RANSim: Simulating a W-CDMA Fading Channel with Bursty Traffic Arrivals

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Abstract

This paper details a simulator, RANSim, that was developed to model the data transmission process of a faded DS-CDMA radio channel in a Radio Access Network (RAN). The results are graphs depicting the slot success rate as a function of the number of interfering users and the packet throughput as a function of the offered load of the system. The slot success rate is dependent on the state of the channel during the slot transmission period and the average packet throughput is a good indicator of the performance of the channel.

1 Introduction

There are an increasing number of people using mobile devices to access the multitude of data services that are now available via wireless technology. These services require radio access networks that will support the demand for higher data rates and better quality of service. To satisfy that demand, research needs to be done into what the characteristics of such networks would be. By doing performance testing on networks which do not physically exist, or are not yet fully rolled out, engineers may determine the limitations of these systems, such as the maximum number of users that can be practically accommodated in the system. Thus, performance testing could provide them with an insight into the effectiveness of their specification implementations and on the specifications themselves.

[Landman 2003] developed a simple Hidden Markov Model (HMM), based on a two-state (fade, non-fade) channel scheme to analytically model bursty IP traffic on a Direct-Sequence Code Division Multiple Access (DS-CDMA) radio channel. The motivation for RANSim was to validate the theoretical results of the analytic performance model using a computer simulation, by producing quantitative results which could be compared to the that of the model. The purpose of this comparison served to increase the level of validity of the HMM and to give the author sufficient confidence to be able to analyse trends in the produced metrics.

The layout of the paper is as follows. The next section provides the background information needed to understand the cellular theory behind the simulator. Section 3 is a detailed description of the steps followed to develop a valid solution to the problem. The final section presents the analytical and simulated numerical results for comparison.

2 Background

In Third Generation (3G) cellular systems, communication takes place between a fixed Base Station (Node B) and the User Equipment - UE (the 3G term for mobile devices). A coverage area in a 3G cellular system consists of overlapping cells, with each cell containing relatively low power radio transmitters, namely one Node B and many UE (refer to Figure 1). These UE communicate with other parties through the Node B.

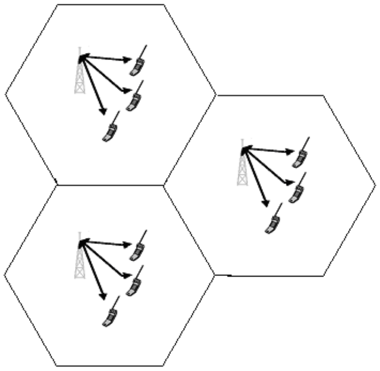


Figure 1: Three Cells Within a Radio Network

The communication from a Node B to a UE is known as a forward link or a downlink. The communication from a UE to a Node B is known as the reverse link or uplink. Downlink data transmission is of more interest to researchers for the following two main reasons.

1. The communication down the radio channel is more likely to suffer errors since the UE can move around, either moving closer to other UE or further from the Node B making communication difficult.
2. Future wireless devices will focus much more on client server communication. In such situations much more data flows from the server to the client than from the client to the server, thus the downlink of the radio channel will be the portion of the network with the bigger demands in situations where there are many users causing low channel throughput and where users demand high data rates.

The performance and capacity of a cellular system is limited by two different phenomena [Kritzinger 2003]:

1. **Multipath fading:** Two types of multipath fading are described below.

   Rayleigh
   Rayleigh fading normally occurs in a Non-Line-Of-Sight environment and is caused by the signal being reflected off objects within the network cell causing multiple signals to arrive out of phase at the receiver. As the UE moves around the cell, some of the reflected signals reinforce the received signal, while others counteract one another. This can result in very high levels of attenuation of the signal. Thus in a Rayleigh fading environment there will be rapid changes in the amount of fading that the receiver is experiencing.

   Ricean
   Ricean fading normally occurs when there is a dominant signal, such as in Line-Of-Sight environments as is typical for stationary UE.

2. **Multiple Access Interference (MAI):** Wideband (W) CDMA uses DS-CDMA as a multiple access technique in that one frequency channel is used for both the uplink and the downlink. This allows multiple users to simultaneously share the same spectrum (i.e.channel frequency) by bundling serveral user signals together for transmission over the radio-channel. To detect the signal of a certain UE, the received signal is decoded with a user specific pseudo noise (PN) code. However, these PN codes are not perfectly orthogonal, and this results in each user signal appearing as low-level background interference to all other user signals on the network, called MAI. This interference varies with time and, as more users access the network, MAI increases and the quality of the received signal decreases. While the MAI caused by any one user is generally small, as the number of interferences increases the MAI becomes substantial.

