Formal Modelling and Analysis of TCP for Nodes Communication with ROS

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Abstract. TCP (transportation control protocol) is widely used for supporting communications between robotic nodes with ROS (robotic operation system) for critical-task implementation. The probability of bit errors and lost packets is much higher for moving nodes under WLAN. So it is essential to analyze the performance and the reliability of the communication processes for nodes with ROS. It is built that the communication model of nodes for TCP in ROS by MDP(Markov Decision Process) and the reliability of that is analyzed in this paper. The Specifications of the TCP for nodes communication is formalized into the objective properties by PCTL(Probabilistic Computation Tree Logic), and the satisfiability of the properties is verified by the probabilistic model checker. The results can help the designers to make better strategies for the communication process over TCP in ROS of robotic nodes.

Keywords: Node network communication · Probabilistic model checking · Markov decision process

1 Introduction

With the increasingly development of robotic technology, many new applications are deployed in distributed nodes with ROS for cooperative tasks. The correctness and reliability of communication among nodes is getting more important in critical-task system. The transportation of commands and data among nodes with ROS is based on TCP(transport control protocol), which plays an important role for the communication reliability of nodes. Some work have been made on reliability analysis of TCP in WLAN. A adaptable TCP segment size scheme is proposed to improve the TCP communication performance in wireless environment [1]. Data link layer and subsection connection is developed for improving the performance of TCP protocol in wireless network [3]. A reliability sorting algorithm is put forward for TCP data packet for the limited covert channel in [4]. These references basically use simulation, emulation or other traditional verification methods to analysis or improve the optimized methods for the reliability of TCP communication protocol.

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Formal method is based on strictly mathematical reasoning to analyze or check the correctness of design and implementation, which can be an automatic checking for a finite status system. Model checking can provide automatic checking whether a system abstraction model satisfy the properties, which are formalized from the specifications of design. A colored Petri net model for the TCP's connection is used to verify the correct of the communication protocol [7]. The verification and analysis for SpaceWire [8] communication protocol at the exchange level by model checking. The real-time properties of the session level of nodes with ROS [9] is verified by Uppaal. The Probabilistic model checking combines probability analysis and general model checking method technology, and it is a useful for the description of non-deterministic stochastic systems. The paper focuses on the analysis and verification of the reliability of the TCP transportation for nodes with ROS by probabilistic model checking (Table 1).

Table 1. Symbolic representation of the node1.

Symbol	Function
idle	Initial state, no request for connection
request	Sends the request signal
req_num	The number of sending request
ack1_num	The number of backtrack from the node2
ack2_num	The response number from node1 to node2
RECEIVE_NUM	The upper limit of receive message
SEND_NUM	The upper limit of send message
P	The rate of package lost

2 Formal Modelling of Nodes Communication Based on TCP

The operation communication between ROS nodes is controlled by a main node running as roscore, which is responsible for monitoring and management the all functional nodes' communication. All of the nodes must register in the ROS Master node while they start, and all nodes can communicate with each other after authorized by the master node. XML-RPC communication protocol is the calling mechanism of the communication between ROS nodes' communication, which is based on TCP protocol, and by adding the port on the transport layer, it can be represented corresponding application layer communication. In order to analysis and verify the performance of the nodes' communication protocol, this paper builds formal model and gives probabilistic analysis for the connection set up and sending or receiving message of the nodes.

The Markov Decision Process model for the connection and communication between node1 and node2 is built for the verification. The node1 model is shown in Fig. 1, While establishing the models for node1 and node2, the action translates from initial state "idle" to send-request state "request". After sending a request, the node1 will wait for confirmation information from the node2. If the node1 receives the confirmation from the node2, it will send a signal to the node2 again, if the node2 successfully receives the confirmation signal, then the connection was established successfully. Conversely, if the node1 does not receive confirmation signal from the node2 within the prescribed time limit, the node1 will keeping sending a signal to the node2 until it receives confirmation signal from the node2 or it reaches maximum retransmission limit. In order to make modelling and analysis the problem of establishing connection and sending message between node1 and node2, the paper extends the model by adding the sending data into the model after the connection is established successfully.

