AN EFFICIENT APPROACH FOR SPEEDING UP SIMULATION OF WIRELESS NETWORKS

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ABSTRACT

There have been an increasing demand for wireless communication technologies and therefore there exists a necessity of designing efficient tools for enhancing the computational effort of their performance analysis. Wireless communication systems are characterized by highly variable parameters associated with the wireless channel itself as well as with changes in channel performance dependent on the number of active users. Because of that simulation studies of such networks may be very time-consuming. A simple and effective way of speeding up such simulations can lead through employment of distributed processing power of modern computer networks. In this paper we report results of a performance study of a wireless network obtained by applying one special scenario of stochastic simulation, known as **M**ultiple **R**eplications **I**n **P**arallel, or *MRIP*, in which multiple processors operate as individual simulation engines, generating output data that are submitted to a global analyzer for on-line data analysis. The global analyzer is responsible for stopping (distributed) simulation when the statistical error of results reaches the required level. MRIP is an attractive scenario for speeding up computationally intensive stochastic simulation since it can be fully automated. The goal of this paper is to show up the advantage of using this approach in performance evaluation studies such complex and highly dynamic stochastic systems as wireless communication networks. Both the issue of speeding up the simulation, and the importance of producing results with an appropriate (small) statistical error, will be addressed.

1 INTRODUCTION

There have been an increasing demand for wireless communication technologies and therefore there exists a necessity of designing efficient tools for enhancing the computational effort of their performance modeling and analysis. Structural complexity of modern telecommunication networks causes that in many situations computer simulation is the only way of investigation of these highly dynamic stochastic systems. For example, in the problem investigated in this paper, a wireless communication network, operating under **C**ode **D**ivision **M**ultiple **A**ccess (CDMA), experiences highly variable conditions, caused by random properties of communication channels, mutual interference of signals generated by multiple active users, etc. Simulation provides a powerful tool to prototype such networks during the design, as well as during the development and operational phases.

Stochastic nature of the processes occurring in telecommunication networks means that one needs to produce the final results with a known (small) statistical error. Additionally, in all simulation studies aimed at assessing long-run performance of networks, the output data are highly correlated, so

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they have to be analyzed using special statistical techniques. Development of accurate methods of statistical analysis of correlated simulation output data has attracted a considerable scientific interest and effort. For a thorough treatment of this and related problems see [11]. Unfortunately, straightforward simulation of complex networks can require prohibitively long simulation times despite of increasing power of modern computers. It's not unusual for a simulation experiment to take days or weeks, for yielding results with an acceptable level of statistical error. In this situation, a considerable interest has been focused on parallel and distributed simulation of telecommunication networks. Speeding up execution of simulation is a challenging research problem which has attracted a considerable scientific interest and effort. Much of the research has been directed toward a scenario where many processors cooperate in executing of a single replication of simulation. A somewhat under-valued scenario uses many processors that are engaged into running their own replications of the simulated system and cooperate with central analyzers (one central analyzer for each performance measure analyzed), that are responsible for observing the stopping criteria of the simulation. We refer to this approach as **M**ultiple **R**eplications **I**n **P**arallel *(MRIP)* (see [12] for a discussion of its properties in the context of steady-state simulation), whereas the former is generally known as **S**ingle **R**eplication **I**n **P**arallel *(SRIP)*.

Despite of its simplicity, the MRIP approach seems to resolve satisfactorily the two main problems of stochastic simulation of telecommunication networks. Such a conclusion can be drawn on the basis of performance evaluation study reported in this paper. We have investigated performance of a wireless network operated under CDMA, using the **B**inary **P**hase **S**hift **K**eying (BPSK). The analyzed network consists of one wireless cell and a varying number of **W**ireless **T**erminals *(WTs)* and one central **B**ase **S**tation *(BS)*. The wireless links are considered to be unreliable, and subjected to **A**dditive **W**hite **G**aussian **N**oise (AWGN). The purpose of this study was to investigate the long-run quality of service experienced by users of such a network, measured by the jitter of successfully transmitted data segments (as a function of the segment length, and the number of active mobile users) and by the segment loss probability. The simulated model is discussed in more detail in section 2.