As suggested by [Landman 2003], packet traffic is carried along Dedicated Channels (DCH), but for a high packet inter-arrival rate or large size packet occurrences, the Radio Link Control (layer 2 of the radio interface) buffers get filled and queuing takes place. This causes data to be transported on the Dedicated Shared Channel (DSCH). Since this project attempts to assess the maximum number of users that the network could accommodate, the DSCH is modelled.

3 Approach

RANSim is a software tool that dynamically simulates a DS-CDMA fading channel between the Node B and a single UE. RANSim models only downlink data transmission for the reasons listed in Section 2. The model takes into account that there could be more than one UE in the cell, wanting to transmit data simultaneously, thereby causing interference for the transmission of data addressed to the desired user. This interference is related to the total number of UE in the system:

- Those UE that are **contending** for slots on the same channel (i.e. the DSCH) as the desired user.

- Those UE that are using other channels in the network, and are the cause for the majority of the **interference** to the desired user's transmission.

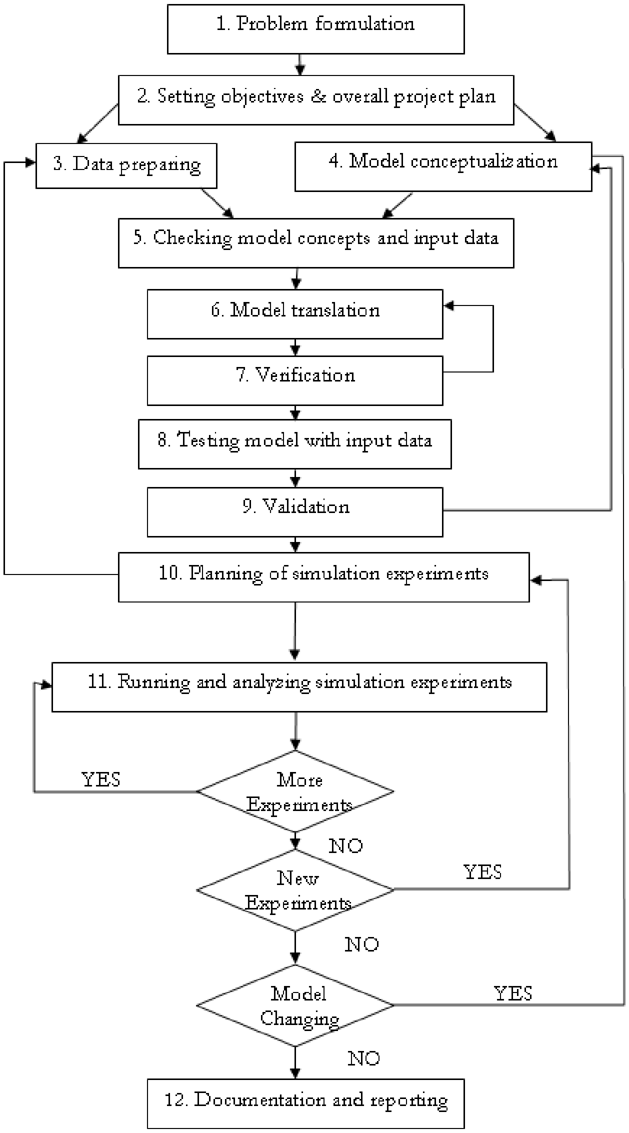


Figure 2: Development steps of RANSim

Figure 2 modified from [Banks et al. 2001] illustrates the steps followed to develop RANSim. A synopsis of each step is given below.

3.1 Problem Formulation

Every simulation study begins with a statement of the problem. This phase involved reading through the Third Generation Partnership Project (3GPP) specifications and consulting the author of [Landman 2003] to elicit the requirements of the system.

3.2 Setting Objectives and Overall Project Plan

Objectives of the study were specified at this stage. The overall plan for reaching these objectives included identifying involved people, deciding which language to program in, identifying which simulation type would develop from the real-world system, listing of the parameters to be varied and alternatives to be tested, drawing up the project planning, etc.

3.3 Model Conceptualisation

This refers to the specification of an operation algorithm of the simulated system. The real-world system under investigation was abstracted by a conceptual model. The problem was divided into two sections:

Graphical User Interface (GUI)
Since the purpose of the simulator is to allow the user to investigate the performance of the modelled DSCH under different channel conditions, a user-friendly interface was needed to allow the user to specify the properties of the DS-CDMA downlink radio channel to be simulated. The virtual radio channel is then simulated and the GUI presents the performance metrics in graph output for evaluation.

