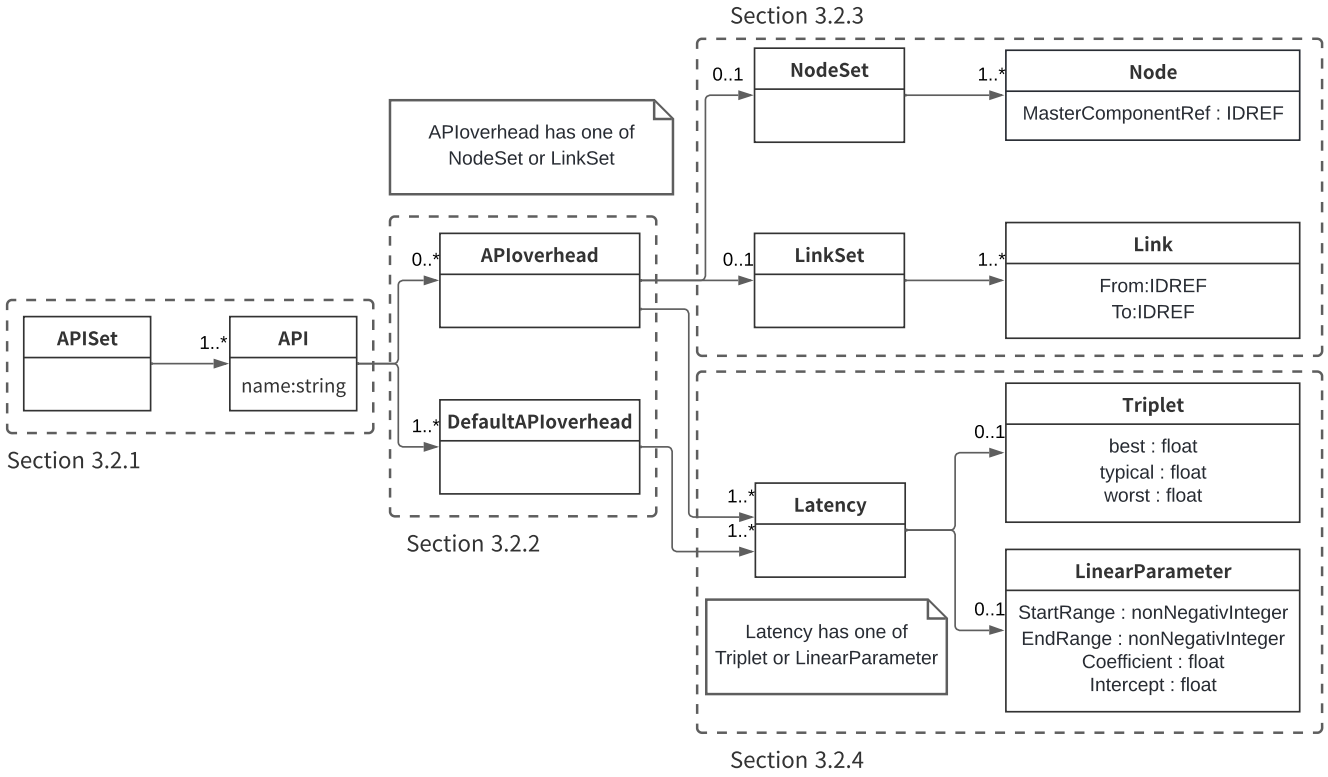

Fig. 2 The proposed schema.

Table 1 OS and APIs investigated

Function	MPI [15]	MCAPI [16]	eMCOS [17]	ROS [18]
Initialize	✓	✓		✓
Finalize	✓	✓		✓
Get node ID	✓	✓	✓	
Get node name			✓	✓
Create node		✓	✓	✓
Delete node	✓		✓	✓
Exit node		✓	✓	
Message send	✓	✓	✓	✓
Message receive	✓	✓	✓	✓

2.2.3 Code Generation Phase

This phase aims to generate the parallelized C code from parallelized BLXML. MBP follows the parallelized BLXML, which includes core assignments and reconstructs the C code for each assigned core to generate parallelized C code.

3. Approach

An implementation of a schema that can describe software overhead will be described. In addition, this section introduces a method to incorporate the proposed schema into SHIM 2.0. Note that this paper does not explain the arguments and use cases that led to the implementation. For more information, please refer to the previous paper [19].

3.1 Design of Proposed Schema

The design of the proposed schema, which can describe software overhead per API, is described. Software overhead can be described more accurately than in SHIM 2.0 because software overhead can be described in units of API. In addition, the proposed schema can be incorporated into SHIM 2.0.

3.1.1 Goals of Proposed Schema

The goal is to create an additional schema for describing software overhead information independent of communication libraries. This schema should be able to describe each of the API overheads involved in communication. The proposed schema is also intended to be incorporated into SHIM 2.0.

3.1.2 Select API Required for Communication

The proposed schema is designed to allow the overhead to be described on a per-API basis to measure the communication's performance accurately. One reason is that the existing SHIM has difficulty expressing the communication overhead of the API. Another reason is that many common APIs are easy to standardize, as shown in **Table 1**.

3.2 API Overhead Representation in Proposed Schema

This subsection describes each element of the proposed schema shown in **Fig. 2**. Note that, as noted above, the discussion that led to the implementation is not presented in this paper.

3.2.1 APISet and API

APISet is the top element of the proposed schema, and the multiplicity of *APISet* to *API* is at least one. *API* is used to distinguish which API is being represented by the name attribute when representing the API overhead.

3.2.2 APIoverhead and Defaultoverhead

APIoverhead and *Defaultoverhead* are elements that summarize API overhead. *Defaultoverhead* defines the basic overhead

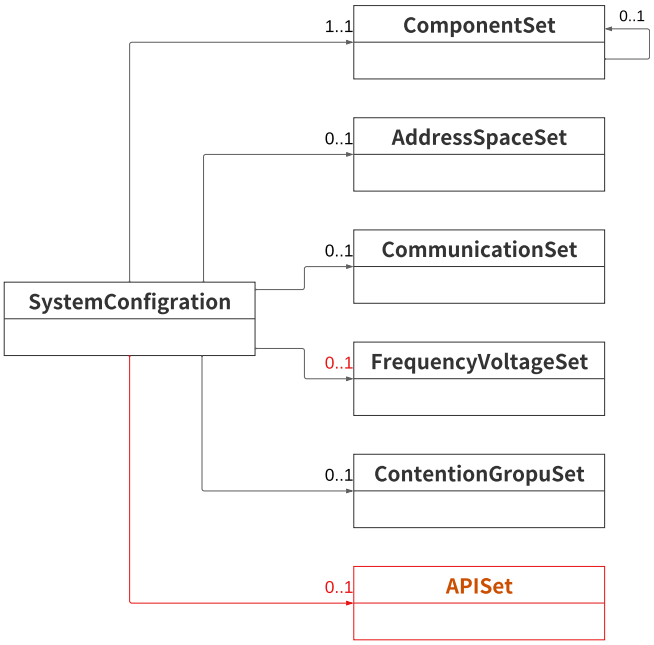

Fig. 3 Overall after incorporating the proposed schema.

of each API on the target processor, and *APIoverhead* defines the API overhead for different performance. In this way, the amount of description can be greatly reduced.

3.2.3 NodeSet, Node, LinkSet, and Link

NodeSet, Node, LinkSet, and Link represent the core or combination of cores on which the API is executed. The proposed schema adopted the idea of grouping *Node* and *Link* by *NodeSet* and *LinkSet* respectively. Each *Node* and *Link* defines either one or a combination of two operating cores. Therefore, combinations belonging to the same *NodeSet* and *LinkSet* have the same API overhead. Note that in [19], Node is Core and Link is Connection, names were changed for consistency with SHIM 2.0.

3.2.4 Latency, Triplet, and LinearParameter

Triplet can define the fixed overhead with three parameters: worst, typical, and best. On the other hand, *LinearParameter* contains the parameters needed to calculate the varying overhead using "linear formulas." Define the coefficient and intercept as necessary parameters for the linear equation. In this paper, the least-squares method is used to compute these two parameters. Furthermore, the proposed schema divides linear expressions by range, allowing for the use of appropriate parameters when calculating overhead. *Latency* is the element provided to select these two exclusively. The mechanism for exclusive selection is similar to the way *APIoverhead* selects *NodeSet* and *LinkSet*.

3.3 Proposed Schema is incorporated into SHIM 2.0

This section describes how the proposed schema is incorporated into SHIM 2.0. In addition, the new specification of the partitioning method is described.