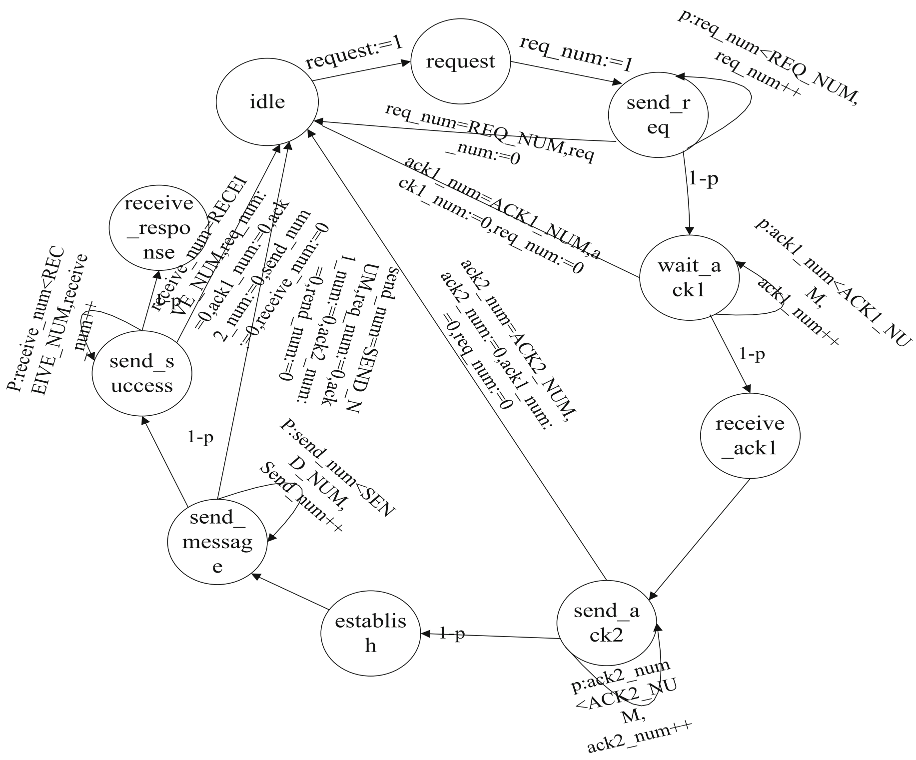

Fig. 1. Node1 communication process modelling

In the similar way, the model of the node2, which is receiver side, also describes the process of the three-way-handshake connection and data transmission. When a connection is requested from the node1 to the node2, the state of the node2 will change, and it will transfer from the initial state “idle” to the “wait-req” state. After receiving the request signal, the node2 turns into the “receive-req” state. Then after sending the confirmation signal to the node1 successfully, the node2 will be to “send Send-ack1” state, if the progress is successful, the node2 will transfer to receive “reveive-ack2” state, and wait for the acknowledgement signal from the node1, if it successfully receives the confirmation signal from the node1, it will move to “establish” state.

Next, the node1 and the node2 will send data each other. When the node2 receives the request from the node1 successfully, the node2 sends the corresponding service [15] to the node1, if the node1 receives the response message from the node2, then the transition have been completed successfully, During the period, the lost package may made the failure transmission between the node1 and the node2, it is taken into account in the formal models by adding the probability to the MDP models in the paper.

3 Verification and Probability Analysis

Critical properties for the nodes communication, which is translated into PCTL formula, is extracted from the design specification. Based on the formal models of the nodes that we have set up aboved, the properties are automatically verified by PRISM model checker and further be analyzed.

In the model of node1, c = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 respectively represent the node1 is at idle, request, send- req, wait-ack, receive-ack1, send-ack2, establish, send-message, send-success, receive-response state; and the node2 state s = 0, 1, 2, 3, 4, 5, 6, 7 respectively represent the node2 is at idle, wait-req, receive-req, send-ack1, receive-ack2, establish, receive-message, response-success state.

Property 1. The maximum probability under different package lost?

Pmax=?

[Fc=9&req_num=1&ack1_num=1&ack2_num=1&send_num=1&receive_num=1]

In Fig. 2, the horizontal axis represents the rate of the package lost in the wireless network, the vertical axis represents the maximum probability of the connection established and sending data successfully between the node1 and the node2. As Fig. 2 is shown, when the error probability is 0.05, the maximum probability of sending the correct data is less than 75%, the results is very important for optimizing the network in the design phase.

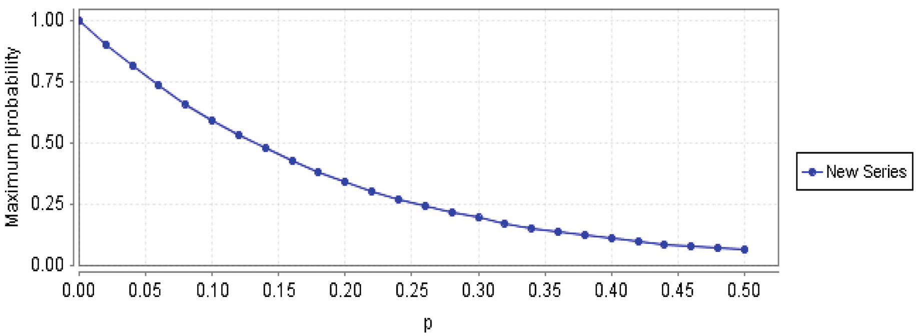

Fig. 2. The maximum probability under different package lost

Property 2. The maximum probability of the sending data successfully under different retransmission?