Simulation Engine (SE)
To implement the SE, a conceptual model of the physical system was defined. Before code translation of the conceptual model took place, the model was validated to ensure that it had been abstracted to the appropriate level for the problem. The computer model was then verified to ensure that the system model had been correctly implemented. Since the primary task of the SE is to simulation the communication of radio-frames from a Node B to a UE, the basic components of every communication system as defined in [Haykin 2001] was used to highlight the flow of traffic through RANSim. Figure 3 shows the identified components.

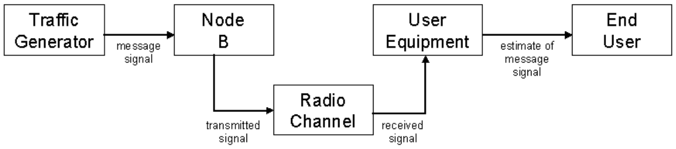


Figure 3: Conceptual Model Showing the Flow of Data Through RANSim

3.3.1 SE Component Descriptions

Traffic Generator
The Traffic Generator generates packet sizes and inter-arrival times for packets of all user connections in the DSCH. These values are generated according to empirical models as specified by the user. This information is used to produce data for the IP packets which are sent to the Node B and queued to be processed.

Node B
The Node B component implements the simplified Node B functions. It receives packet traffic for all UE connections to the DSCH from the Traffic Generator. It segments the received packets into fixed size slots and stores them in an ordered queue. Upon availablility of a radio-frame from the DSCH, the Node B is responsibile for inserting these slots into the radio-frame until the radio-frame has no more available slots and buffers the remainder for the next radio-frame, or until there is no more UE data. The Node B inserts slots from the available contenders according to the specified slot scheduling algorithm.

Radio Channel
The Radio Channel component is a simplified model of a physical W-CDMA 3G radio channel. At the start of every time interval (for example, 10 milliseconds) a frame is transmitted. This frame transmission takes into account both the multipath fading and MAI that the frame is exposed to.

User Equipment
This component models an individual UE. Upon receival of a frame containing multiple slots, for all DSCH contending users - it extracts its own slots. It checks each slot for errors. If there is an error, it needs to request a retransmission from the Node B. If there is no error, it should wait until all slots of a packet have been received and can then reconstruct the original packet.

3.4 Data Preparation

This step was to ensure that the model produces realistic results, by ensuring that the input data was representative of that in the real world. To model the random behaviour of the identified components, probabilistic expressions were used, for example to as a solution to the traffic generation problem, the inter-arrival time (the time between packet arrivals) was modelled by means of a two-state exponential distribution and the message size (the size of the packets arriving at the Node B for processing) was modelled by means of a geometric distribution. Statistical considerations were taken into account when describing the random variables used in the system.

3.4.1 Characteristics of Traffic Generation

To model the traffic of our system, we need to calculate the **sizes** and **arrival times** of all the packets that are going to be transmitted over the channel during a simulation run.

Inter-arrival Times
In the simulation model, traffic arrives at the Node B for a particular UE, as two independent Poisson processes G_1 and G_2, which are modulated by probabilities as described below.

- G_1 corresponds to Poisson arrivals at a low rate, and r_1 is the probability of moving from G_1 to G_2
- G_2 corresponds to Poisson arrivals at a high rate, and r_2 is the probability of moving from G_2 to G_1

The effective combined Poisson arrival rate, G, which is used to develop the HMM in [Landman 2003], can be written as

$$G = \frac{r_2 G_1 + r_1 G_2}{r_1 + r_2}$$

In the Poisson Process, the number of arrivals in a time interval of size τ has a Poisson distribution:

$$P(A(t+\tau) - A(t) = k) = e^{-G\tau} \frac{(G\tau)^2}{k!}$$

where $A(t)$ is the number of arrivals up to time t. The parameter G is known as the **rate** of the process, because in t time units, Gt arrivals will occur. This means that packets arrive at a rate of G per time interval.

Packet Sizes

In our model we assume that IP traffic arrives at the Node B as packets of independently varying lengths for transmission to the UE. Therefore, we define packet length, that is the number of data bits per packet, l, to be geometrically distributed:

$$P_{pkt\_length}(l) = P(l) = (1-b)^{l-1}b$$

where the mean packet length is b^{-1} bits.

