XTP specification and validation with LOTOS

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ABSTRACT
The validation is a very important phase in the development cycle of communication protocols. This activity is frequently accomplished by a reachability analysis. In this paper, we are interested in the study of the XTP protocol that constitutes a new high speed transport protocol standardized by ISO. The objective is to detect different types of logic errors, before implementation phase, such as deadlock, unspecified reception and boundedness. To specify and verify XTP protocol, we use two formal models, the communicating finite state machine (C.F.S.M) to describe the behaviour of11we external transitions and the formal description language LOTOS to study the global behaviour of internal executions between XTP endpoints. In the first model, we validate this protocol by using ValiPro tools. The use of C.F.S.M is to prove the correctness of XTP global behaviour. In the second model, we use LOTOS for studing the protocol data transmission level. So, we present two implementation strategies for data transmission mechanisms which will act on the user data transfer. The choice of moment for sending control packet and its transmission frequency will play a very role in state space level of the reachability tree. To supervise data transmission mechanism and transfer control packets, we propose an implementation method for XTP Timers.

1. Introduction

The new High-Speed Networks based on optic fibers allow to integrate different types of applications such as data transfer, voice and video [ALK. 93]. The integration of different types of services in the same application on the same network and the nature of the application induce specific requirements such as quality of service (QoS), High throuput and low delay [TAN. 92].
To satisfy these requirements, two approaches are available [WIL. 90] :

- Implement existing protocols in order to minimize the processing time of data control and to increase the transmission performances. Effectivelly, the first work in this way had been concentrated on standards transmission control protocols as TCP [POS. 81] and TP4 [REC. 84a]. The implementation of these protocols did not display high and good perfornances even in the context of local area networks [CHE. 87, DAB. 87, HEA. 89, MEI. 87].
- Design new protocols with mechanism specifically architectured for High bandwith, low delay and low errors rate communication like XTP (Xpress Transfert Protocol) [PEI. 92] and VMTP (Versatile Message Transaction Protocol) [CHE. 88].

Our goal in this paper is to study the XTP protocol that represents one of the new transport protocols within ISO.

Otherwise, the protocol conception becomes more difficult. In order to detect the logic errors such as deadlock, unspecified reception and boundedness, it is necessary to verify results after the specification and before the implementation phase.

In general, a communication protocol specification can be accomplished with a formal model. The modelisation tools can be graphics such as Petri Nets [MER. 71, DAN. 80], communicating finite state machine [BOC. 78, ZAF. 78] or as programming language such as LOTOS [LAG. 89], Estelle [BUD. 87], Promela [HOL. 91]. However, in this paper, we are based on communicating finite state machine to describe the global XTP behaviour and on LOTOS to study the protocol data transmission level. Thus, we present two implementation strategies for data transmission mechanism [ALK. 93], and we propose an implementation for XTP Timers used by the XTP protocol for synchronization, and both control flow and errors.

The rest of this paper is organized as follow. The section 2 presents a study of XTP protocol as well as different types of packets that constitute the protocol. The section 3 is devoted to XTP specification and validation using communicating finite state machine model. In section 4, we present XTP specification and validation by using the programming language LOTOS. Finally, concluding remarks are given in section 5.

2. XTP protocol

In Classical transport protocols like TCP or TP4, the bottelneck problem is located at receiver entity, that manages a set of timers to acknowladege and supervise the flow control. To reseolve this problem, XTP tilts over a party of control fonctions (errors and flow control) from the receiver to the transmitter, that rediuces the timers number. However, the XTP transmitter must periodically request the receiver state information to supervise and to manage the association. So, two simplifications of the receiver have been proposed in [CHE. 87] :

- reduction of the number of receiver Timers (only one Timer for releasing association);
- generation of control messages only as response of transmitter request.

2.1. XTP protocol structure

In XTP, seven packets types, using a fixed header syntax, provide exchange mechanisms for both Information and Control in an association between a transmitter and a receiver. Some of them are using exclusively in Control Segment in order to generate control messages, while others in Information Segment for data transfer [FOR. 95].

- Control Segment

The Control Segment reports the state of the context that sent it. XTP packets containing a Control Segment, as their payload, are referred to as control packet.