Because of the initial complete uncertainty about the length of steady-state simulation needed for obtaining results with a satisfactory (small) statistical error, and having suspected that very long simulation times would be required, we directed our attention on an implementation of MRIP scenario of distributed stochastic simulation in AKAROA-2 [17], a package offering automatic control of the final error of simulation results, as well as automated parallelization of (ordinary) simulation programs on multiple processors of a local area network. For additional speeding up of our simulation experiments, we linked AKAROA-2 with PTOLEMY [16], a package regularly used in the Telecommunication Networks Group at the Technical University of Berlin, Germany, for constructing simulation models. The advantages of using AKAROA-2 in performance evaluation studies of wireless networks are discussed in Section 3. We look there at the issue of speedup of simulation under MRIP, as well as at the importance of drawing conclusions about the quality of performance of telecommunication networks on the basis of results with small statistical errors.

2 SIMULATION SCENARIO AND MODEL

The analyzed scenario of a wireless network consists of a specific number of **W**ireless **T**erminals *(WTs)* operating within one wireless cell. All WTs communicate with one central **B**ase **S**tation *(BS)*, which coverage defines the cell boundaries (see figure 1). We assume a CDMA based mobile communication system with a number of codes much higher than the number of active WTs. The wireless link is considered to be unreliable with a varying **B**it **E**rror **P**robability (BEP). The value of the BEP depends on the number of used channels k. For the chosen scenario we assume that transmission may be affected by an **A**dditive **W**hite **G**aussian **N**oise (AWGN) and the **B**inary **P**hase **S**hift **K**eying (BPSK) is used. The basic bit rate of a CDMA channel is 64 kbit/s.

Using the simplest ARQ mechanism (*Send and Wait*), like it is discussed in [1] and suggested by the recent wireless LAN standards [6, 7], each erroneous packet is retransmitted. The following stored packets have to wait until the packet has been transmitted successfully. So, during that time

