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Sławomir NOWAK, Mateusz NOWAK
Instytut Informatyki Teoretycznej i Stosowanej PAN

SYNCHRONISATION CONCEPT FOR DISTRIBUTED SIMULATION OF NETWORKS WITH PACKET LOSS[1]

Summary. We propose a concept of a new synchronisation method of distributed event-driven simulation of computer networks with non-zero rate of lost packets (frames), e.g. wireless networks. Thanks to treating straggler messages (all or some of them) as messages informing of damaged frames, better performance of distributed simulation is expected..

Keywords: network simulation, distributed simulation

KONCEPCJA METODY SYNCHRONIZACJI DLA ROZPROSZONYCH SYMULACJI SIECI ZE STRATAMI PAKIETÓW

Streszczenie. Zaproponowano nową koncepcję synchronizacji dla rozproszonej symulacji sieci komputerowych z niezerową stopą utraty pakietów (ramek). W metodzie tej opóźnione komunikaty traktowane są jako komunikaty, zawierające informacje o uszkodzonych ramkach. W ten sposób można uzyskać większą wydajność symulacji rozproszonej.

Słowa kluczowe: symulacja sieci komputerowych, symulacja rozproszona

1. Introduction

Computer simulation is essential for investigation of network properties in order to confirm analytical models, in research on new technologies and protocols, and also in forecasting of phenomena occurring in networks, especially in large and non-typical topologies.

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Computer simulators are based on discrete events. They can be evaluated from the point of view of simulation quality, accuracy of library models, and also simulation performance. Simulation experiments, in spite of continuous increase of processors performance, are still time-consuming. One of directions of simulation technique development is looking for new, more effective simulation methods, allowing shortening of simulation duration.

It is possible to parallelisable the event-driven simulations. In space-parallel simulation the model is divided into parts, and every part is simulated on different simulation node by local process of simulation (LP), communicating with another LPs via messages sent over computer network.

For synchronisation of LP's two groups of synchronization algorithms are used — conservative and optimistic ones. These methods are of general use, i.e. they are suitable for any discrete events simulation. However, in some types of simulation specific properties of the model can be used in order to increase the simulation efficiency.

In this chapter existing synchronisation algorithms used in distributed simulation are shortly characterised. Experiments proving that their usefulness in distributed simulation of computer networks is limited to specific cases are shown. In the latter part we propose a concept of a new simulation synchronisation method. This method is suitable for networks with non-zero frame loss rate, like wireless ones, as it uses the fact of dropping some frames.

2. Synchronisation in parallel simulation

In parallel event-driven simulation (PDES) every event is described by a simple data structure. There are no fundamental difficulties with construction of parallel simulator and sending these structures over the network ([1, 2]). Notwithstanding, there are some issues to solve.

Main problem is synchronisation among local simulation processes. In parallel simulation every local process of simulation stores its own simulation clock, and its own event list, which is processed independently of other LPs. It can happen, that LP receives message about event occurring in timestamp lesser than current simulation clock value. Attempt to process such a message (called straggler message would break causality constraints and would lead to erroneous simulation. To prevent such a situation, synchronisation algorithms have been were worked out.

Currently two families of synchronisation algorithms are used in distributed simulation – conservative algorithms and optimistic ones.

Conservative synchronisation algorithms, like Null Messages ([3, 4]) prevent LP to progress with simulation clock unless it is sure it would not receive straggler message. Conservative methods are simple to implement, but they have low performance, as a lot of rvative methods are simple to implement, but they have low performance, as a lot of time is consumed for exchanging synchronisation messages (called Null Messages) among LPs.

Time Warp synchronisation algorithm ([5, 6]) is a basic algorithm in the group of optimistic synchronization methods. LP does not wait for other nodes to synchronise ("optimistically" assumes no straggler message will arrive), but stores past states of the model. When straggler message is received, simulator with its data (e.g. event list and simulation clock) and state variables of the model are rolled back to the state from before the message time stamp. Rolling back the simulation on a single LP usually leads to roll-backs also on other nodes, as every message sent during rolled-back period of simulation must be cancelled. Optimistic algorithms work in general with better performance than conservative ones, but they require a lot of memory for remembering past simulation states, and simulation roll-backs are time-costly.

For understanding performance issues of distributed simulation the concept of lookahead (or link delay) is essential. Lookahead is a difference between value of simulation clock, when new event message is generated and time when the event will occur. For example, in computer networks simulation this is typically the time between the moment of start of frame sending process in transmitter and the moment of receiving complete frame in receiver.

LP will receive straggler message, when the difference between values of sender's and receiver's simulation clocks is greater than lookahead on simulated link between them. Therefore, the shorter the lookahead is, the more likely it is to receive straggler message and the lower the performance of parallel simulation is.