3.3.1 Incorporation of proposed schema into SHIM 2.0

Since the proposed schema is designed with SHIM 2.0 in mind, the proposed schema can be incorporated without modification. Next, the modifications to SHIM 2.0 that are necessary to incorporate the proposed schema are described. The entire modified schema is shown in **Fig. 3**. The multiplicity of *FrequencyVoltageSet* is set to zero or higher because the XML split specification, which is explained in Section 3.3.2, is involved. In addition, although the addition of *APISet* eliminates the role of *CommunicationSet*, *CommunicationSet* is not deleted and is deprecated.

The elements of SHIM 2.0 that are changed by the addition of *APISet* are described. The element to be changed is *Performance*. Previously, the performance had a *Pitch* element and a *Latency* element. These two elements inherited *AbstractPerformance*. After the change, *Pitch* and *Latency* have been modified to select two elements, *Triplet* and *LinearParameter*. For more information, please refer to the previous paper [19].

3.3.2 XML Split Specification to SHIM 2.0

Here, a new XML split specification for SHIM 2.0 is described. The proposed XML split specification aims to improve the reusability of the SHIM schema. The proposed XML split specification utilizes *ComponentSet*, which represents the core of SHIM, as the division unit because *ComponentSet* is the main element of the SHIM schema and is reused frequently. In addition, set the multiplicity of *FrequencyVoltageSet* to "0" or greater for the XML partitioning specification. In this way, XML with only *ComponentSet* can be created. The XML schema uses the ID/IDREF attribute for the reference relation; the ID/IDREF attribute indicates the reference relation between two elements and must be unique in the same XML. Here, an element with the ID attribute can be referenced by another element with the IDREF attribute; if the ComponentSet is split, this ID/IDREF attribute reference relationship is broken.

If the reference relationship is broken by splitting, not only the broken reference relationship but also other reference relationships will not function properly. Therefore, the reference relations in the undivided part were to be maintained by deleting the broken reference relations.

On the other hand, when reusing split XML, a problem arises when composing the main XML (XML containing essential information such as memory access information) and split XML (split *ComponentSet*), which results in duplicate IDs. This problem was solved by assigning a rule to the *ID* attribute to avoid duplication as much as possible. The rules are as follows: "short name of element_file name_random number." This approach eliminates the possibility of duplicate *ID* to the greatest extent possible. The reason for not eliminating duplicates completely is that centralized management of *ID* would be too costly.

ComponentSet can be split using these two ideas. However, repairing referential relations must be considered when reusing the split *ComponentSet* because the referential relations have been deleted to solve the first problem. The repair process is divided into *Cache* and *FrequencyVoltageSet*, which ComponentSet references. As for the *Cache* reference, only one level outward *Cache* can be referenced by SHIM definition and can be repaired automatically. *FrequencyVoltageSet*, on the other hand, is not constrained by references and must be repaired manually.

Algorithm 2 Get Message Size for Overhead Description File

1: **Input:** Simulink model, BLXML
2: **Output:** Message size MS
3: $MS_L \leftarrow$ List of message sizes for signal lines from BLXML
4: **if** MS_L are all equal **then**
5: $MS \leftarrow$ average of MS_L
6: **else**
7: $MS_T \leftarrow$ average of MS_L
8: $MS_P \leftarrow \{\}$
9: **for** $i = 1$ to $2\times$ length of MS_L **do**
10: Perform core allocation using MS_T
11: $MS_E \leftarrow$ Extract average of message size from parallelized C code
12: **if** MS_E equals MS_T **then**
13: $MS \leftarrow MS_T$
14: **return** MS
15: **else if** MS_T is in MS_P **then**
16: $MS \leftarrow$ average of MS_P
17: **return** MS
18: **else**
19: Append MS_E to MS_P
20: $MS_T \leftarrow$ average of MS_E
21: **end if**
22: **end for**
23: $MS \leftarrow$ average of MS_P
24: **end if**

Algorithm 1 Overhead Description File Generation

1: **Input:** Number of cores N, Message size MS
2: **Output:** Overhead Description File
3: $A \leftarrow$ Matrix of size $N \times N$
4: **for** $i = 1$ to N **do**
5: **for** $j = 1$ to N **do**
6: **if** $i = j$ **then**
7: $a_{i,j} \leftarrow 0$
8: **else if** (i, j) belongs to a Link **then**
9: Reference Link at APIoverhead for $a_{i,j}$
10: Get LinearParameter for $StartRange \leq MS < EndRange$
11: Get coefficient as $Coef_{i,j}$ and intercept as $Inte_{i,j}$
12: **else**
13: Reference Defaultoverhead.
14: Get LinearParameter for $StartRange \leq MS < EndRange$
15: Get coefficient as $Coef_{i,j}$ and intercept as $Inte_{i,j}$
16: **end if**
17: $a_{i,j} \leftarrow Coef_{i,j} \times MS + Inte_{i,j}$
18: **end for**
19: **end for**
20: Generate Overhead Description File from A

4. Using the Proposal Schema in MBP

This section describes how the proposed schema is used in MBP. First, the generation method of the communication overhead description schema used in MBP is explained. Next, the method for obtaining the message size, a necessary parameter in the generation method, is introduced.

4.1 Generating Communication Overhead Description Files from Proposed Schema

In order for MBP to use SHIM communication overhead information, a communication overhead description file must be created. This is because MBP reads the overhead description file in the core allocation phase and performs core allocation considering the communication overhead. The algorithm shown in **Algorithm 1** is described in the following.

First, the elements of Input are explained. The number of cores is obtained from SHIM. The message size is obtained in the method outlined in Section 4.1.

In Line 3, initialize a $N \times N$-sized matrix A. Each entry $A_{i,j}$ in this matrix represents the overhead of communication from core i to core j. This matrix format allows for a structured representation of communication costs across all core pairs, facilitating efficient calculation and data management. In Line 8, there is no communication between the same cores ($i = j$). Therefore, the overhead is calculated as zero. This assumption simplifies the model by eliminating unnecessary calculations for non-existent self-communications.

Lines 9-16 obtain the parameters needed to calculate the communication overhead between the different cores ($i \neq j$); from the elements corresponding to Link and MS, the coefficients and intercepts are obtained. The coefficient in this context quantifies the incremental increase in communication overhead per unit increase in message size or other relevant metric. The intercept represents the baseline overhead associated with establishing a communication link, irrespective of the data quantity being transmitted.

The coefficients $Coef_{i,j}$ represent the incremental delay or overhead added per unit of message size or other scaling factor, while the intercept $Inte_{i,j}$ represents the baseline overhead that exists even when no data is being transmitted. Calculate the communication overhead using the coefficients and intercept obtained in Line 17. It is particularly useful for quickly estimating communication delays in complex multi-core systems where direct measurement for every possible communication scenario would be impractical.

This procedure generates a communication overhead description file that can be used for allocation and estimation in MBP. The advantage of the proposed method is that the time required to generate the communication overhead description file is short.

4.2 Methods to Determine Message Size for Calculating Communication Overhead

Since the average communication message size in the Simulink model may deviate from the actual situation, the simulation was repeated to determine the communication message size. The message size must be determined to create a communication overhead description file, as discussed in Section 4.1. The algorithm shown in **Algorithm 2** is described in the following.

In Line 3, get the list of signal line message sizes MS_L from

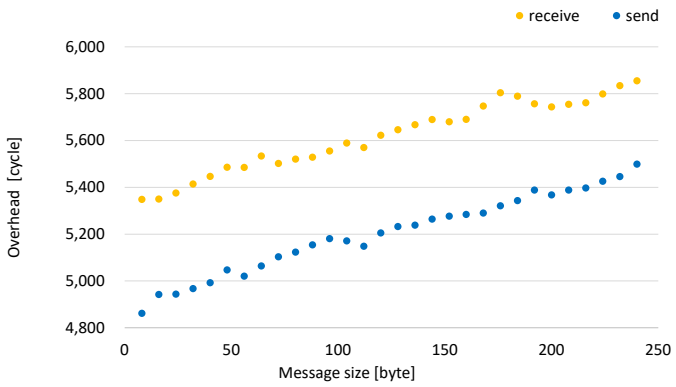

Fig. 4 Overhead of inter-core communication.

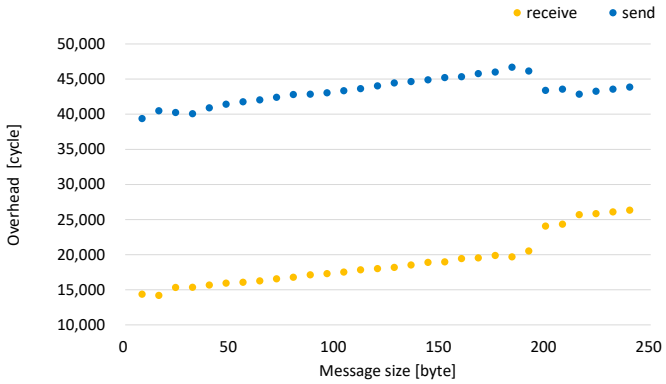

Fig. 5 Overhead of inter-cluster communication.