The Control Segment is included in CNTL, ECNTL, and TCNTL packets. The CNTL packet conveys control information such as flow control window values through the Common Control segment. The ECNTL packet additionally conveys error control information through its Error Control segment. The TCNTL packet is used to negociate a traffic specification by its Traffic Control segment. These three packet types are responsible for state information exchanges between contexts.

- Infromation Segment

The Infomation Segment contains the user data and diagnostic information. XTP packets containing an Information Segment, as their payload. This segment contains higher layers data or transport layer messages. Four packets use this Information Segment. The FIRST packet is the initial packet of an association and contains an Address Segment, a Traffic Specifier, and optionally a Data Segment. DATA packets are used for subsequent data transfer and contain only Data Segment. The FIRST and DATA packets are the two packet types responsible for user data transfer. The JOIN packet is used to join an in-progress multicast association. Its format is the same as a FIRST packet without the optional Data Segment. Finally, the DIAG packet uses a Diagnostic Segment to convey diagnostic information such as the destination has not received a packet.

2.2. XTP Timers

There are four timers that facilitate the protocol's control procedures [FOR. 95]. Lost packets are discovered using the WTIMER. A lost association is discovered using the CTIMER.

The CTIMEOUT timer monitors a synchronizing handshake limiting the length of time the handshake is attemped. When a control packet is sent, its *sync* field value is saved in the "saved_sync" variable, and the WTIMER is armed. If the WTIMER expires before a control packet arrives whose *echo* field value is equal the value in "saved_sync", the context enters into the synchronization handshake procedure, and the CTIMOUT is started. The objective is to probe the receiver with control packets at exponentially increasing time intervals until there is a successful handshake, or the CTIMOUT expires and the association is aborted. No data-bearing packets are allowed to be sent during synchronization handshake, including retransmitted data; retransmission may proceed once the handshake has completed.

The RTIMER is the rate control timer used to govern the frequency of sending bursts of data. Rate control governs the producer-consumer relationship between XTP endpoints. Rate control is concerned with how fast packets and their contents can be processed, or consumed, at the receiver.

The output packet rate is regulated by two contexts fields that are *rate* and *burst* of Traffic Specification Segment. The *rate* value specifies the maximum data rate in bytes per second. The *burst* value specifies the maximum number of bytes to be sent in a burst of packets. The *burst* value devided by the *rate* value gives the time period for RTIMER.

The WTIMER is the timer that guards against the loss of a packet with the SREQ bit set. Whenever, a packet is sent with the SREQ bit set, the transmitter increments his "saved_sync" value by one and places it into the *sync* field of the packet. The context sending the packet with the SREQ bit set also arms his WTIMER. The WTIMER is the amount of time that the transmitter will wait for the arrival of the control packet as response at his request.

The CTIMER is the timer that ensures that the other endpoint of the association is still alive. When a context becomes active, the CTIMER is armed. If the CTIMER expires and there are data to transfer, the CTIMER is reloaded. And if there are no data to transfer, the CTIMER is reloaded and the context enters into a synchronizing handshake to ensure that there is no data to transmit or retransmit.

3. Communicating finite state machine

3.1. Presentation

A communication protocol specification can be accomplished with one of formal models. In spite of the difference of the formal models, the common technique used for verification of a communication protocol is the reachability analysis. This generates all accessible global states from an initial global state constituting a reachability graph. Each global state is constituted by locals states of process that compose the system and the contents of communication channels.

The major problem of the reachability analysis is the state space explosion. Several reduction methods have been developped for state space reduction, for example [BEN. 94] uses a technique based on suppression of redundancy sequences.

Some logical errors can be detected by the reachability analysis, and are defined in the following :

- A deadlock state is a global stable state where all communicating finite state machines are in receiving state.
- A blocking reception state occurs when at least one communicating finite state machine is in receiving state and it cannot receive any message.
- An unspecified reception is a reception that is executable but not specified.

- A reception is noexecutable if and only if it is specified and not executable.
- For a bounded system, an emission is noexecutable if and only if its execution introduces an overflow.

3.2. XTP specification and validation

In this section, we are interested in the study of XTP specification using communicating finite state machines. This model can be seen as a preliminary step before the XTP implantation with LOTOS. For this, we used ValiPro (Validation Protocols) [BEN. 96] as tool for modeling, simuling and testing communcation protocols. This tool allows to validate systems composed of an arbitrary of communicating finite state machine's in the limit of the available memory size. It allows to detect logical errors such as deadlocks, blocking reception and capacity overflow. The communcation medium from one process to another is assumed to be error-free. A send event causes a message to enqueued in a FIFO channel, while a receive event dequeues a message from a channel.