3. Distributed simulations

The OMNeT++ [7] is a popular simulation tool which includes support for parallel simulation. It allows LP's to communicate in several ways (basic methods are Named Pipes for shared memory multiprocessors and MPI for distributed systems). Synchronisation is accomplished with Null Messages.

For parallel execution in OMNeT++, the model is to be partitioned into several logical processes that will be simulated independently on different hosts or processors. The rules to run models in parallel are following:

- modules may communicate via sending messages only; no direct method call or member access is allowed, unless connected to the same process;
- any use of global variables is not possible;
- limitations on direct sending : no sending to a submodule of another module is possible, unless mapped to the same process;

- non-zero link delays must be present in communication between processes;
- only static topologies are supported.

The INET framework [8] is an open-source communication networks simulation package for the OMNeT++ simulation environment. The INET framework contains models for several Internet protocols: beyond TCP and IP there is UDP, Ethernet, PPP and wireless networks.

However, as INET was not prepared with parallel simulation in mind, further actions were needed. The process of adaptation of INET to work in parallel was done by authors and is presented in [9].

Thanks to appropriate modifications in source code and resignation from global objects it was possible to conduct simulation research for chosen models and estimate simulation performance for different variants of simulation model.

Performance of simulations turned out to be hardly greater than sequential ones.

4. A new algorithm of synchronisation

Universal synchronisation algorithms not fully fulfil expectations of significant improvement of the parallel simulations performance. There is a need to develop specialized mechanism for chosen, specific class of problems.

In case of lack of synchronisation algorithm processes have to drop delayed messages. Dropping messages leads to imprecise simulations and errors.

Authors propose a new algorithm of synchronisation, limited to the simulation of networks with packet loss only. It concerns especially simulations of wireless networks, which are sensitive to disturbances.

Wireless networks usually have a non-zero rate of damaged frames. Algorithm presented in this chapter uses this property for improving parallel simulation performance. The frame damages come from two sources – collisions and electromagnetic disturbances. Collisions arise as a result of concurrent transmissions from radio devices and their existence and rate is strictly dependent on the performance of devices. Network simulator can easy identify and react to situation of collision. The external disturbances are however independent from the activity of simulated radio devices, as they come from noisy environment [10]. Dropping of some frames due to external disturbances must be simulated by marking randomly chosen frames as damaged.

The suggested algorithm will treat straggler messages as if they were informing about damaged frames, which cannot be further processed.

The algorithm must ensure that the rate of damaged frames set by user is preserved during the simulation. If the number of straggler messages is low, additional frames chosen by simulator on random basis must be marked as damaged.

Presence of straggler message comes from the difference in values of the simulation time clock on LPs sending and receiving the message. If receiving LP gets ahead sending a message, it is likely that it will receive straggler messages. Therefore, after receiving straggler message, receiving LP must freeze for a moment to allow sender of the straggler message to introduce little delay to slow down its simulation loop.

It seems, that the lookahead in typical wireless links, e.g. from 802.11 group may be too small to achieve error rate low enough. The lower the lookahead is, the odds of receiving struggler message are higher. Frames in wireless transmissions, e.g. some administration frames, like CTS or ACK in 802.11 [11] are very short, so the lookahead may be too small to achieve low error rate by simple treating straggler messages as damaged. Additional mechanisms must be introduced to hold desired error rate also on the links with small lookahead, where the rate of straggler messages can be higher than error rate set by user. Introduction of some "classic" synchronization mechanism seems necessary. As simulation rollbacks are (potentially) more effective than null messages, simulator must have a possibility to rollback a simulation in the case of the delay of straggler message is not greater than some threshold. Thanks to that mechanism, allowing short rollbacks, but not requiring introduction of fossil collection mechanism, process of synchronisation will be under better control.

The new synchronisation method for networks with packet loss combines the good points of conservative and optimistic algorithms. As a result better simulation performance is expected.

The open question is, whether statistical properties of packet stream, in which delayed packets are dropped, will be correct and similar to the streams of frames, measured in real networks. However developing effective mechanisms, able to comply with simulations with non-zero rate of packet loss, is expected.

5. Simulation tool and experiments

An attempt to modify existing simulator (OMNet++) was made, but introducing new synchronisation method with rollback mechanism into existing code was too complicated. Therefore creation of a new parallel simulator from scratch seems to be better solution, and such a simulator is currently being worked out.

