

# **AERONAUTICAL CHANNEL SIMULATION IN NETWORK SIMULATORS FOR INCORPORATION INTO OPNET**

**Author: Tianyin Zhang and Nur Jaber**  
**Advisor: Dr. Richard Dean**  
**Morgan State University**

## **ABSTRACT**

This paper discusses channel simulation using OPNET Modeler in support of iNET. It shows how wireless communication is simulated, how to simulate the special aeronautical channel of iNET, and how to deliver the aeronautical channel, test article, and ground station as reusable components for future simulation. Network simulation is a critical tool for iNET and it enables design decisions that cannot be made analytically due to the complexity of the problem. This work addresses the incorporation of the aeronautical channel into the OPNET Modeler tool set as this piece of iNET is unique and is not available in OPNET Modeler.

## **KEYWORDS**

iNET, simulation, Markov, channel, OPNET

## **INTRODUCTION**

The iNET study is aiming at adapting cutting-edge network technologies to replace the current inefficient point-to-point telemetry system. The new Telemetry Network System (TmNS) will have test articles, ground stations working together with an interconnected packet network [1]. The ground station may request data generated by the sensors that are equipped on test articles. Raw data will be packetized within the test article intranet then sent to the ground station via an aeronautical channel.

Currently, network architectures are being developed by the iNET community. Verification of these new designs is of great importance before putting everything into practice. This could be done by building the proposed designs and testing them physically or by using computer software simulation tools. Although physical testing is the ultimate measure for any network design, it is a very costly and time-consuming process due to the nature of the test subjects. Furthermore, flexibility is a major issue when testing a network as large and complex as iNET. Therefore, simulation of iNET is of vital significance because it produces faster, reliable and more cost-effective results than actual testing.

OPNET Modeler is our choice as the simulator for the iNET simulation task by the research team at Morgan State University (MSU) based on its advantages of graphical user interface and strong community support. The objective of the research team is to provide the iNET community with a toolbox in OPNET Modeler that will allow engineers and researchers run and customize iNET simulations. In this paper, we focus on the aeronautical channel, explain why it's critical and provide methodologies to simulate it in OPNET Modeler.

At MSU, channel modeling and modulation schemes are two of the major research focus areas, where integrating a specific aeronautical channel and coding scheme into a network simulation to generate realistic testing data. Incorporating these into simulators such as OPNET to support the development of new protocols and to plan operational testing has significant potential impact to the iNET program.

## **BACKGROUND**

When a test article communicates with a ground station, it sends packets through radio link just as a personal computer exchanges information with a wireless router in a Wireless Local Area Network (WLAN). However, there is significant difference between these two environments. Computers within a WLAN tend to be static while test articles may be operating at a velocity of Mach 2. As a result, there are large Doppler Shifts and multipath fading in the iNET environment and they make communications over the aeronautical channel critical. If we had a computer that operates in a WLAN moving in such high speed, the performance of the network will degrade dramatically. Additionally, with a maximum transmission data rate of 5 Mbps, it is required to balance the high data throughput and flexibility [1]. Therefore, evaluating the performance of the telemetry network system is of great importance. To do this in a simulation, components such as the test article, ground station, gateway and the aeronautical channel must be implemented in a simulator. Although there are several standard protocols and components such as TCP/IP and WLAN in modern simulators, the iNET components such as aeronautical channel, test article and ground station are yet to be created and they are unique to the iNET environment.

OPNET Modeler has been selected as the simulator for iNET by the research team at MSU. It has several advantages over the other two candidate simulators, NS-3 and QUALNET. OPNET Modeler provides graphical user interface (GUI) as well as a number of editors to simplify modeling in different levels. It also has an effective supporting team and an active developing team that keep the software up to date. As mentioned before, although OPNET Modeler provides a toolbox for standard components such as WLAN, components unique to iNET are yet to be created. This paper describes providing an aeronautical channel component for OPNET Modeler so that engineers in the iNET community can make use of it and customize their simulations. Test article nodes and ground station nodes can then be used as a prototype on this channel.