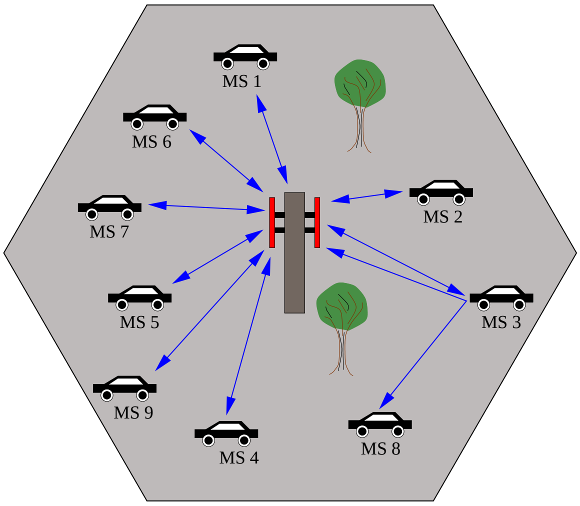

Figure 1: Wireless Scenario: Nine Terminals Communicating With One Base Station

the effective bit rate decreases from B_{good} to B_{bad} and simultaneously the jitter for single MAC packets, as well as for segments at higher layers of network's protocols, increases. We assume that a resulting bit rate B_{bad} is not acceptable for the required throughput specified by the QoS parameters. Further the increased jitter is not acceptable for the application. **S**imultaneous **MAC** **P**acket **T**ransmission (SMPT) is a method that overcomes the problem of instable bandwidth and high delay variation by utilizing parallel channels (see [3]). The main ideas are as follows. As long as no error occurs the packets are transmitted sequentially using one CDMA channel. When a packet is corrupted at τ_{start}, the sender will recognize the change in channel state by the missing acknowledgment. Under the assumption that errors on wireless channels are correlated (bursty), the sender will *probe out* the channel by sending probing packets (see [4]) at a rate adjusted to the channel's conditions. At τ_{change}, when a probing packet is successfully acknowledged, the sender suddenly takes the advantage of using parallel channels to correct the affected jitter. The sender will proceed to used multiple channels up to τ_{stop}, determined by equation 1. The joint bit rate $B_{joint,k}$ using k CDMA channels of bit rate B_i, is generally smaller than the sum of the bit rates of all channels. This is because the higher number of used channels results in a higher bit error probability [2, 5]. With an increasing number of allocated channels the overall noise level will increase, resulting also in a lower effective bit rate for all WTs. Therefore mechanisms are needed which protect the system against performance degradation due to the SMPT approach. For example, a base station, which has full knowledge about the dimension of the system, might assign only a limited number of channels to each mobile. Alternatively, a mobile might stop using excessive number of channels if the throughput does not improve. This leads to the assumption that an optimal number of channels can be found, which has low influence on other wireless mobile terminals and assures stability of bandwidth. After bad channel conditions during $\tau_{start} - \tau_{change}$, we compensate the bit rate degradation $\omega = (B_{good} - B_{bad}) \cdot (\tau_{start} - \tau_{change})$ by using multiple CDMA channels. In order to recognize the changes of the link quality an information feedback is needed. In general a CDMA radio front-end can support several channels in parallel. It is obvious that there exists a platform dependent number of channels which can be used in parallel by one mobile. Depending on the system properties this maximum number can even equal one, although a number of channels up to 8 seems to be realistic.

The main analytical problem is to investigate the influence of SMPT on the QoS parameters in terms of jitter and segment losses, as well as these effects with those ones characterizing ordinary sequential transmission.

$$\sum_{\tau_{change}}^{\tau_{stop}} B_{channel} = B_{good} \cdot (\tau_{change} - \tau_{start}) \qquad (1)$$

As mentioned, the simulations have been performed using the `Ptolemy` simulation tool [16] and AKAROA-2 [17]. It required linking AKAROA-2 with the Ptolemy interface `akstars` (see figure 2). We formed a communication system with $3, 6,$ and 9 WTs and one BS. The channel between the WT and the BS was modeled with a multilayered Markov chain, considering two channel states (*bad* and *good*) and the impact of used channels on the BEP. The main parts of the simulation model are the protocol implementations of the WT and BS. Each WT generates a stream of transport units (like UDP segments and therefore called *segments*) with a specific load, and passes these segments to the DLC layer via the network layer, where each of them is divided into a group of DLC packets. To each packet a header with length ζ is added. This header ζ is used to identify DLC packets in the right order and to assign the DLC packets to the appropriate segments and equip them in the means for error detection. The frame, which is composed by one DLC packet and the header ζ is called a **D**ata **L**ink **C**ontrol **P**acket **D**ata **U**nit (DPDU). All DPDUs are stored in a queue with a fixed buffer capacity L_{Queue} within the DLC layer and will be sent with different ARQ based transmission methods over the wireless link. There is no error correction scheme assumed, so packets with one or more bit errors will not be decoded successfully on the receiver side and will be considered lost. If a segment can not be transmitted within given maximum delay and/or a given bounded jitter, the sender side MAC entity will stop transmitting this segment and proceeds with the next segment. The discarded segment will be counted as lost. The receiver side MAC recognizes this loss by detecting the increased segment number in the header of the next received packet. The load generation module generates packets with constant bit rate, allowing variable as well as fixed segment sizes at a specific load level. We neglect the fading effects and assume an optimal power control within the WTs. Nevertheless, using the wireless channel, each WT will influence other WTs by an increased background noise. To get a feeling how SMPT will influence the QoS offered by a wireless link the resulted jitter will be investigated.