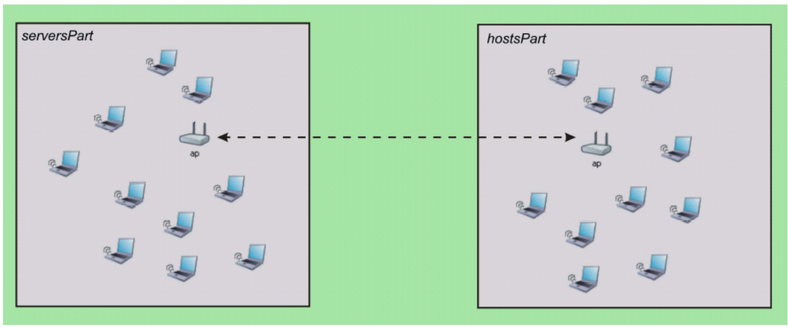

Fig. 1. Network topology
Rys. 1. Topologia badanej sieci

The simulator capabilities:

- a detailed evaluation of wireless networks (with supporting mobility, different power of signals etc.);
- an effective evaluation of distributed simulations;
- creation of a tool to simulate the Internet (thousands of nodes);

Till now the implementation of parallel simulations tool together with Null Messages synchronization method was prepared.

Simplified model of wireless network, based on CSMA/CA mechanism (with RTS, CTS and ACK messages exchange after each frame) was also implemented. Topology of modeled network is shown in Fig. 1. Network consists of two segments of wireless network connected with radio link. Hosts send data packets to given receivers – both in local and remote network segment. Frames for remote receivers are passed to switching device, conducting frames to radio link of 1.5 Mbps capacity. Latency of this link was the simulation parameter.

Two variants of topology, with the same physical scheme, were used in experiments:

A. All hosts in segment 1 communicate to hosts in segment B. All traffic passes through radio link, which is bottle-neck of the network.
B. In every segment 5 hosts communicate to hosts in the same segment and 5 to hosts to another segment. Radio link between access points is shared by 5 connections.

In parallel simulation each segment was simulated by another logical process. Experiments were conducted with OMNeT++/INET on following hardware configurations:

C. PC1 – single workstation with single-core AMD Sempron 3400 processor, 512 MB RAM, Windows XP.
D. PC2 – single workstation with dual-core processor Intel Core2, 3GHz, Windows Vista.

For results comparison simulations were conducted in parallel and serial versions. In serial simulation entire network was modeled by a single simulation process, in parallel one segment A and segment B were placed in different LPs.

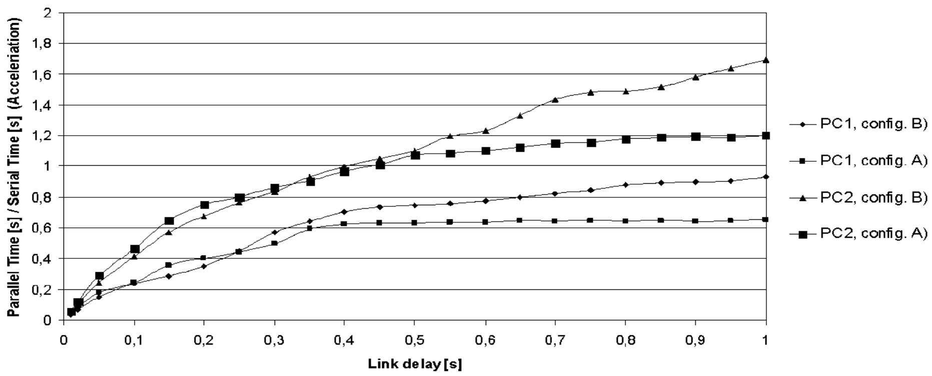

Fig. 2. Simulation results
Rys. 2. Wyniki symulacji

The link delay on radio link connection was the parameter of the experiments. Null Messages algorithm was used. The bigger is delay, the more seldom are synchronization messages and lesser influence of synchronisation on simulation performance is. Performance (measured in simulation seconds per minute of wall-clock time) appeared very sensitive for changes of this value.

Simulations were performed in serial and parallel configuration. Fig. 2 illustrates acceleration, defined as proportion of simulation time achieved for serial and parallel simulation. Result close to 2 means almost linear acceleration achieved on two processors (cores).

Results verify, that Null Messages algorithms does not improve performance of simulation significantly. Speed of simulation can be better only for long and not very loaded links between network nodes. In typical configurations, with low latency and intensive communication parallel simulation appears to be slower than sequential one.

6. Conclusion

New synchronisation method for networks with packet loss combines advantages of conservative and optimistic synchronization methods. Higher performance of parallel simulation is expected. This algorithm is expected to allow effective mechanisms of synchronization to be worked out, which could be used in simulation of networks with non-zero lookahead and non-zero rate of damaged packets. Its use will be limited to models of networks, where rate of damaged (lost) packets or frames is significant.