BLXML. In Line 4 - 5, if all elements of MS_L are equal, then the average value of MS_L is directly MS. However, if different message sizes exist, the following procedure is used to determine MS. Initializes the average value of MS_L as MS_T in Line 7. Use MS_T to allocate cores and extract the average message size MS_E from the parallelized C code in lines 10 - 11. If MS_E is equal to MS_T, adopt MS_T as MS and terminate the algorithm in lines 12 - 14. If MS_T exists in the historical list MS_P, adopt the average value of MS_P as MS and terminate the algorithm (Lines 15 - 17). If neither of the above conditions is met, add MS_E to MS_P and compute the new MS_T as the mean value of MS_E. (Lines 18 - 21). If the message size does not remain constant even after looping twice the number of communications, the average of MS_P is used (Line 23). However, since the number of communications is finite, Line 23 is never reached.

5. Evaluation

Then, the proposed schema for the MPPA3-80 Coolidge processor [20] is created, and communication overhead calculated from the schema and the number of descriptive parameters used to calculate communication overhead are compared to those of SHIM 2.0. The difference in communication overhead calculation parameters depending on the number of linear formulas will also be confirmed. Furthermore, the usefulness of using multiple linear formulas is demonstrated by calculating the communication overhead and comparing the results. Finally, the communication overhead description file generated by the proposed method uses MBP to parallelize, and the execution times are compared to show the usefulness of the proposed schema. Additionally, it

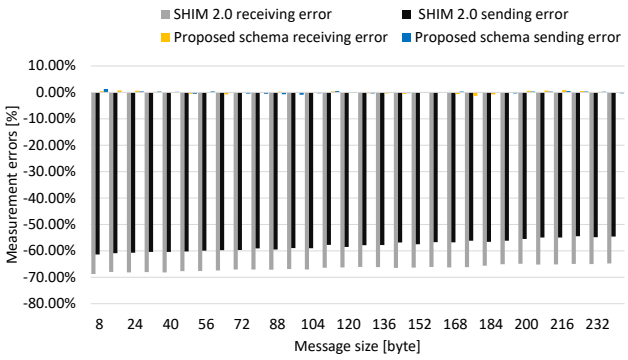

Fig. 6 Comparison of communication overheads (inter-Core).

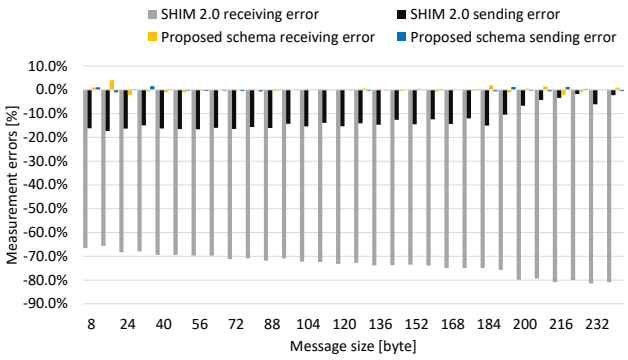

Fig. 7 Comparison of communication overheads (inter-Cluster).

is important to note that the proposed method is not dependent on the Kalray MPPA3-80 and can be applied to other devices as well, including RISC-V multi-core processors such as the P870 and the P870-A provided by SiFive [21, 22].

5.1 Evaluation Environment

This paper uses the Kalray MPPA3-80 Coolidge processor, a homogeneous processor. MPPA3-80 Coolidge is a clustered many-core processor comprising five clusters, each with 16 cores for a total of 80 cores. The communication overhead of the MPPA3-80 Coolidge processor was measured on an actual device, and the results are shown in **Figs. 4** and **5**. Each measurement was repeated 1,000 times, and the average value of the center 80% of the acquired values was used. The target real-time operating system was eMCOS, and eMCOS functions were utilized to measure the execution time.

5.2 Evaluation of Proposed Schema

Three evaluations were conducted to confirm the effectiveness of the proposed, i.e., evaluations of communication overhead error, error reduction through multiple linear formulas, and description reduction.

5.2.1 Communication Overhead Evaluation

The errors between the communication overhead calculated by the proposed method and SHIM 2.0 and the actual measurement are shown in **Figs. 6** and **7**. In fact, only the communication part is measured because SHIM 2.0 was not able to perform the calculation. This is because the target API was too complex to parse and SHIM 2.0 could not estimate on an instruction-by-instruction basis. On the other hand, the proposed schema calculates com-

Table 2 Parameters used to calculate communication overhead

	Coefficient	Intercept	Link	MessageSize
Send	2.1	5,357.2	Inter-core	All
	31.6	14,266.2	Inter-cluster	Less than 200 bytes
	37.4	12,330.1	Inter-cluster	Greater than 200 bytes
Receive	2.4	4,906.1	Inter-core	All
	59.4	39,495.1	Inter-cluster	Less than 200 bytes
	10.1	41,191.6	Inter-cluster	Greater than 200 bytes

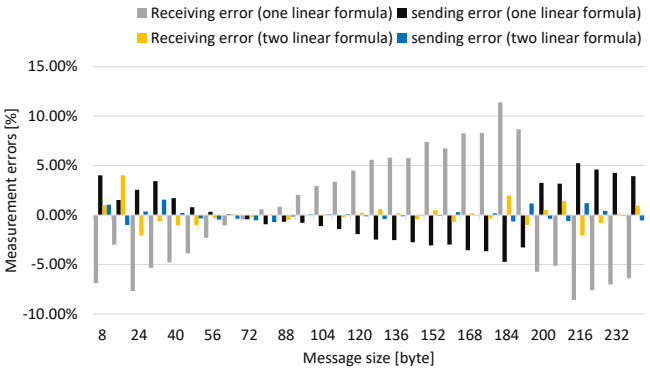

Fig. 8 Comparison of communication overhead (difference in the number of formulas).

munication overhead using the formula $Coef_{i,j} \times MS + Inte_{i,j}$. The parameters used in the communication overhead formula of the proposed schema are shown in **Table 2**. As discussed in Section 3.2.4, this parameter was calculated from the measured values using the least squares method.

A comparison of the results shows that SHIM 2.0 underestimates the communication overhead. This occurred because SHIM 2.0 measures only the communication part and does not consider other related processes, such as memory allocation required for communication. In contrast, the proposed schema measures overhead of other processes per API; thus, the result shows an average improvement rate for the *send* API about 97.9%, and an average improvement rate for the *receive* API about 98.7%. This value is within the SHIM target of 20%, which is sufficient for practical application.

5.2.2 Error Reduction by Multiple Expressions

In the given scenario, two separate linear equations are utilized to approximate the communication overhead for sending and receiving operations, respectively. This differentiation is crucial because the processes involved in sending and receiving data often have distinct characteristics and resource requirements, which can significantly impact communication overhead.

The first linear equation, with a *Coefficient* of 48.5 and an *Intercept* of 12,999, is used to estimate the overhead for receiving operations. The coefficient here likely represents the incremental overhead per unit of data received, while the intercept might account for fixed costs associated with initiating or terminating a receive operation. The second linear equation, with a *Coefficient* of 20.0 and an *Intercept* of 40,800, is designed for sending operations. In this case, the lower coefficient suggests that the variable overhead per unit of data sent is less than that of receiving. However, the higher intercept indicates a greater fixed cost, possibly due to the complexities and resources involved in preparing or dispatching data.

By using two different formulas, the model can more accurately reflect the differing nature and costs of sending and receiving data, leading to a more precise and realistic estimation of communication overhead in systems where these activities may vary in frequency, size, and complexity.

Table 3 Comparison of the amount of communication overhead

	Existing schema (SHIM 2.0)	Proposed schema
Communication combinations (α)	6,320 combinations	20 combinations
Message size combinations	30 combinations	–
Number of linear formulas (β)	–	two combinations
Number of lines for default overhead description	–	eight lines
Number of lines for individual overhead description	six lines	(β) × six lines + (α) × three lines
Number of lines for the communication overhead description	1,137,600 lines	80 lines

The error between the results calculated by the formula $Coef_{i,j} \times MS + Inte_{i,j}$ using the parameters and the actual measured values is shown in **Fig. 8**. The results demonstrate that the error was smaller when multiple linear formulas were used than when only a single linear formula was used. This is because the increase in communication overhead does not fully scale with the message size. If the error is to be further reduced, this can be achieved by setting the range to three and using three linear expressions. Thus, using multiple linear formulas improves the flexibility of the schema.