Based on the separate description of processes and data, ValiPro allows the modularity and provides several validation techniques. We briefly present the diffrent techniques implemented under and which are :

- the classical reachability analysis which is a reference in comparaison with the other techniques. It gernerates exhaustively all states from a given initial global state. Its main characteristic lies in the fact that we execute only one action which allows the passage from a global state to another. This technique detects diffrent types of logical errors such as deadlock and unspecified reception.
- the optimal classical technique which mainly consists in the reducing the search time of state among the which already exist a computed address. It generates the same state space as the classical technique.
- the reduction method of the reachability analisys is a method of parallel execution of actions, permitting reduction of the reachable state space. The main of this technique is based on suppression of redundanty sequences.

So, XTP endpoints will be modeled by a system of two finite state automatas, and we suppose that the channels connecting both automatas are unidirectionnels, reliables and FIFO. The initial state for both automatas is represented by "Close" state in figures 3.1, 3.2, 3.3, and 3.4. The following conventions are used : the "?" prefix corresponds at reception messages and "!" at transmission messages.

The transmitter can transmit :
- !FIRST : establishement association request.
- !DATA : data transfer.
- !TCNTL : traffic specification or traffic modification.
- !WCLOSE : end of data transmission
- !DIAG : association reject.
- !CNTL : association common control.
- !END : association release.

and can receive :
- ?CNTL : acknowledgement request.
- ?ECNTL : retransmission request.
- ?TCNTL : traffic specification or traffic modification.
- ?DIAG : association reject.
- ?output : transmission request.
- ?RCLOSE : acknowledgement of end of transmission.
- ?END : deconnection.

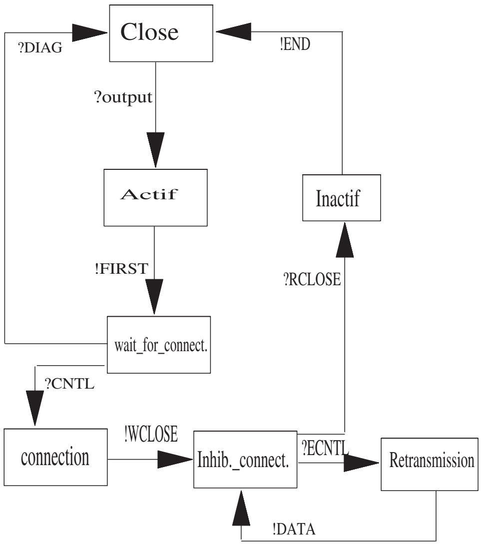

figure 3.1. Association establishement procedure of transmitter viewpoint

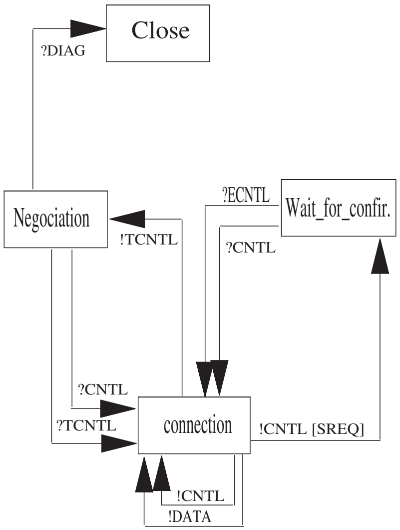

figure 3.2. Data transfert control procedures of transmitter viewpoint

The receiver can transmit :
- !TCNTL : traffic specification or traffic modification.
- !DIAG : association reject.
- !CNTL : association common control.
- !END : deconnection.
- !ECNTL : retransmission request.
- !RCLOSE : acknowledgement of end of transmission.