At present stage of work possibility of parallel simulations with OMNET++/INET package was studied. For the purpose of testing of new methods, new simulation tool was also implemented. Simplified model of wireless communication was worked out, aimed at verification of new simulator. Parallel simulations were conducted with use of classic Null Messages conservative synchronization method, both in OMNET++ and in new simulator.

Next stage will embrace implementation of described synchronization algorithm. Simultaneously, work on wireless networks models will be conducted, as well as on other networks with high packet loss ratio. Properties of packet stream flowing between LP's connected with use of described method will be examined to prove their similarity to real packet streams and confirm correctness of simulation results.

Authors expect significant increase of simulation performance for some models of wireless networks.

BIBLOGRAPHY

1. Fujimoto R.: Parallel and Distributed Simulation Systems. Wiley Series on Parallel and Distributed Computing. John Wiley and Sons, Inc., 2000.
2. Law A. M., Kelton W. D.: Simulation Modeling and Analysis. McGraw-Hill, Inc., 2nd edition, 1991.
3. Bryant R. E.: Simulation of packet communication architecture computer systems. Technical Report TR-188, MIT Laboratory for Computer Science, Cambridge, MA, USA, 1977.
4. Chandy K. M., Misra J.: Distributed simulation: a case study in design and verification of distributed programs. IEEE Trans. Soft. Eng., SE-5(5) , 1978, p. 440÷452.
5. Jefferson. D.: Distributed simulation and the Time Warp operating system. In Proc. of the 11th Annual ACM Symposium on Operating System Principles, ACM Press, New York, November 1987, p. 77÷93.
6. Jefferson D., Sowizral H.: Fast concurrent simulation using Time-Warp mechanism. In Distributed Simulation, 1985, p. 63÷69.
7. OMNeT++ homepage: http://www.omnetpp.org.
8. INET homepage: http://www.omnetpp.org/staticpages/index.php?page=20041019113420757 .
9. Nowak M., Nowak S.: Parallel simulations with modified INET simulation package. Theoretical and Applied Informatics,17(2), 2007.
10. Willig A., Kubisch M., Wolisz A.: Results of bit error rate measurements with an IEEE 802.11 compliant PHY. Technical Report TKN-00-008, Technical University Berlin, Telecommunication, Networks Group, Berlin, September 2000.
11. IEEE 802.11 WG. Wireless LAN medium access control (MAC) and physical layer (PHY) specifications, 1999. ANSI/IEEE Std 802.11, 1999 Edition.

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Omówienie

W artykule zaproponowano nową metodę synchronizacji dla rozproszonej symulacji sieci komputerowych. W metodzie tej opóźnione komunikaty traktowane są jako komunikaty zawierające informacje o uszkodzonych ramkach.

Nowa metoda synchronizacji dla sieci ze stratami ramek łączy zalety zachowawczych i optymistycznych metod synchronizacji i pozwala oczekiwać wyższych prędkości symulacji. Zastosowanie tej metody ogranicza się jednak tylko dla szczególnych modeli.

Otwarty pozostaje problem, czy własności statystyczne strumienia pakietów, w którym pakiety spóźnione będą uznane za uszkodzone, będą na tyle podobne do własności rzeczywistych strumieni pakietów, by wyniki symulacji uznać za prawidłowe. Mechanizm ten, nad którym obecnie pracują autorzy, daje jednak nadzieję na opracowanie uproszczonych mechanizmów synchronizacji możliwych do zastosowania tam, gdzie łącza sieciowe pomiędzy węzłami sieci symulowanymi w różnych LPS mają nie tylko niezerowe opóźnienie (co jest warunkiem każdej symulacji rozproszonej), ale też niezerową stopę uszkodzonych pakietów.

Na obecnym etapie prac zbadano możliwość symulacji równoległych z wykorzystaniem pakietu OMNET++/INET. W celu implementacji nowego algorytmu synchronizacji zostało opracowane nowe narzędzie do symulacji zdarzeń dyskretnych. W celu weryfikacji poprawności zaimplementowanego narzędzia symulacyjnego opracowany został uproszczony model komunikacji w sieci bezprzewodowej. Symulacje równoległe zostały przeprowadzone z wykorzystaniem synchronizacji Null Messages.

Obecnie trwają prace nad zaimplementowaniem opisanego algorytmu synchronizacji. Jednocześnie będą trwały prace nad budową modelu sieci bezprzewodowej oraz innych modeli sieci ze stratami pakietów.

Adresses

Sławomir NOWAK: Instytut Informatyki Teoretycznej i Stosowanej PAN, 44-100 Gliwice, ul. Bałtycka 5, emanuel@iitis.gliwice.pl.

Mateusz NOWAK: Instytut Informatyki Teoretycznej i Stosowanej PAN, 44-100 Gliwice, ul. Bałtycka 5, mateusz@iitis.gliwice.pl.