5.2.3 Description Reduction

The results of comparing the amount of description of the SHIM 2.0 and the proposed schema are shown in **Table 3** compares the amount of description. Here, the evaluation target was a Coolidge processor comprising five clusters of 80 cores. The message size ranges from 8-240 bytes (240 bytes is the upper limit of Coolidge processor) in increments of eight bytes for a total of 30 message sizes.

First, SHIM 2.0 requires all communication combinations to be described. Therefore, the number of *Communication combination* was $80 \times 79 = 6,320$ On the other hand, the proposed schema describes inter-core communication as *Defaultoverhead*; thus, only the inter-cluster communication needs to be considered, which is $5 \times 4 = 20$. Next, in SHIM 2.0, the *Message size combination* is 30. On the other hand, in the proposed schema, *The number of linear formulas* is two. In addition, since all inter-core communication is represented by default overhead, there are six lines.

Finally, *The number of lines for individual overhead description* is the calculation that yields SHIM 2.0 to be $6,320 \times 30 \times 6$ for 1,137,600 lines. In contrast, the proposed schema can be represented by $8+2*6+20\times3$ for 80 lines; thus, the proposed schema can reduce the amount of description significantly compared to SHIM 2.0, which can lessen the user's burden when creating or using the SHIM.

Table 4 Comparison of the proposed method and other methods

	MATLAB Simulink	Consider Communication	Parallel Code Generation	Estimation API Overhead	Use SHIM	Improvement SHIM
MBP for CPUs and GPUs [23]	✓	✓	✓			
HS-MBP [24]	✓	✓	✓			
MBP [10]	✓	✓	✓		✓	
RBM & DEOM [25]	✓	✓	✓		✓	
Honda et al. [13]	✓	✓		✓	✓	
Mikami et al. [26]	✓			✓	✓	✓
Kobayashi et al. [19]	✓	✓		✓	✓	✓
This paper	✓	✓	✓	✓	✓	✓

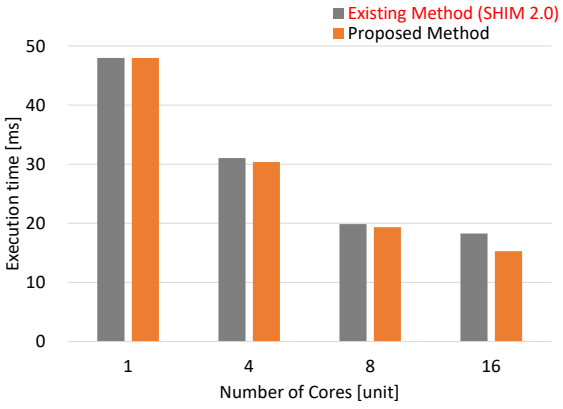

Fig. 9 Comparison of execution times for random models (constant message size).

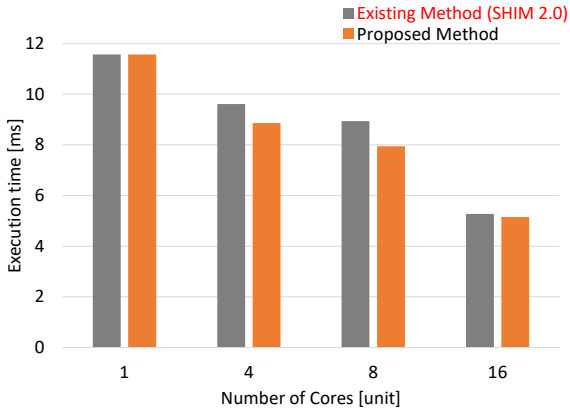

Fig. 10 Comparison of execution times for *map_callback* models.

5.3 Execution Time Evaluation in MBP with the Proposed Schema

To evaluate the usefulness of the proposed schema, a communication overhead description file is generated using the method described in Section 4, and the results of using the file in MBP are presented here. In this evaluation, a random model was generated using the functionality of SLForge [27], and a model representing a part of the actual automatic operation function was used.

First, the parallelization results when using the random model are reviewed. As shown in **Fig. 9**, the results of the execution time for core allocation use both the MBP and proposed approaches. The findings indicate that the execution time decreased when more cores were used, and the execution time was further reduced when implementing the proposed method. Specifically, with 16 cores, a speedup of 1.19 times was achieved, indicating a noteworthy improvement.

Next, the parallelization results when using the models representing a portion of the actual autonomous driving functionality are reviewed. Here, the compared model represented the *map_callback* function in the standard distribution transform [28] of Autoware.Auto. In addition, the models were data parallelized to allow parallelization, and a model of 55,000 treatments was divided into 32 parts. The execution time results for the core allocation using the conventional and proposed methods are shown in **Fig. 10**.

As can be seen, the same as the random model, the execution time is reduced as the number of cores increases, and the execution time is further reduced when the proposed method is applied. The execution time reduction for the eight-core case was less than that for the other cases; however, this was because the increase in overhead time due to the increase in the number of communications was more significant than the speedup due to parallelization. However, since the purpose of this paper is only to improve SHIM, MBP, an existing method, will not be discussed.

In this way, the proposed schema improved the results of the existing method MBP by generating a communication overhead description file. This indicates that the proposed schema is more valuable than SHIM 2.0.

6. Related Work

This section introduces the exsiting studies and compares them with this study in **Table 4**. MBP [23], linear programming (ILP)-based code parallelization for execution platforms with the same number of CPUs and GPUs, was proposed by Zhong et al. This method converts a Simulink model into a DAG and considers task allocation and communication costs to achieve speedup.

The other is HS-MBP [24], an integrated development environment for generating parallelization code and executables for FPGA-based MPSoCs (FP-HSoCs), proposed by Ryota et al. The parallelized C code is automatically generated from Simulink models and converted to a form corresponding to each PE (Processing Element) as an extension of the existing method, MBP.

MBP method for parallelizing Simulink models on heterogeneous multi-core processors was proposed by Zhong et al. [10]. First, groups the blocks hierarchically to form dozens of clusters.

In these clusters, the core allocation is performed in a mixed integer linear programming (MILP) formulation that considers load balancing. Next, block dependencies extend the Model-based parallelization method to the block level.

Two methods to minimize the makespan were proposed by Kojima et al. [25]. The Remapping Blocks Method (RBM) uses the MBP results to remap the blocks to the core. As a result, the critical path can eliminate inter-core communication while maintaining load balancing. Deciding Execution Order Method (DEOM) determines the execution order in which the entire process is completed and is faster. These methods increase the parallelism of blocks compared to conventional methods and speed up processing while distributing the load.

These studies mainly generate parallelized codes and are similar to this study. However, this study differs from existing studies in that it does not propose a parallelization code generation method and improves the input for the generation method. In addition, this study applies to existing studies using SHIM.

The method for estimating the total execution time on a many-core processor of an embedded system developed with the MATLAB/Simulink model in model-based development is proposed by Honda et al. [13]. This study measured various performance information of MPPA2-256 Bostan.

A regression analysis method to estimate the execution cycle of each instruction in LLVM-IR was proposed by Mikami et al. [26]. Two methods are used in this study. A software performance estimation method using SHIM was proposed, including an estimation formula considering finite registers. The second is to estimate the execution cycle for each LLVM-IR instruction stored in SHIM by regression analysis and improve the measurement of LLVM-IR instructions.

These studies mainly estimate the overall execution time. In this respect, this study is similar in that it computationally estimates the communication overhead.

In the previous work [19], we proposed a new schema for describing communication overhead per-API without relying on communication libraries. This approach was assessed through a detailed requirements analysis, use case studies, and instance diagram example evaluation. On the other hand, this paper shows a method to create an actual hardware SHIM based on our proposed approach, along with a method to generate a communication overhead file from this SHIM. Furthermore, the practicality of this method was confirmed by integrating the generated communication overhead file into a parallelization technique. In addition, a new partitioning method was proposed to improve the reusability of the schema further.

7. Conclusion

In this paper, a schema that can be expressed per API was proposed to solve the problem in the existing SHIM schema in terms of expressing communication overhead. The proposed schema improves the error by up to 60% compared to the existing SHIM schema by calculating the communication overhead using multiple linear expressions. In addition, the proposed schema reduces the description amount by greater than 90% compared to the existing SHIM schema by collectively describing the cores and combinations of cores on which the API operates. Moreover, the proposed schema can be incorporated into the existing SHIM schema; thus, a communication overhead description file was generated from the proposed schema and applied to the current tool. The proposed schema was applied to MBP, and the allocation algorithm for clusters achieved a speedup of up to 14%. Furthermore, an XML partitioning specification was proposed to improve the reusability of the existing SHIM schema.