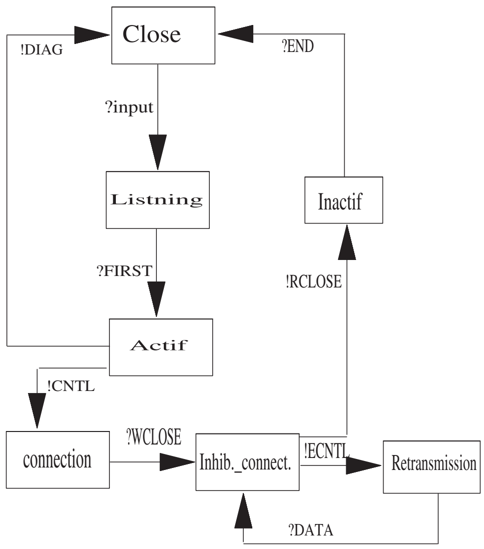

figure 3.3. Association establishement procedure of receiverer viewpoint

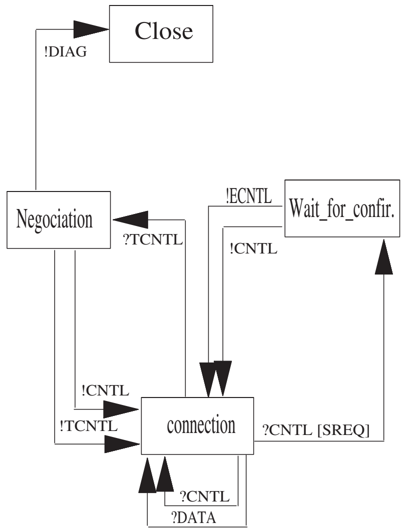

figure 3.4. Control procedures of receiver viewpoint

and can receive :

- ?TCNTL: traffic specification or traffic modification.
- ?DIAG : association reject..
- ?CNTL : association common control.
- ?END : deconnection.
- ?ECNTL : retransmission request.
- ?WCLOSE : end of transmission.
- ?input : reception request.

The different types of XTP messages are represented by positive values in the reachability tree given by ValiPro.

In validation phase, We bounded the FIFO channels connecting both automatas in order to reduce the number of states of the reachability graph, and we have used two methods for the construction of reachability tree. The classical method (figure 3.5) allows the verification of all properties such as the detection of deadlocks, of blocking receptions, of capacity overflow. The reduction method (figure 3.6) gives the same properties as classical method, but this technique allows to minimize states space of XTP reachability tree.

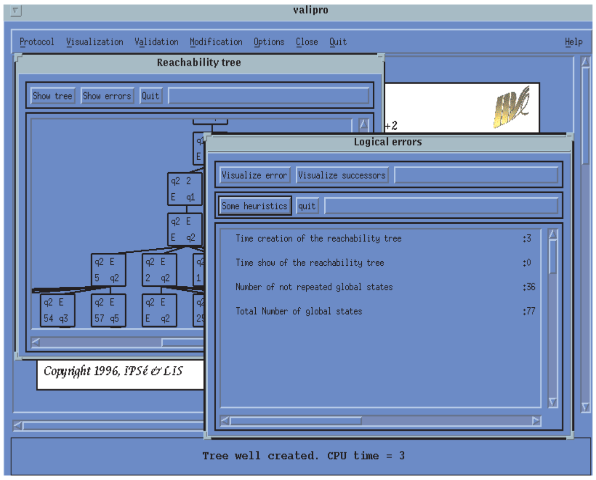

figure 3.5. XTP validation with classical method in ValiPro

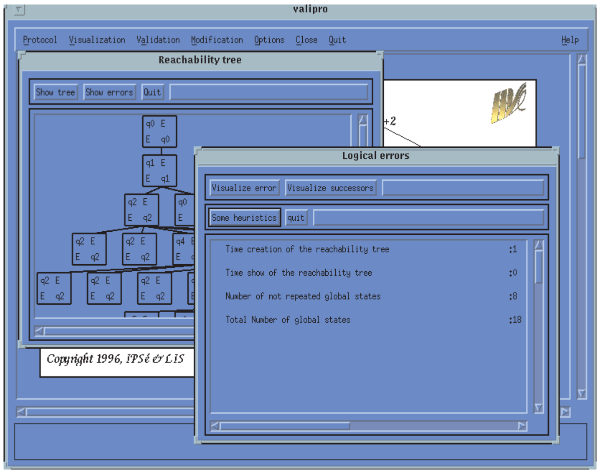

figure 3.6. XTP validation with reduction method in ValiPro

The XTP reachability tree, given by classical method shows that its state space is larger than one of reduction method.

	Total number of global states	Number of not repeated global states
Classical method	77	36
Reduction methode	18	8

The reachability analysis given by both methods does not detect the presence of logic errors, because each message sending by the transmitter process is received tidy and consummed by the receiver process, and at the final global state, both channels are empties.