Fading

The general Ricean PDF is given by

$$\begin{aligned} P_{sig}(u) = {} & \frac{(1+K)}{\bar{p}} e^{-K} u e^{-\frac{1+K}{2\bar{p}}u^2} \\ & I_0\left(\sqrt{\frac{2K(1+K)}{\bar{p}}}u\right), \quad u >= 0 \end{aligned}$$

$I_0(x)$ is the modified Bessel function of the first kind and order zero [Haykin 2001], where $\bar{p}$ is the local mean power given by $\bar{p} = \frac{1}{2}A^2 + \mu$. K is defined as the *Rice Factor* and represents the ratio between the LOS component of the signal and the scattered component. If $K = 0$, the distribution becomes a Rayleigh faded distribution. [Landman 2003]

3.5 Checking Model Concepts and Input Data

All decision-makers for the simulator met regularly to discuss decisions made about the conceptual model and descriptions of the input data. An example of this was the discussion of which types of probability distributions should be used to describe the random input variables.

3.6 Model Translation

The conceptual model constructed in Section 3.3 was coded into a simulation model using Microsoft .NET C#.

3.7 Verification

This refers to the process of determining whether the program is an accurate and acceptable implementation of the conceptual model. Verification for the simulator was achieved through two types of techniques:

- **Common sense techniques** which included an intensive walk-through of each component to ensure that the resulting output was correct for simple cases. Multiple output files were written to ensure that the relevant variables behaved as expected. C#'s debugger was also used check the system flow and ensure that the model was correctly implemented.
- **Documentation** included commenting of code and report writing.

3.8 Testing the Model with Input Data

Here sensitivity of simulation results was checked towards changes of parameters of probability distributions for model random input variables. If some of the parameters seemed to be critical from that point of view, it was checked to see if their values were modelled precisely enough. If not, additional efforts were made when specifying values of these parameters.

3.9 Validation

This refers to determining whether the conceptual model is an accurate representation of the real system. The ideal way to validate a model is to compare its output with that of an existing system. Unfortunately in the case of RANSim, this was impossible - however many alternative methods were used such as the restriction of following the steps illustrated in Figure 2.

3.10 Planning of Simulation Experiments

Experiments with the simulation model were planned by making various decisions including:

- choosing input parameter values to be investigated or tuned,
- deciding how many simulation runs were to be performed for each experiment,
- determining the length of simulation runs and
- deciding on the warm-up period needed before the virtual channel was in a steady-state.

3.11 Running and Analysing Simulation Experiments

Simulation experiments were performed in this step in accordance with the above-developed plans, and the results were accordingly analysed to estimate measures of performance for the scenarios that were simulated.

3.12 Documentation and Reporting

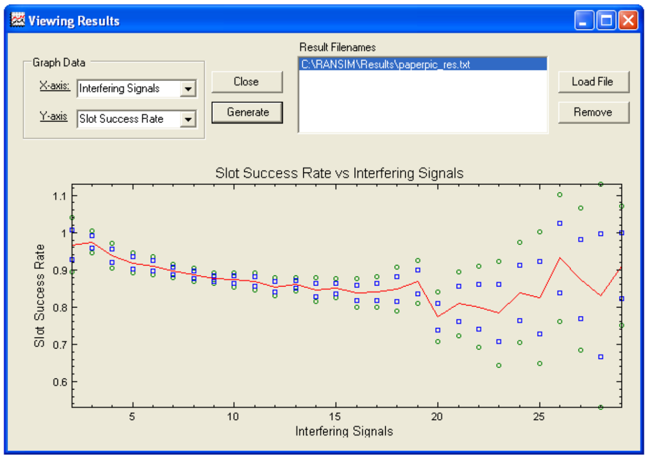
Documentation is needed for many reasons. If the simulation model is going to be reused, it may be necessary to understand how the simulation model operates in order to give the user confidence in the implementation thereof. Another example of the importance of documentation is that it facilitates the modification of a system if the workings of the system are well described.

4 Results

4.1 RANSim Graph Interpretation

Figures 4 and 5 are screen shots of RANSim depicting the typical output presented to the user. Figure 4 is a graph of the slot success rate vs. the number of interfering signals in the network. The red line shows the mean of of the observations per unique number of interfering signals. The blue squares indicate the upper and lower standard deviation from the mean, while the outer green circles plot the % confidence interval range (in this particlar case 95%) of the mean. One can see that the confidence levels decrease dramatically around twenty interfering signals. This can be avoided if the simulation is run for a longer period.

Figure 5 is a screen shot illustrating the performance metrics of the packet throughput vs. the offered load of the system for a number of simulation runs. The packet throughput is the fraction of the offered load G (described in Section 3.4.1) that is successfully transmitted across the channel in a time slot.