In the future, based on the proposed communication description scheme, more accurate estimations are expected to be realized, which could be utilized in parallelization and contribute to the safety and real-time performance of autonomous driving.

Acknowledgment

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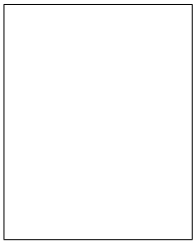

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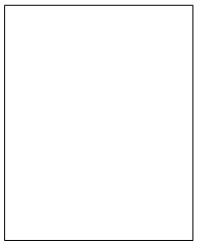
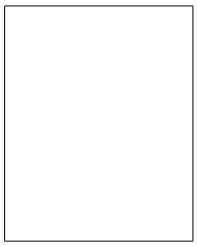
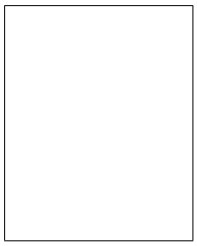


Yutaro Kobayashi is received M.E. degree in computer science from the Graduate School of Science and Engineering, Saitama University in 2023. His research interests include embedded systems and model-based development.



Hiroshi Fujimoto has been a member of Technology Headquarters in eSOL Co., Ltd, since October 2015. He is engaged in the development of parallel processing software that runs on multi/many-cores.



Takuya Azumi is a Professor at the Graduate School of Science and Engineering, Saitama University. He received his Ph.D. degree from the Graduate School of Information Science, Nagoya University. From 2008 to 2010, he was under the research fellowship for young scientists for the Japan Society for the Promotion of Science. From 2010 to 2014, he was an Assistant Professor at the College of Information Science and Engineering, Ritsumeikan University. From 2014 to 2018, he was an Assistant Professor at the Graduate School of Engineering Science, Osaka University. His research interests include real-time operating systems and component-based development. He is a member of IEEE, ACM, IEICE, and JSSST.

2024-05-20
[Journal of Information Processing]
Title: Communication Overhead Description Schema for Multi Core Processor in Model-based Development
Authors: Yue Hou, Yutaro Kobayashi, Hiroshi Fujimoto, and Takuya Azumi

Dear Editor and Reviewer,

We are pleased to resubmit our manuscript entitled "Communication Overhead Description Schema for Multi Core Processor in Model-based Development" for consideration in your esteemed journal. This submission follows a previous round of review where it received mixed feedback, including one conditional acceptance and one reject decision.

Following the insightful comments from the reviewers, we have undertaken substantial revisions to address the concerns raised.

We have emphasized our manuscript's focus on the communication overhead schema, explaining how our proposed methodology allows for faster construction and reduced descriptive complexity of the schema. Additionally, we have addressed the source of the schema files by specifying the providers or creators of the XML used.

To further clarify the choices in our methodology, we have elaborated on why we employed a linear model to describe inter-core communication overheads. Considering factors such as spatial distance, data volume, network topology, and traffic load, a multidimensional approach could capture the complexity of inter-core communications more accurately. However, implementing more complex models, such as those involving cubic equations, would increase computational costs and the complexity of the model. For many practical applications, particularly those with limited computational resources or real-time processing capabilities, simpler models may be more appropriate.

Please note that all changes made in the manuscript are highlighted in red for your ease of review. We believe these revisions comprehensively address the previous concerns and significantly enhance the value of our work. We appreciate your time and consideration in reviewing our revised manuscript and look forward to your feedback.

Yours sincerely,

Yue Hou,
Saitama University
Email address: hou.y.556@ms.saitama-u.ac.jp

1 Response to Meta-reviewer

1.1 Response to Peer Review Feedback: Addressing Non-Acceptance Reason Based on Conditional Acceptance Requirement 1 of Meta-reviewer

Comment:

As the meta-reviewer in the previous submission mentioned, the accuracy of the overhead estimation results does not rely on the schema itself but on the models for the estimation.

Suppose the authors want to show the effectiveness of the proposed schema extension for the communication overhead estimation. In that case, it is required to provide the evaluation that the schema can describe various communication models in addition to the linear model.

The linear model is naive to describe/compute communication overhead among cores/nodes that it is insufficient to show the proposed extension's effectiveness. However, the proposed schema extension supports only the linear model. Evaluating how much the proposed extension is adjustable for various overhead models will be required.

Our reply:

Thank you for your insightful comments and suggestions regarding our manuscript. We appreciate your concerns about the simplicity of the linear model used in our study to estimate communication overhead among cores/nodes. We acknowledge that a multi-dimensional approach could more accurately capture the complexities of inter-core communication by considering factors such as spatial distance, data volume, and network topology and traffic load. Indeed, these elements significantly influence communication latency in real-world scenarios. However, our choice to use a linear model in this study was deliberate, based on several key considerations:

Simplicity and Understandability: The linear model provides a clear and straightforward approach, beneficial in the initial stages of research. Its simplicity facilitates quicker iterations and validations of the proposed schema, making it easier for both developers and users to adopt during the early phases.

Practical Implementation: Implementing more complex models, such as those involving cubic equations, would increase both computational overhead and schema complexity. For many practical applications, particularly where computational resources or real-time processing capabilities are limited, a simpler model may be more appropriate.

And we revised the article to clarify the problem points and specific solutions we hoped to address with our proposal approach. Also, in the evaluation section, it is made clear why linear equations are used to describe the inter-core communication delays, and the significance of each parameter is explained in detail. Meanwhile the experimental results show that using our proposal approach, not only can we achieve a higher accuracy of inter-core delay estimation, but also can greatly reduce the amount of description and make it easy to use. We hope this response clarifies our modeling choice. We remain committed to exploring more comprehensive models in future work to enhance the predictive accuracy and applicability of our schema.

Adjusted sentences in the "Introduction" section (Section 1)

The latest version of SHIM [14] currently still lacks an efficient method to describe inter-core communication latency, which poses significant challenges. This deficiency leads to substantial inaccuracies in time predictions within the Model-based Parallelizer (MBP) due to the omission of inter-core communication latency calculations. Furthermore, the lack of a concise communication description necessitates extensive documentation of latency between cores, resulting in increased number of lines for the communication overhead description to more than ten thousand lines.

Adjusted sentences in the "Introduction" section (Section 1)

To address these issues, a revised schema is proposed that measures communication overhead in per-API units for more precise estimates and also simplifies the schema's structure to reduce its volume. This enhancement facilitates ease of use and construction, allowing for a more accurate and comprehensive representation of communication overhead. Additionally, it improves the reliability and efficiency of performance evaluations in multi-core environments.

Adjusted sentences in the "Evaluation" section (Section 5.2.2)

In the given scenario, two separate linear equations are utilized to approximate the communication overhead for sending and receiving operations, respectively. This differentiation is crucial because the processes involved in sending and receiving data often have distinct characteristics and resource requirements, which can significantly impact communication overhead. The first linear equation, with a $Coefficient$ of 48.5 and an $Intercept$ of 12,999, is used to estimate the overhead for receiving operations. The coefficient here likely represents the incremental overhead per unit of data received, while the intercept might account for fixed costs associated with initiating or terminating a receive operation. The second linear equation, with a $Coefficient$ of 20.0 and an $Intercept$ of 40,800, is designed for sending operations. In this case, the lower coefficient suggests that the variable overhead per unit of data sent is less than that of receiving. However, the higher intercept indicates a greater fixed cost, possibly due to the complexities and resources involved in preparing and dispatching data.
By using two different formulas, the model can more accurately reflect the differing nature and costs of sending and receiving data, leading to a more precise and realistic estimation of communication overhead in systems where these activities may vary in frequency, size, and complexity.

1.2 Response to Peer Review Feedback: Addressing Non-Acceptance Reason Based on Conditional Acceptance Requirement 1 of Meta-reviewer

Comment:

> Regarding the usability and reusability for the users, I do not think the number of descriptions to be written in the XML files becomes a problem because processor vendors or software tools would provide the information/files. The authors should explain the SHIM use cases while clarifying by whom and how the XML files are provided to discuss usability/reusability.