We have used communicating finite state machine to describe the XTP behaviour aspect, but to study the protocol data transmission level, concretelly the internal executions between XTP endpoints, we use the LOTOS language

4. LOTOS Language

4.1. Presentation

LOTOS is a formal description technique for distributed systems specification. It was originally developed for the formal specification of ISO's open system interconnection. Consequently, part of LOTOS applications can be found in the area of formal specification of telecommunication protocols and services [MOO. 94].

A LOTOS specification is a set of processes definition and types. LOTOS has an embeded blocs structure. The processes definition describes the control structure and types definition describes data structure. The data structure is based on the formal theory on abstract data types, in particular the methods of equational specification of data types with initial algebra semantics. Most of the concepts are based on the abstract data type technique ACT-ONE [EHR. 85]. While, the control structure describes the systems *externally observable behaviour* by describing the temporal relations among the interactions. The concept for this description technique are based on process algebraic methods or process algebras, specially on Milner's work on CCS [MIL. 80].

Moreover, LOTOS presents different tools, which are dedicated to the efficient compilation, simulation, formal verification, and testing of descriptions written in the OSI LOTOS. We are used the CADP toolbox (Caesar/Aldebaran Distribution Package) [GAR. 92], that contains several closely interconnected components :

1- ALDEBARAN is a tool for verifying communicating systems, represented by labelled transitions systems (LTS), i.e., transition machines, the transitions of which are labelled by action names. The verification algorithms used in ALDEBARAN are based either on the Paige-Tarjan algorithm for computing the relational coarsest partition, or on symbolic LTS representation using Binary Decision Diagrams.

2- CAESAR is a compiler which translates LOTOS descriptions into LTSs. CAESAR interfaces a number of verification tools for LTSs and temporal logic evaluators, including ALDEBARAN. CAESAR translation algorithms proceed in several steps. First the LOTOS description is translated into a simplified process algebra called SUBLOTOS. Then an intermediate Petri Net model is generated which provides a compact structured and user-readable representation of both control and data flow. Eventually the LTS is produced by performing reachability analysis on the Petri Net.

3. CAESAR.ADT is a compiler that translates the data part of LOTOS specifications into libraries of C types and functions.

Each LOTOS sort is translated into an equivalent C type and each LOTOS operation is translated into an equivalent C fonction (or macro-definition). CAESAR.ADT also generates C functions for comparing and printing abstract data types values, as well as iterators for the sorts of the domain in which is finite.

4.2. XTP specification and validation

In XTP, the control procedures are dedicated to the transmitter for managing and monitoring the association. Consequently, the transmitter must request periodically the receveir to transmit his control data in order to obtain his information state. Thus, two bits SREQ and DREQ are presented in all XTP packets, used by transmitter, for request receiver information state [ALK. 93, FOR. 95]. At the reception of one of these bits, the receveir must response by transmitting the CNTL packet.

The XTP specification does not give details about the moment and the frequency of transmission of packets with SREQ bit set to the receiver. We used two implementation strategies for flow control and we propose an implementation for XTP Timers. So, we assure that the data transfer is reliable. The different messages between transmitter and receiver after the association establishment are :

- DATA containing user data;
- CNTL with the SREQ bit set as a control packet.

The transmitter receives from the receiver a CNTL packet as acknowledgement of transmitted data. When he transmits a CNTL packet with the SREQ bit set, he arms his WTIMER. If the WTIMER expires, because of a response delay, the transmitter must initialize a synchrozing handshake that consists to transmit a CNTL packet with the SREQ bit set and wait for the response from the receiver. This synchronization has two objectives :

- reevaluate the WTIMER;
- reach a coherent global state between transmitter and receiver.

We used two strategies which will act on the user data transmission. The choice of the moment for setting the SREQ bit in the CNTL packet and his transmission frenquency will play a very important role in states space level of reachability tree given by both strategies.