OPNET Modeler is a packet simulator. Instead of manipulating the signal directly, it simulates networks based on its packet behavior. Computations about fading effects, multipath, path loss, etc. will be associated with each packet and eventually determine if the packet is going to be received by the destination or dropped. This approach fits the new iNET Network Telemetry System since it is aiming to adapt networking technologies into the current telemetry architecture.

OPNET Modeler uses what so called Radio Transceiver Pipeline to model wireless transmission. Each stage does necessary computations and stores results in the packet. Computations include possible receivers, path loss, received power, signal to noise ratio at the receiver, bit error rate, packet error rate, and more. Every packet sent by the transmitter goes through all the pipeline stages and eventually to the receiver where it is determined if the packet is lost due to packet error. The iNET Aeronautical Channel creates a unique fading effect which impacts the SNR yielding a dynamic bit error rate on the packet. The major challenge is how to build a channel that captures all those fading effects without the elaborate processing that would be required for a physical simulation. To do so, we introduce the Markov Model to create a customized SNR Stage of the Radio Transceiver Pipeline in OPNET Modeler. This captures the properties of the packet behavior on the channel without that associated complexity.

### MARKOV MODEL

Markov Model has been used for channel approximation and is considered to be accurate [2]. A Markov Model consists of a set of states and a transition matrix M. It works in a similar way as a finite state machine. The probability of the next output of the system depends only on the current state and the transition matrix as

$$P(X_{n+1}|X_1, X_2, \dots, X_n) = P(X_{n+1}|X_n) \quad (1)$$

Where,

$P(X_{n+1}|X_n)$  = Probability of  $X_{n+1}$  given  $X_n$ .

With the help of Markov Model, it is possible that we can capture the unique pattern of aeronautical channel and model the Doppler and multipath fading it causes. To do so, we may define different states that indicate specific channel conditions as well as the Transition Matrix. Here is an example of a simple Markov Model that simulates a channel with two different states, namely a good channel and a bad channel. When staying in a good channel state, the Markov Model yields an SNR of 30dB. A bad channel, on the other hand, will produce an SNR of 5dB. The Transition Matrix M is defined as follows:

$$M = \begin{bmatrix} 0.8 & 0.2 \\ 0.7 & 0.3 \end{bmatrix} \quad (2)$$

Where,

M = Transition Matrix.

The model can be described by Figure 1.

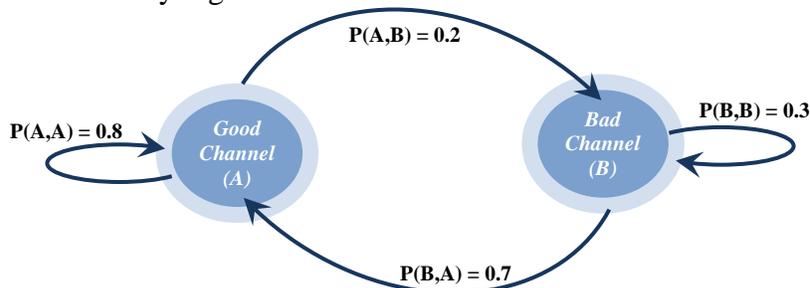


Figure 1: Markov Model based on Equ. 2.

It means that the probability of staying in the good channel is 0.8 if currently the system is in the good Channel state and a 0.2 probability of transitioning into the bad channel state. In the same way, the second row defines the behavior of the bad channel state. Such a Markov Model will produce the following signal series in Figure 2.