Our reply:

> Thank you for your insightful feedback on our manuscript. We appreciate the time and effort you have taken to review our work. Regarding your comment on the usability and reusability of the SHIM XML files, we have added explanations in the manuscript to address the concerns about the source of these schemas.
>
> The creation of SHIM XML files by hardware providers is indeed essential for the effective usage of software tools. However, it is important to note that not all hardware providers supply these XML files, which can limit the adoption of certain hardware. To mitigate this issue, we propose the use of freely available reference authoring tools, along with detailed specifications. These tools enable users who have access to technical manuals and hardware (such as simulators or evaluation boards) to generate SHIM XML files for most multi-core and many-core systems. This approach significantly enhances the accessibility and integration of SHIM XML, making it easier for users to adopt and utilize the hardware effectively.
> We hope this clarification addresses your concerns regarding the usability and reusability of the SHIM XML files.

Added sentences in the "SHIM" section (Section 2.1)

The creation of SHIM XML by hardware providers is essential for software tool usage, yet not all providers supply this XML. This limitation could hinder hardware adoption. To address this, freely available Reference authoring tools, accompanied by specifications, allow users with access to technical manuals and hardware (such as simulators or evaluation boards) to generate SHIM XML for most multi-many-core systems, thus enhancing accessibility and integration.

2 Response to 1st reviewer

2.1 Response to Peer Review Feedback: Addressing Non-Acceptance Reason Based on Conditional Acceptance Requirement 1 of reviewer 1

Comment:

> I have understood the differences from the existing SHIM 2.0 method sufficiently.
> However, it is believed that novelty and utility are not sufficiently demonstrated compared to general parallelization frameworks or parallelization methods.
> Please demonstrate the significance of methods that take into account this communication overhead, not limited to MBD methods.

Our reply:

> Thank you for your insightful feedback on our manuscript. We appreciate the time and effort you have taken to review our work.
> We understand your concerns regarding the novelty and utility of our methods compared to general parallelization frameworks or parallelization methods. Our research primarily focuses on optimizing the schema for describing inter-core communication latency, rather than on parallelization itself. In our paper, we have not discussed the utility of parallelization or its impact on parallelization performance. Instead, our study is dedicated to simplifying the description of communication latency within the schema. Traditional methods for describing latency can be extremely verbose, often requiring tens of thousands of lines. Our approach significantly reduces the complexity and volume of these descriptions, providing a more efficient and streamlined schema representation. We believe this clarification highlights the novelty and utility of our work. By reducing the descriptive burden and improving the accuracy of execution time estimates, our method offers substantial improvements in the field of schema optimization. We hope this addresses your concerns and underscores the significance of our contributions within the intended scope.

We have address the problems and proposed method in SHIM 2.0 in the "Introduction" section. We have also added references to the latest version of SHIM by citation [13], in the hope of showing that the problems we've mentioned haven't yet been solved in the latest version of SHIM.

Adjusted sentences in the "Introduction" section (Section 1)

> The latest version of SHIM [14] currently still lacks an efficient method to describe inter-core communication latency, which poses significant challenges. This deficiency leads to substantial inaccuracies in time predictions within the Model-based Parallelizer (MBP) due to the omission of inter-core communication latency calculations. Furthermore, the lack of a concise communication description necessitates extensive documentation of latency between cores, resulting in increased text volume that complicates data importation and editing.

[14] IEEE-Standard-Association, "SHIM 2.0," https://www.document-center.com/standards/show/IEC-63504-2804

Adjusted sentences in the "Introduction" section (Section 1)

To address these issues, a revised schema is proposed that measures communication overhead in per-API units for more precise estimates and also simplifies the schema's structure to reduce its volume. This enhancement facilitates ease of use and construction, allowing for a more accurate and comprehensive representation of communication overhead. Additionally, it improves the reliability and efficiency of performance evaluations in multi-core environments.

2.2 Response to Peer Review Feedback: Addressing Non-Acceptance Reason Based on Conditional Acceptance Requirement 2 of reviewer 1

Comment:

Despite not appearing to be related to papers on autonomous driving, I feel a sense of discomfort with the use of "autonomous driving system" at the beginning of the Abstract and Introduction.

Our reply:

Thank you for your insightful feedback on our manuscript. We have carefully considered your comment regarding the use of "autonomous driving system" at the beginning of the Abstract and Introduction. We understand your concern and would like to clarify the relevance of this context to our research.

In the field of autonomous driving, Simulink is frequently used for simulation and modeling. As autonomous driving systems become increasingly complex, Model-based Development (MBD) is being progressively adopted in system development. The use of Simulink in MBD development is also becoming a growing trend. Our research focuses on task parallelization within the context of MBD, which is highly relevant to the development of autonomous driving systems. Therefore, we believe that referencing autonomous driving systems at the beginning of the Abstract and Introduction helps to set the context and underline the applicability of our work.

We hope this explanation addresses your concerns and clarifies the significance of our research in the context of autonomous driving system development.

Added sentences in the "Abstract"

Autonomous driving systems require a wider range of functionalities than traditional embedded systems, making Model-based Development (MBD) with MATLAB/Simulink essential. This approach allows early simulation and validation, enhancing safety and reducing development time. At the same time, the real-time requirements of multi-tasking for autonomous driving cannot be ignored.

Added sentences in the "Introduction" section (Section 1)

In development of these systems, Model-based Development (MBD) has raised for its functionalities such as early simulation, and validation [3,4]. Furthermore, low power consumption is also required to enable installation in automobiles. Thus, more comprehensive functions are required than those of conventional embedded systems [5]. To meet these requirements, many-core processors are being adopted. Many-core processors offer high computational performance and energy efficiency [6-8]. Efficient utilization of these processors, however, necessitates understanding their complex specifications, which can extend development times.

[3] MathWorks. Automated Driving Toolbox. https://jp.mathworks.com/products/automated-driving.html

[4] Miura, Keita and Tokunaga, Shota and Ota, Noriyuki and Tange, Yoshiharu and Azumi, Takuya, "Autoware toolbox: Matlab/simulink benchmark suite for ros-based self-driving software platform," In *Proceedings of the 30th International Workshop on Rapid System Prototyping (RSP)*, pp. 8–14, 2019

Adjusted sentences in the "Introduction" section (Section 1)

In MBD, MATLAB/Simulink is noted for its automatic C code generation from models, but it does not support parallelized code generation [9]. Addressing this, the Embedded Multicore Consortium's Model-based Parallelizer (MBP) facilitates the automatic generation of parallelized C code. This integration streamlines simulation and code generation for multi-many-core processors, enhancing development efficiency. Utilizing SHIM (Software-Hardware Interface for Multi-Many-Core) to abstract essential processor information minimizes the reliance on physical hardware [10-13].

2.3 Response to Peer Review Feedback: Addressing Non-Acceptance Reason Based on Conditional Acceptance Requirement 3 of reviewer 1

Comment:

Is the proposed method only effective for Karlay MPPA3-80? Additionally, is there a specific reason for targeting Karlay MPPA3-80?

Our reply:

Thank you for your insightful feedback on our manuscript. We appreciate the time and effort you have taken to review our work.

We have carefully considered your comment regarding the effectiveness of the proposed method for the Kalray MPPA3-80 and the reason for targeting this specific processor. In the field of autonomous driving, our research focuses on task parallelization within Model-based Development (MBD). Autonomous driving systems have higher demands on device performance, power consumption, and other factors compared to traditional systems. The availability of devices equipped with multi-core processors that meet these stringent requirements is limited. The Kalray MPPA3-80 is one of the few processors that satisfy these criteria, making it an ideal target for our study.

Furthermore, we would like to emphasize that our proposed method is not dependent on the Kalray MPPA3-80 and can be applied to other devices as well. This flexibility underscores the broad applicability of our method across different hardware platforms. We have added a clarification on this point in the main text to ensure that the method's adaptability is clear.

We hope this explanation clarifies our choice and demonstrates the broader applicability of our method.

Added sentences in the "Evaluation" section (Section 5)

Additionally, it is important to note that the proposed method is not dependent on the Kalray MPPA3-80 and can be applied to other devices as well, including RISC-V multi-core processors such as the P870 and the P870-A provided by SiFive [21,22].

[21] Chishiro, Hiroyuki and Suito, Kazutoshi and Ito, Tsutomu and Maeda, Seiya and Azumi, Takuya and Funaoka, Kenji and Kato, Shinpei, "Towards Heterogeneous Computing Platforms for Autonomous Driving," In *Proceedings of IEEE International Conference on Embedded Software and Systems (ICESS)*, pp. 1–8, 2019

[22] SiFive. SiFive Performance P870/P870A. https://www.sifive.com/cores/performance-p870-p870a.

3 Response to 2nd reviewer

3.1 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 1 of Reviewer 2

Comment:

I cannot catch the originality or novelty for the idea behind proposed method.