3 SIMULATION OUTPUT DATA ANALYSIS AND FINAL RESULTS

As mentioned, all simulation experiments reported in this paper were executed using AKAROA-2. This means that the accuracy of all estimates was automatically assessed sequentially during simulation, and the simulation was stopped when statistical errors of the results reached an assumed accuracy. That was measured by the relative statistical error, defined as the ratio of the half-width of the confidence interval and the point estimate, at a given confidence level. To avoid using the results obtained by too short simulation runs we ran each experiment three times, using different sequences of pseudo random numbers, and accepting the results produced by the longest run only[15]. Conducting steady-state simulation, we have used a standard procedure of AKAROA-2 for sequential determination of the length of the initial transient stage, based on a sequential version of Schruben's test for testing stationarity of time series; see [14] and [11]. On the other hand, output data in steady-state were analyzed by applying the method of **O**verlapping **B**atch **M**eans (OBM), proposed by Meketon and Schmeiser [9]. Our preliminary investigations of the OBM have shown that this method is very robust concerning its underlying assumptions (e.g. independence among batches), and yields confidence intervals containing the theoretical values with probability close to the nominal confidence level, especially in the case of highly dynamic stochastic processes. An analysis of the performance of this method, as applied to queuing networks, can be found in [10].

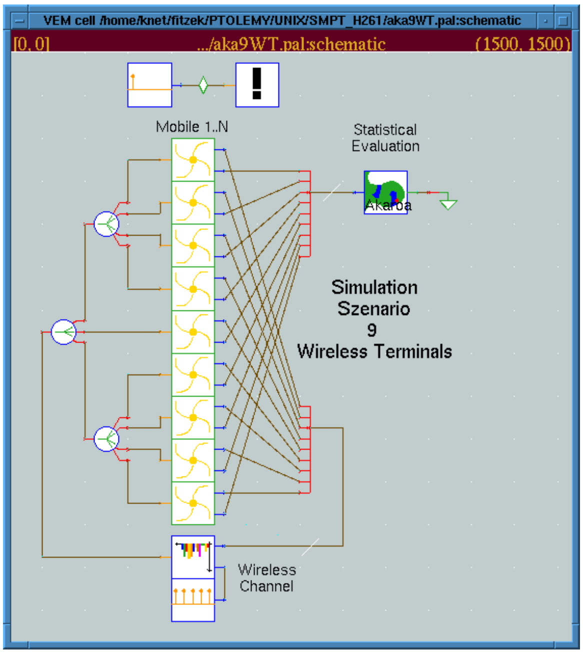

Figure 2: Ptolemy Simulation Scenario with Nine Wireless Terminals and the Akaroa Star

As one can expect, in all considered scenarios of the investigated wireless network the length of simulation was increasing with the number of WTs and the assumed confidence level of results. Figure 3 shows the speedup of simulation executed under AKAROA-2 on 10 processors, for 3 different simulated scenarios. The speedup is measured here as the ratio of the execution time of simulation on one processor T(1), and the execution time of simulation on 10 processors T(10). One can see an important property of MRIP : it performs even

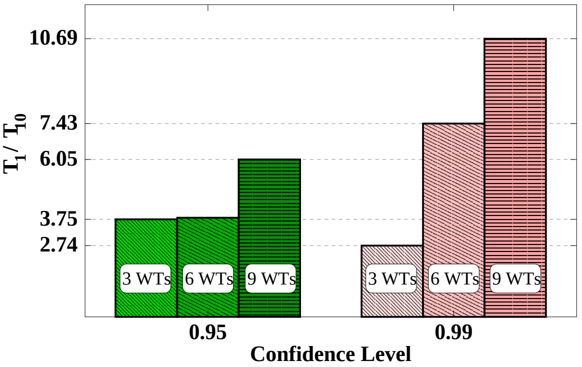

Figure 3: Reduction in Time by Applying MRIP with Ten Processors for Different Scenarios (3 up to 9 Wireless Terminals)

better if one applies it to longer simulations.

Although we have used an almost homogeneous set of processors, the above results can be to some extent inaccurate, as they can vary with the system load of a given **L**ocal **A**rea **N**etwork (LAN). A better way of studying this phenomenon would be to analyze an average number of observations required for stopping the simulation when it reaches an acceptable level of statistical error.