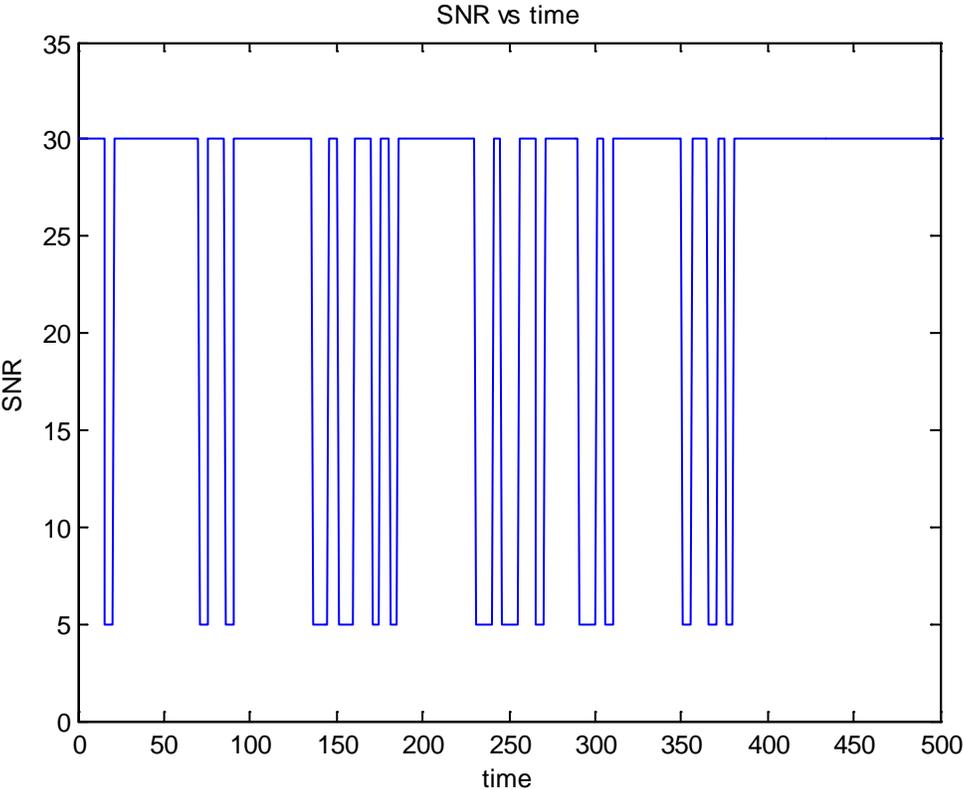


Figure 2: Output of Markov Model

To model the fading effect of the Aeronautical Channel, we use Markov Model to create an impact factor on the received power at the receiver. As mentioned before, different states may be defined to represent various channel conditions such as good channels, bad channels, or different fading effects. By properly composing the parameters of the Markov Model, we may create an Aeronautical Channel that is very close to a real channel. The question now becomes how to build the Markov Model into OPNET Modeler.

As described above, OPNET Modeler uses the Radio Transceiver Pipeline to model wireless transmission. When a test article sends a packet to the ground station, it goes through 14 pipeline stages before it reaches the destination. Figure 3 shows the Pipeline stage model.