Our reply:

Thank you for your detailed feedback and critical observations regarding our manuscript. We acknowledge the concerns raised about the originality and clarity of the proposed method and its significance compared to the existing schema such as SHIM 2.0. The novelty of the our proposed method is that we proposed a new schema to describe inter-core communication overhead.

Adjusted sentences in the "Introduction" section (Section 1)

To address these issues, a revised schema is proposed that measures communication overhead in per-API units for more precise estimates and also simplifies the schema's structure to reduce its volume. This enhancement facilitates ease of use and construction, allowing for a more accurate and comprehensive representation of communication overhead. Additionally, it improves the reliability and efficiency of performance evaluations in multi-core environments.

3.2 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 2 of Reviewer 2

Comment:

> I cannot understand what is the research problem to be solved in this paper. While the authors claim "a schema that can be expressed per API was proposed to solve the problem in the existing SHIM" in Conclusion, the problem itself is not clear at least for me.

Our reply:

> Thank you for your detailed feedback and critical observations regarding our manuscript. The problem is that the previous approach covers only the communication aspect and does not account for processes required for communication such as memory access and the acquisition of IDs for sending and receiving. Thus, the problem lies in the underestimation of communication overhead during estimation. And the lack of a concise description requires extensive documentation of the delay between cores, leading to a much larger description of the communication overhead. We have adjusted the sentences in the "Introduction" section to clarify the issue of SHIM 2.0.

Adjusted sentences in the "Introduction" section (Section 1)

The latest version of SHIM [14] currently still lacks an efficient method to describe inter-core communication latency, which poses significant challenges. This deficiency leads to substantial inaccuracies in time predictions within the Model-based Parallelizer (MBP) due to the omission of inter-core communication latency calculations. Furthermore, the lack of a concise communication description necessitates extensive documentation of latency between cores, resulting in an increase of more than ten thousand lines for the communication overhead description.

3.3 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 3 of Reviewer 2

Comment:

> In the first review, the meta reviewer mentioned that "Again, the performance improvement is due to the communication overhead estimation method (equation), not the schema representation. This paper does not have enough consistency among the objectives, methods, and evaluations." I feel this observation is very critical for this paper. The meta reviewer also mentioned that "This is not a problem with the schema but a problem with the overhead estimation method." However, the current form of the revised paper did not explain the reason why the proposed schema contributes to reducing the communication overhead.

Our reply:

> Thank you for your detailed feedback and critical observations regarding our manuscript. First, we need to clarify that our proposed approach does not reduce the inter-core communication overhead. The contribution of our proposed method has two main aspects. On the one hand, it imports the inter-core communication overhead and thus reduces the error in the execution time prediction. On the other hand is the ability to greatly reduce the notation of the description file using our description method, thus facilitating import and editing.
>
> In order to make our goal, methodology, and evaluation clearer, we have adjusted the composition and syntax of some parts of the article in the hope of better demonstrating the usefulness of our proposed methodology.

Adjusted sentences in the "Introduction" section (Section 1)

The latest version of SHIM [14] currently still lacks an efficient method to describe inter-core communication latency, which poses significant challenges. This deficiency leads to substantial inaccuracies in time predictions within the Model-based Parallelizer (MBP) due to the omission of inter-core communication latency calculations. Furthermore, the lack of a concise communication description necessitates extensive documentation of latency between cores, resulting in increased number of lines for the communication overhead description to more than ten thousand lines.

Adjusted sentences in the "Introduction" section (Section 1)

To address these issues, a revised schema is proposed that measures communication overhead in per-API units for more precise estimates and also simplifies the schema's structure to reduce its volume. This enhancement facilitates ease of use and construction, allowing for a more accurate and comprehensive representation of communication overhead. Additionally, it improves the reliability and efficiency of performance evaluations in multi-core environments.

Adjusted sentences in the "Evaluation" section (Section 5.2.2)

In the given scenario, two separate linear equations are utilized to approximate the communication overhead for sending and receiving operations, respectively. This differentiation is crucial because the processes involved in sending and receiving data often have distinct characteristics and resource requirements, which can significantly impact communication overhead. The first linear equation, with a $Coefficient$ of 48.5 and an $Intercept$ of 12,999, is used to estimate the overhead for receiving operations. The coefficient here likely represents the incremental overhead per unit of data received, while the intercept might account for fixed costs associated with initiating or terminating a receive operation. The second linear equation, with a $Coefficient$ of 20.0 and an $Intercept$ of 40,800, is designed for sending operations. In this case, the lower coefficient suggests that the variable overhead per unit of data sent is less than that of receiving. However, the higher intercept indicates a greater fixed cost, possibly due to the complexities and resources involved in preparing and dispatching data.
By using two different formulas, the model can more accurately reflect the differing nature and costs of sending and receiving data, leading to a more precise and realistic estimation of communication overhead in systems where these activities may vary in frequency, size, and complexity.

3.4 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 4 of Reviewer 2

Comment:

> Actually, the communication overhead is calculated by the formula $Coef_{i,j} * MS + Inte_{i,j}$ as shown in Line 17 of Algorithm 1. This is an estimation and there is no discussion why the extention of the exisitng schema is required. This is why I judge this paper did not fulfill the requirements of the 1st review by the meta reviewer.
>
> Additionally, I cannot catch what is the essential point of the algorithm uniquely proopsed by the authors. What is the originality and novelty of this paper? To help readers understand the novelty, the authors should compare the algorithms for the case without proposed schema. This means that the authors should describe how the communication overhead is estimated in the existing schema (SHIM 2.0). Also, the authors should highlight the differences from the extended SHIM in [16] because Table 4 implies the different extension from this paper.

Our reply:

> Thank you for your detailed feedback and critical observations regarding our manuscript. First of all, our goal is to achieve a higher precision estimation as well as a simpler way to describe it, so we propose a linear equation to describe the inter-core communication overhead. Existing models lack a simple way of describing the inter-core communication overhead, or require tens of thousands of lines to describe the inter-core communication overhead.

Adjusted sentences in the "Introduction" section (Section 1)

The latest version of SHIM [14] currently still lacks an efficient method to describe inter-core communication latency, which poses significant challenges. This deficiency leads to substantial inaccuracies in time predictions within the Model-based Parallelizer (MBP) due to the omission of inter-core communication latency calculations. Furthermore, the lack of a concise communication description necessitates extensive documentation of latency between cores, resulting in increased text volume that complicates data importation and editing.

Adjusted sentences in the "Introduction" section (Section 1)

To address these issues, a revised schema is proposed that measures communication overhead in per-API units for more precise estimates and also simplifies the schema's structure to reduce its volume. This enhancement facilitates ease of use and construction, allowing for a more accurate and comprehensive representation of communication overhead. Additionally, it improves the reliability and efficiency of performance evaluations in multi-core environments.

Adjusted sentences in the "Evaluation" section (Section 5.2.2)

In the given scenario, two separate linear equations are utilized to approximate the communication overhead for sending and receiving operations, respectively. This differentiation is crucial because the processes involved in sending and receiving data often have distinct characteristics and resource requirements, which can significantly impact communication overhead. The first linear equation, with a $Coefficient$ of 48.5 and an $Intercept$ of 12,999, is used to estimate the overhead for receiving operations. The coefficient here likely represents the incremental overhead per unit of data received, while the intercept might account for fixed costs associated with initiating or terminating a receive operation. The second linear equation, with a $Coefficient$ of 20.0 and an $Intercept$ of 40,800, is designed for sending operations. In this case, the lower coefficient suggests that the variable overhead per unit of data sent is less than that of receiving. However, the higher intercept indicates a greater fixed cost, possibly due to the complexities and resources involved in preparing and dispatching data.
By using two different formulas, the model can more accurately reflect the differing nature and costs of sending and receiving data, leading to a more precise and realistic estimation of communication overhead in systems where these activities may vary in frequency, size, and complexity.

3.5 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 5 of Reviewer 2

Comment:

Furthermore, the quality of English used in this paper is poor and it is very hard for reader to understand the body of contents. I think this paper is not valuable to readers.

Our reply:

Thank you for your feedback. I would appreciate it if you could specify multiple points regarding the aspects of the English language that need improvement.

Please note that I have previously used the advanced editing service from Enago for this manuscript, which includes checks by native English speakers in the field of computer science. The service covered:

- Language (expressions, grammar, etc.)
- Academic phrasing
- Formatting adjustments to meet submission guidelines
- Technical accuracy
- Academic writing style
- Paper structure
- Logical flow of arguments

For reference, here is the link to the service I used:
https://www.enago.jp/advanced-editing

Given this, I would be grateful for detailed feedback on how I can further improve the quality of the English in the paper.