WT		P = 1	P = 10
3	I	0.51/3645/243	0.51/2916/486
	II	0.52/3705/247	0.51/3108/518
	III	0.50/3885/259	0.52/2964/494
6	I	0.51/4464/248	0.54/2976/496
	II	0.51/4035/269	0.51/1614/269
	III	0.50/4608/256	0.51/3072/512
9	I	0.53/2988/249	0.53/4494/749
	II	0.53/3585/239	0.54/5736/956
	III	0.52/3660/244	0.52/4410/735

Table 1: Simulation Results for 3, 6 and 9 WTs (Confidence Level of 95% and Relative Error of 5%)

Table 1 and Table 2 depict the results characterizing the performance of the analyzed wireless network in the three scenarios (with 3, 6 and 9 WTs), obtained when using 1 or 10 processors, and assuming 95% and 99% confidence levels of results, respectively. For each wireless terminal in each scenario, the first value stands for the jitter estimate, the second value stands for the sample size required for achieving the relative error of 5%, and the third value stands for the length of the initial transient phase of the simulation, i.e. the number of observations discarded before the steady state had begun.

WT		P = 1	P = 10
3	I	0.51/5103/243	0.51/7290/972
	II	0.52/5187/247	0.51/6072/765
	III	0.50/4662/259	0.51/7554/1000
6	I	0.51/8928/248	0.54/4464/744
	II	0.52/8877/269	0.51/3228/538
	III	0.50/9216/256	0.53/4572/762
9	I	0.53/10458/249	0.55/9777/486
	II	0.53/10038/239	0.53/13623/518
	III	0.52/10248/244	0.53/12820/494

Table 2: Simulation Results for 3, 6 and 9 WTs with (Confidence Level of 99% and Relative Error of 5%)

One can clear observe that under MRIP, distributing simulation on more processors is much more efficient, as one may need fewer observations for stopping simulation (with the same level of statistical error) than in the case of fewer processors. Different (short) lengths of the transient phases justify the application of the sequential stationarity tests (such as the test implemented in AKAROA-2), instead of discarding an arbitrary (fixed) number of observations. Discarding too few initial observations can lead to statistically biased final results [11], while discarding too many observations would unnecessarily lengthen the simulation.

At the end, let us look at the SMPT results. Figure 4 and 5 show the histogram of the jitter of successfully transmitted network layer segments as a function of the segment length (measured in MAC packets). Obviously the SMPT [1] method provides better results in the sense of jitter. Future applications will need stable and bounded jitter in combination with low segment losses. The resulted segment loss probabilities are shown in table 3 and reflects the fact that with SMPT we can expect performance improvements not only the sense of the jitter but also in the sense of segment losses. Therefore we claim that SMPT is able to support future multimedia applications more efficient than other proposals.

The results presented in Figure 4 and 5 were obtained with the relative error of 1% (at the

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[1] Only three codes were allowed to be used simultaneously.

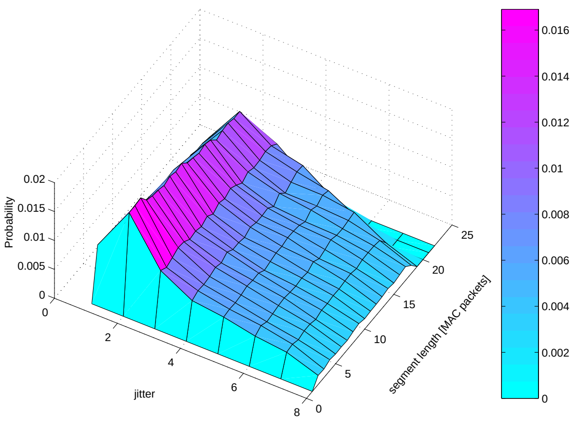

Figure 4: Histogram of the Jitter of Successfully Transmitted Network Layer Segments as a Function of of the Segment Length with Sequential Transmission Method (Confidence Level 99% Relative Error 1%)