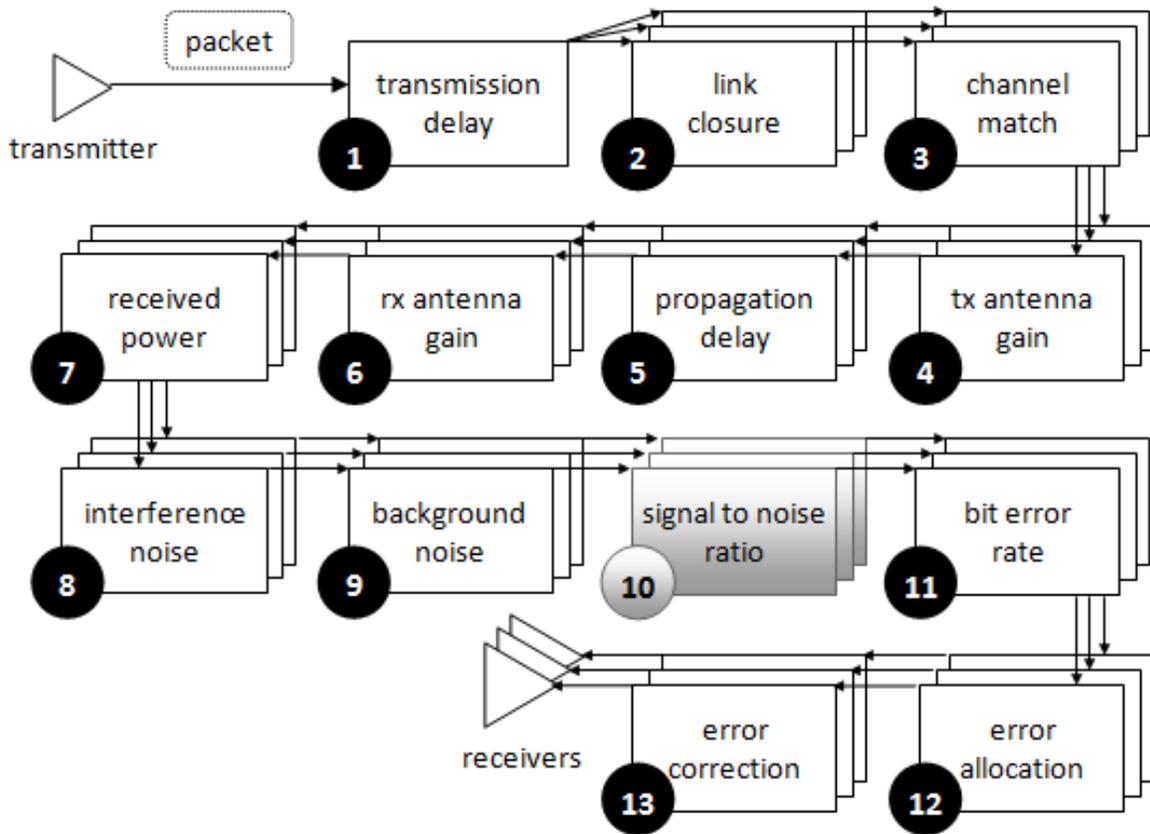


Figure 3: Pipeline Stage Model with SNR Stage Customized

At each stage, certain computation and operations on the packet will be performed by the simulator. Transmission delay, propagation delay, antenna gain, received power, interference, noise, signal-to-noise ratio, and bit error rate will be computed respectively in sequence. Finally at the receiver, the simulator determines if a packet should be accepted or rejected due to packet errors. The pipeline works similarly for the TCP/IP protocol stack. Each stage in the pipeline can be customized to provide new functionalities. The OPNET Modeler offers several models such as WiMax, WLAN, and more. We developed a customized iNET aeronautical SNR stage which integrates a Markov Model that can model aeronautical channel behavior.

## COMPONENTS FOR THE SIMULATION

In order to create a simulation scenario and test the Markov Model design in OPNET Modeler, a package of components need to be implemented first. It contains network nodes such as the test article and the ground station; the aeronautical channel as the communication media between them; Raw Data Generator inside the Test Article such as Sensors and Data Acquisition Units (DAU); and Data storage inside the Test Article such as the Recorder. This paper only shows a prototype of these components to demonstrate the feasibility of Markov Model incorporation with OPNET Modeler.

## TEST ARTICLE

The Test Article is implemented as a mobile node in the OPNET Modeler. As a prototype implementation, it contains several Data Acquisition Units, a Recorder, a Radio Transmitter and Antenna, as shown in Figure 4 below.