The maximum probability for first and second transferring successful is respectively expressed as following:

Pmax=?[F s=7&req_num=1&ack1_num=1&ack2_num=1&send_num=1]

Pmax=?[Fs=7&req_num=1&ack1_num=1&ack2_num=1&(send_num=2|send_num=1)]

The result shows that the maximum probability with first transferring is 0.6587, and the maximum probability is 0.7246 for second try shown in Fig. 3, which coincides with the experiment result, and it verified that the probability changes with the number of retransmission, and they are positive correlation. The results of the analysis lay a foundation to the future research or application about the communication nodes with ROS.

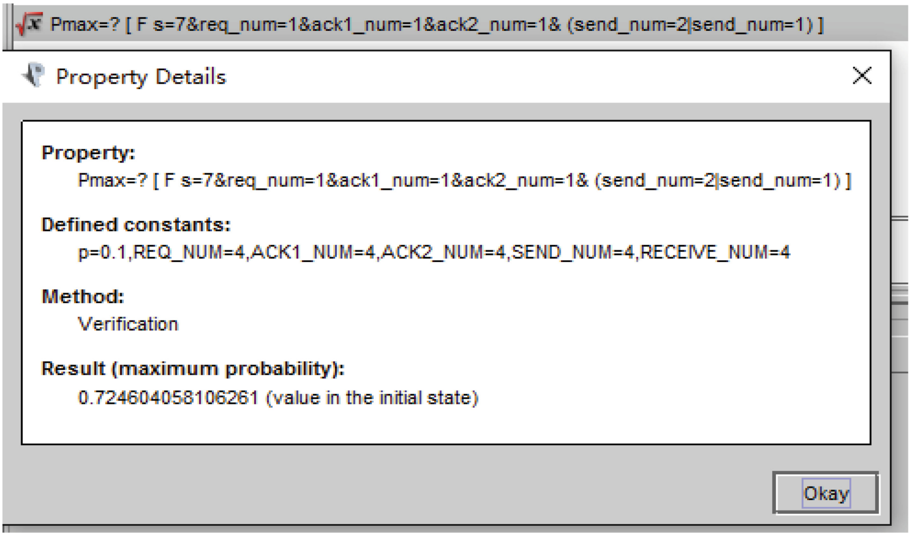

Fig. 3. The maximum probability under twice transmision

4 Conclusion

We builds the formal model and analysis the communication protocol in the wireless network for the nodes with ROS, and extracts some critical properties for analyze and checking. the reliability of the TCP between nodes with ROS is analyzed under different link error probability by probabilistic model checking, which provides useful strategies for designer, and is helpful for avoiding bug at design phrase.

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References

1. Huang, Z.: The real-time operating system development and implemen- tation for industrial robot controller. School of Mechanical Engineering & Automation, Beijing University of Aeronautics, Beijing (2013)
2. Han, H.: Improvement for wireless TCP based on bit error rate monitoring. J. Comput. Appl. **31**(10), 2657–2659 (2011)
3. Li, M., Zhang, Y., Xiang, D.: Improvement mechanism of transmission control protocol in wireless network. Comput. Eng. **42**(1), 103–108 (2016)
4. Wei, S., Yang, W., Shen, Y.: A secret communication method based on reliable packet ordering. J. Chin. Comput. Syst. **37**(1), 124–128 (2016)
5. Wang, Z.: Survey of model checking. Comput. Sci. **40**(6A), 1–14 (2013)
6. PRISM-probabilistic symbolic model checker [EB/OL] (2011). http://www.prismmodelchecker.org/
7. Li, F.: Formal description and verification of TCP protocol based on colored Petri nets. Mod. Comput. **309**(6), 49–52 (2009)
8. Li, Y., Li, X., Guan, Y.: Formal modeling and probabilistic analysis of SpaceWire protocol. J. Chin. Comput. Syst. **34**(9), 25–29 (2013)
9. Wang, Y., Wang, R., Guan, Y.: Formal verification of node to node communication in RGMP-ROS hybrid operating system. J. Chin. Comput. Syst. **36**(10), 2379–2383 (2015)
10. Parker, D.A.: Implementation of Symbolic Model Checking for Probabilistic Systems. University of Birmingham (2002)
11. Su, K., Luo, X., Lu, G.: Symbolic model checking for CTL. Chin. J. Comput. **28**(11), 1798–1806 (2005)
12. TCP three-way-handshake and four recovery summary [EB/OL]. http://blog.csdn.net
13. Li, Z.: Research on design of intelligent gateway in substation. Jiangsu university of science and technology (2007)
14. Liu, Y.: Research on reliability design and test method of device driver. University of Electronic Science and technology (2014)
15. Wu, Y.: Design of P2P instant messaging software based on XMPP protocol. Electronic information technology and instruments of Zhejiang University, Hangzhou (2007)