In the first strategy S1 (figure 3.7.), we transmit the CNTL packet with the SREQ bit set after each transmitted DATA packet. In the second strategy S2 (figure 3.8.), we transmit the CNTL packet with the SREQ bit set when :

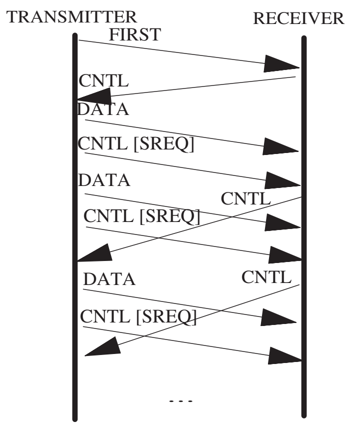

figure 3.5. Data transfert using strategie S1

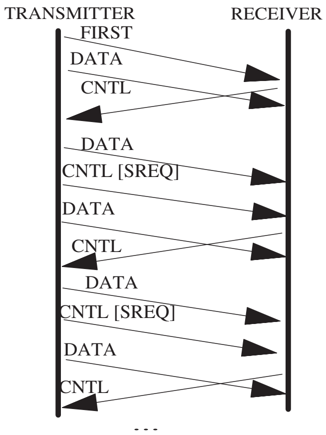

figure 3.6. Data transfert using strategie S2

- a CNTL packet in response at the last CNTL packet with the SREQ bit set has been received by the transmitter;

- the necessary time to transmit user data by the anticipation window is lower than the last known trip-time round.

We validate thus protocol by using the CADP toolbox. We bounded the number of DATA messages in order to reduce the number of state and transitions of reachability graph.

The analysis of both strategies display differences between them. The reachability analysis of S1 shows that his states space is larger than the one of S2, this is caused by the reception of CNTL packets, by the transmitter, that are not always useful for the data acknowledgements. The analysis of S2 offers a states space more lowest than offered by S1. The reachability analysis given by both strategies does not detect the presence of logic errors. All sending messages, by transmitter, are received by receiver.

	Total number of global states	Number of not repeated global states
strategy S1	3347	1925
strategy S2	2963	1571

Morover, we propose in this work an implementation mechanism for XTP Timers. Indeed, a timed extension of LOTOS has been proposed for modeling timing mechanism, [LED. 93] proposes two basic timed operators. The first is only offered during a timed interval and the second operator delays the interaction during a timed interval, while XTP protocol presents the timed notion in parallel with the other interactions.

The proposed implementation is based on counters which allowed us to supervise data transmission control mechanism and the transfer of CNTL packet with the SREQ bit set. Also the use of the counters allowed us to specify diffirent types of XTP Timers. For example, to specify the CTIMER, we supposed that his maximal value is equal to the quantity of packets that will transfered from transmitter. At each data transmission, the counter increments his value. So, his maximal value means that all DATA packets have been transmitted. For specifying the WTIMER, we supposed that his value is constant and it is greater than CTIMER value to allow the transfer of several data packets. We have not specify either CTIMOUT or RTIMER, because we are considered that the rate controle is constant and the communication between endpoints is reliable.

For supervising the CNTL packets with the SREQ bit set transmission management, we implemented a counter that supervises the transfer of these packets. However, this counter increments his value in parallel with the transfer of user data. When it reachs at a value that we specified beforehand, the transfer procedure of CNTL packet with the bit SREQ set is achieved automatically.

5. Conclusion

In this paper, we specified a subset of the XTP protocol with two formal models, communicating finite state machine and formal description language LOTOS. Both formal models are based on reachability analysis. When analysing the XTP protocol by ValiPro and LOTOS, we have not detected the presence of logic errors. The use of communicating finite state machine allowed us to prove the correctness of XTP global behaviour. The main advantage of this model is that the validation of communication protocol can be easily automated. we have not specified the timers mechanism in this model, because the timer values sweep along a large expansion of automata states. By using LOTOS specification, the XTP behaviour analysis allows us to compare two strategies of data transmission. Both strategies lie on the choice and the frequency of sending CNTL packets with SREQ bit set. The difficulty met in the specification phase is the lack of timers. So, we proposed in this work the counters method that allowed us on one hand to specify XTP Timers and the other hand to study the global behaviour of the internal executions between endpoints. So, this method allows us to supervise both control flow and errors mechanisms.

The main advantage of the protocols specification and validation with formal description languages is that it is able to manipulate variables and paramaters.

It is able to specify and validate this protocol with formal description language RT-LOTOS to simulate the internal behaviour in real time, and to compar obtained results with our work. The comparaison will be based on states space of reachability graph obtained by both methods (our work and RT-LOTOS), that allows us to have an explicit analysis of this protocol.

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