3.6 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 6 of Reviewer 2

Comment:

I wonder why the Parts for ComponentSet and CommunicationSet, which could be seen in the title of the sub-sub-section, did not appear in Figure 1 as seen in the title of the other sub-sub-section.

Our reply:

Thank you for your insightful comments and suggestions regarding our manuscript. In response to the review, we have updated Figure 1 to include the parts for ComponentSet and CommunicationSet. We also made minor modifications to the original system model and have clarified once again that our proposal builds upon the existing SHIM framework. We appreciate your insightful comments which have guided these enhancements. Thank you for helping us improve our work.

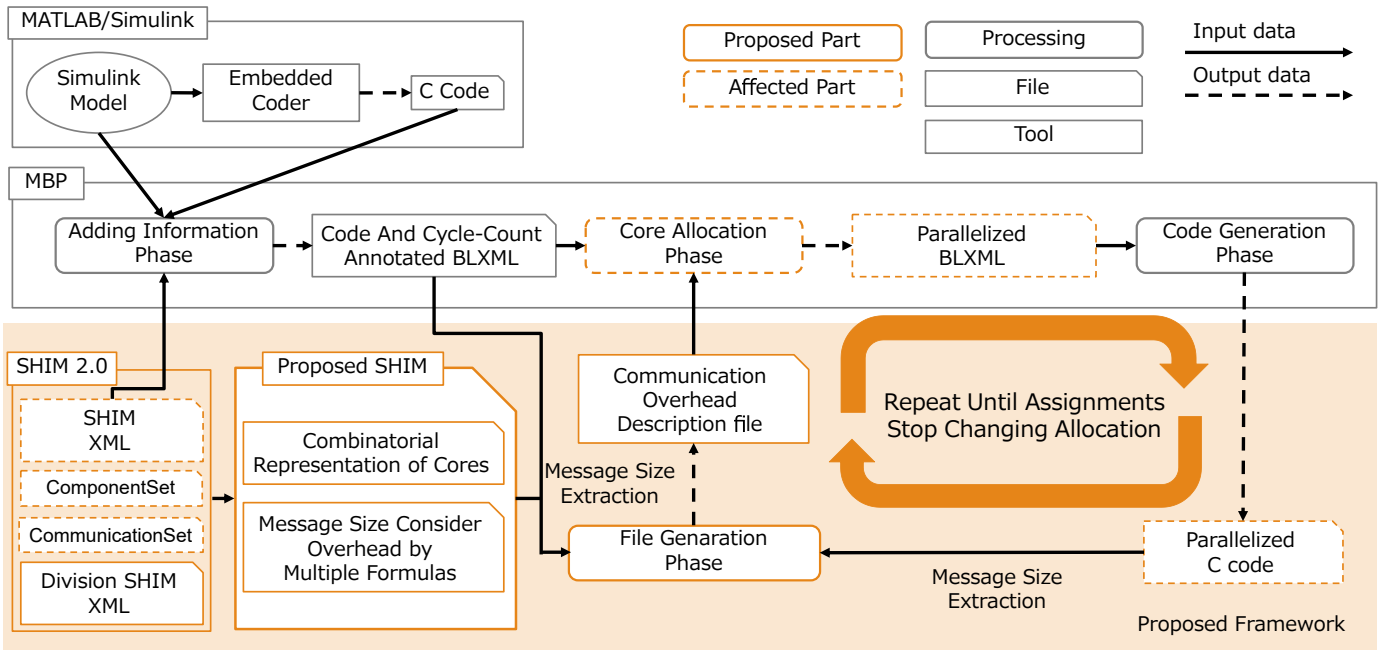


Fig.1 System model.

3.7 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 7 of Reviewer 2

Comment:

> I cannot catch the discussion about multiple linear formulas in Section 5.2.2. In my understanding, all the authors show is a formula $Coef_{i,j} * MS + Inte_{i,j}$ of Algorithm 1 and this corresponds to the single linear formula. How about multiple linear formulas? The authors should present the actual equations to describe it.

Our reply:

> Thank you for your insightful comments and suggestions regarding our manuscript. We apologize for any confusion caused by our initial lack of detailed description. To address this, we have expanded the discussion in Section 4.1 of our paper to better explain the choice of the model used in Algorithm 1 and the significance and importance of each parameter.
>
> In Section 4.1, we clarify why this particular model was selected to describe the inter-core communication overhead. Furthermore, regarding your query about the multiple linear equations mentioned in Section 5.2.2, these are necessary because the inter-core communication involves both *send* and *receive* processes. Both processes are described using the linear models previously mentioned in Section 4.1. We hope this response addresses your concerns and clarifies our choice of modeling approach.

Adjusted sentences in the third paragraph of Section 4.1

In Line 3, initialize a $N \times N$-sized matrix A. Each entry $A_{i,j}$ in this matrix represents the overhead of communication from core i to core j. This matrix format allows for a structured representation of communication costs across all core pairs, facilitating efficient calculation and data management. In Line 8, there is no communication between the same cores ($i = j$). Therefore, the overhead is calculated as zero. This assumption simplifies the model by eliminating unnecessary calculations for non-existent self-communications.

Adjusted sentences in the forth paragraph of Section 4.1

Lines 9-16 obtain the parameters needed to calculate the communication overhead between the different cores ($i \neq j$); from the elements corresponding to Link and MS, the coefficients and intercepts are obtained. The coefficient in this context quantifies the incremental increase in communication overhead per unit increase in message size or other relevant metric. The intercept represents the baseline overhead associated with establishing a communication link, irrespective of the data quantity being transmitted.

Adjusted sentences in the fifth paragraph of Section 4.1

The coefficients $Coef_{i,j}$ represent the incremental delay or overhead added per unit of message size or other scaling factor, while the intercept $Inte_{i,j}$ represents the baseline overhead that exists even when no data is being transmitted. Calculate the communication overhead using the coefficients and intercept obtained in Line 17. It is particularly useful for quickly estimating communication overheads in complex multi-core systems where direct measurement for every possible communication scenario would be impractical.

3.8 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 8 of Reviewer 2

Comment:

> Additionally, what is the advantages for applying the proposed method to the actual applications? The authors should provide some evidences that make clear that the accuracy of estimation of communication overhead reflects to the gain of parallelization.

Our reply:

> Thank you very much for your insightful feedback on our manuscript. We sincerely appreciate the time and effort you have taken to review our work. We apologize for any confusion caused by the way our manuscript may have suggested improvements in parallelization precision. Our primary focus is on schema optimization, specifically aimed at reducing the complexity and volume of descriptions as well as improving the accuracy of execution time estimates.
>
> Accurate estimation of communication overhead is essential for determining core allocation, which is a crucial requirement in embedded systems. As demonstrated in our evaluation (Figure 8), our proposed method significantly enhances estimation accuracy. Regarding your concerns about commercial tools, we recognize that they are often black boxes that make it difficult for us to do more in-depth work or research. And enhanced parallelization tools are a separate area of research. We will consider this issue in our future work and incorporate it into our future research directions.

Adjusted sentences in the "Abstract"

Experimental results show at least a 97.9% improvement in accuracy for estimating communication overhead, over 90% reduction in schema description, and a significant reduction in execution time with our schema.

Adjusted sentences in the "Introduction" section (Section 1)

- This paper shows improvement in results by generating a communication overhead description file with an appropriate message size and using it in existing estimation methods. It demonstrates that the average improvement rate in the error of the estimated communication overhead is at least 97.9%.
- This paper proposes a new XML split specification to reduce the amount of description and the description of cores and combinations of cores by more than 90%, to reduce the burden on the users of SHIM.

Added sentences in the "Conclusion" section (Section 7)

In the future, based on the proposed communication description scheme, more accurate estimations are expected to be realized, which could be utilized in parallelization and contribute to the safety and real-time performance of autonomous driving.

3.9 Response to Peer Review Feedback: Addressing Non-Acceptance Reason 9 of Reviewer 2

Comment:

In Section 6: In the previous work [12] $->$ [16] It is unclear whether the this paper in the sentence "this paper shows a method to create an actual hardware SHIM based on our proposed approach" indicate [16] or the currently submitted paper.

Our reply:

Thank you for your diligent review and insightful feedback on our manuscript. We appreciate the time and effort you have taken to review our work. We apologize for the confusion regarding the citation in Section 6. Reviewer 2's comment is correct that there was an error in our reference. The current correct citation should be [19], indicating the previously published work. We have revised the manuscript to reflect this correction. Thank you once again for your valuable feedback. We hope this clarification resolves the issue.

Added sentences in the "Conclusion" section (Section 7)

In the previous work [19], we proposed a new schema for describing communication overhead per-API without relying on communication libraries.