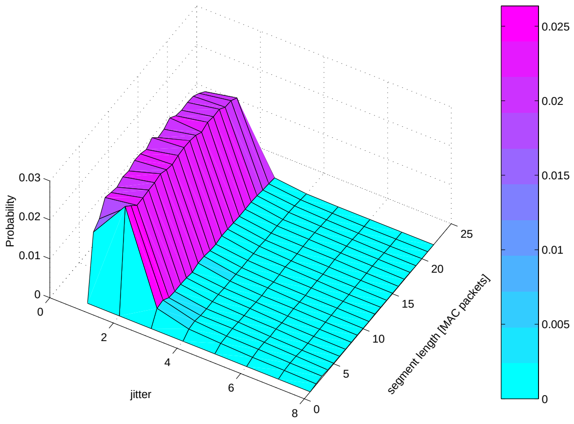

Figure 5: Histogram of the Jitter of Successfully Transmitted Network Layer Segments as a Function of of the Segment Length with SMPT (Confidence Level 99% Relative Error 1%)

Transmission Method	Segment Loss Probability	Mean Jitter [MAC packets]
Sequential	18.24%	2.438
SMPT	11.41%	0.761

Table 3: Losses and Mean Jitter of Segments with Different Transmission Methods for Ten Wireless Terminals (Confidence Level 99% Relative Error 1%)

99% confidence level). They can be compared with those depicted in Figure 6 and 7, obtained with the relative error of 25% (at the 99% confidence level). One can see the importance of using simulation results with appropriately small statistical errors. As Figure 6 and 7 show, the results with too large error may be misleading or, at least, inconclusive. In this context, one could wonder about the credibility of results from stochastic simulation when their statistical error is not assessed at all.

4 FINAL REMARKS

Our results show both importance of sequential analysis of simulation output data, as the only effective way of controlling the statistical error of the final results, and usefulness of parallel simulation in MRIP scenario, as a simple and practical way for speeding up of otherwise very long simulations. Automatic implementation of both these features (the sequential analysis of simulation output data and parallelization of simulation programs) have been incorporated in AKAROA-2. The work on increasing functionality of this package is continued both at the Technical University of Berlin, Germany, and the University of Canterbury in Christchurch, New Zealand.

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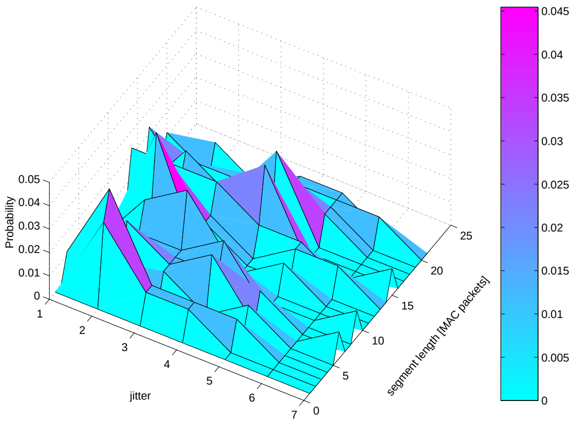

Figure 6: Histogram of the Jitter of Successfully Transmitted Network Layer Segments as a Function of of the Segment Length with Sequential Transmission Method (Confidence Level 99% Relative Error 25%)

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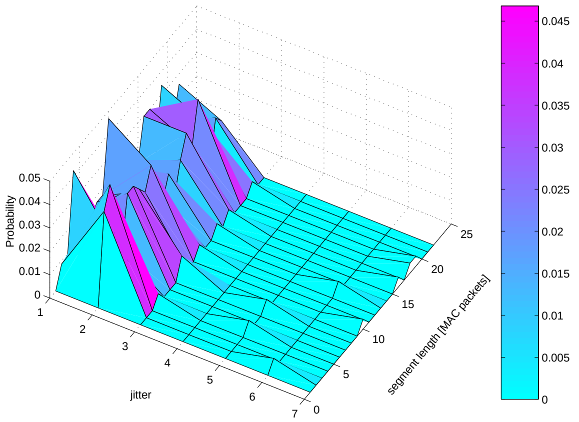

Figure 7: Histogram of the Jitter of Successfully Transmitted Network Layer Segments as a Function of of the Segment Length with SMPT (Confidence Level 99% Relative Error 25%)

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