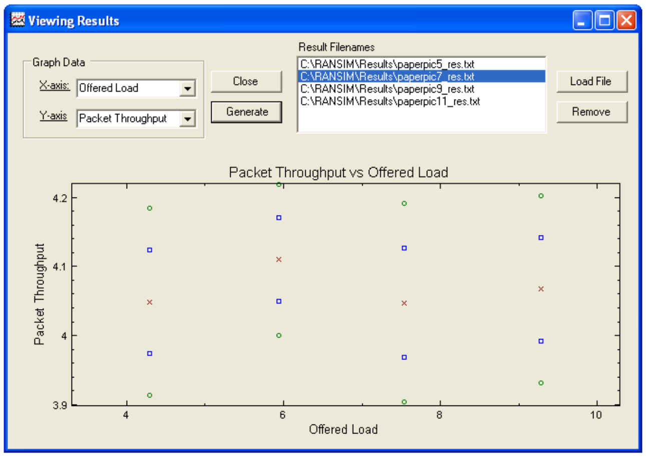
X-axis: Interfering Signals

Y-axis: Slot Success Rate

Result Filenames

C:\RANSIM\Results\paperpic_res.txt

Figure 4: Sample Screen Shot of RANSim Showing the Slot Success Rate as a Function of the Number of Interfering Signals



X-axis: Offered Load

Y-axis: Packet Throughput

Result Filenames

C:\RANSIM\Results\paperpic5_res.txt
C:\RANSIM\Results\paperpic7_res.txt
C:\RANSIM\Results\paperpic9_res.txt
C:\RANSIM\Results\paperpic11_res.txt

Figure 5: Sample Screen Shot of RANSim Showing the Packet Throughput as a Function of the Offered Load of the System

4.2 Comparison of Results with HMM Output

In [Landman 2003], θ is defined to be the MAI signal to user signal ratio threshold which determines what state the channel is in. To correctly parameterise the HMM, an approximate value for θ needed to be found. The author of [Landman 2003] did this by comparing the results of the simulator to the results of the HMM for various values of θ. Figures 6 and 7 compare the slot success rate vs. the number of intering signals for the HMM model, and the simulator model. As is expected, the higher the number of interfering signals the lower the probability of slot success.

Graph 7 shows a graphical comparison between the Slot Success Rate vs. the Number of Interfering Users results from the simulator and the HMM for Ricean fading. Graph 6 shows a graphical comparison between the Slot Success Rate vs. the Number of Interfering Users results from the simulator and the HMM for Ricean fading.

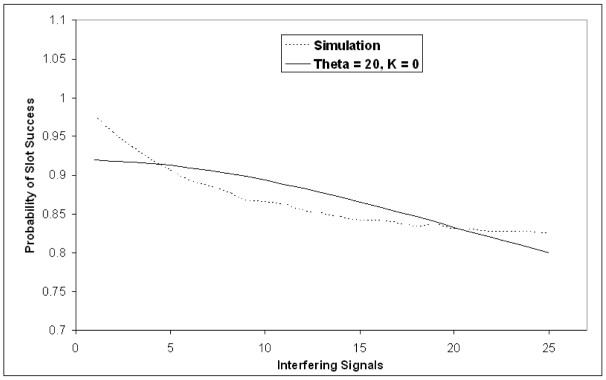


Figure 6: Slot Success Rate as a Function of the Number of Interfering Signals for Rayleigh Fading

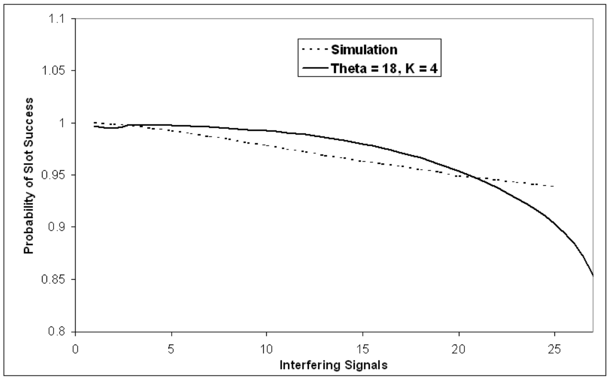


Figure 7: Slot Success Rate as a Function of the Number of Interfering Signals for Ricean Fading

5 Conclusion

Through our project methodology, the simulator achieved a high enough level of validity to give the HMM sufficient confidence that it models the real-world accurately enough to be used for analysing the performance characteristics of a DS-CDMA channel with bursty traffic arrivals.

6 Acknowledgement

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