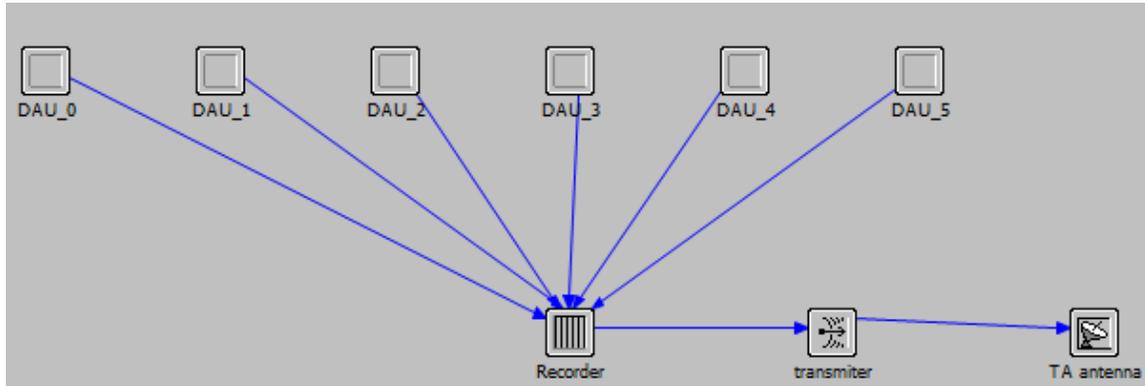


Figure 4: Test Article

Each DAU is generating raw packets at a rate of 1024bps with either constant rate or with some exponential probability. At the Recorder, data gets passed to the radio transmitter and then the antenna. The transmitter is operating at a base frequency of 1GHz, with a bandwidth of 5000 KHz, which produces a data rate of 5 Mbps. This is the maximum data rate that can be archived. In this demonstration we place 6 DAUs in the test article. Therefore the data demand is about 6 Kbps. When a simulation is customized, this can vary to any configuration. The transmission power allocated to packets transmitted through the channel is set to be 1 watt. The antenna offers a transmitter Gain of 1db.

The transmitter object has specified the first six stages of the radio link pipeline stages. The receiver group model is set to the default radio receiver group model since this is a simple point to point radio transmission. The transmission delay model is set to default currently. However, as the Ethernet in the Test Article grows larger, it is possible that the transmission delay will be affected by the potential collision or queuing issues of the network.

## GROUND STATION

The ground station will be communicating with test articles. As a prototype implementation, it contains a radio receiver, antenna, and data sink which is in charge of packet destruction, as shown in Figure 5.

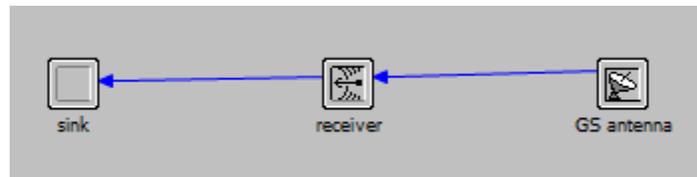


Figure 5: Ground Station

The receiver Gain is set at 15db. It is done by customizing the Ground Station antenna which is derived from the isotropic antenna model. A 15db Gain is assigned to every direction of an isotropic antenna.

The customized SNR stage used for simulating the aeronautical channel has been implemented and associated with the receiver at the ground station. We use a three-stage Markov Model to simulate an aeronautical effect. Due to Doppler Shift, multipath, shadowing and test article status the channel quality may drop or vary significantly. Such effects are considered unique features of an aeronautical channel. The Markov Model is used to capture such effects.

Parameters used for the Markov Model are as follows:

$$S = [0.99 \quad 0.5 \quad 0.01] \quad (3)$$

$$M = \begin{bmatrix} 0.7 & 0.2 & 0.1 \\ 0.8 & 0.2 & 0.0 \\ 0.9 & 0.0 & 0.1 \end{bmatrix} \quad (4)$$

Where,

S = State Definition, M = Transition Matrix.

The model defined has three states, indicating three different channel conditions. The first state represents a good channel. The second state represents a normal channel and it is used to model a varying effect. The third state represents a bad channel that will create a sudden fall in signal-to-noise ratio. These were chosen for this example. Real data values can be substituted later.

## **SIMULATION SCENARIO AND RESULT**

The scenario is defined as follows. A test article starts at San Francisco and flies southeast to Ensenada, 570 miles away from the starting point. The test article has a ground speed of 670 miles per hour. The ground station is located near San Francisco. The simulation lasts 1 hour. During the simulation, the test article will communicate with the ground station while flying to its destination. Figure 6 shows the scenario in OPNET Modeler.

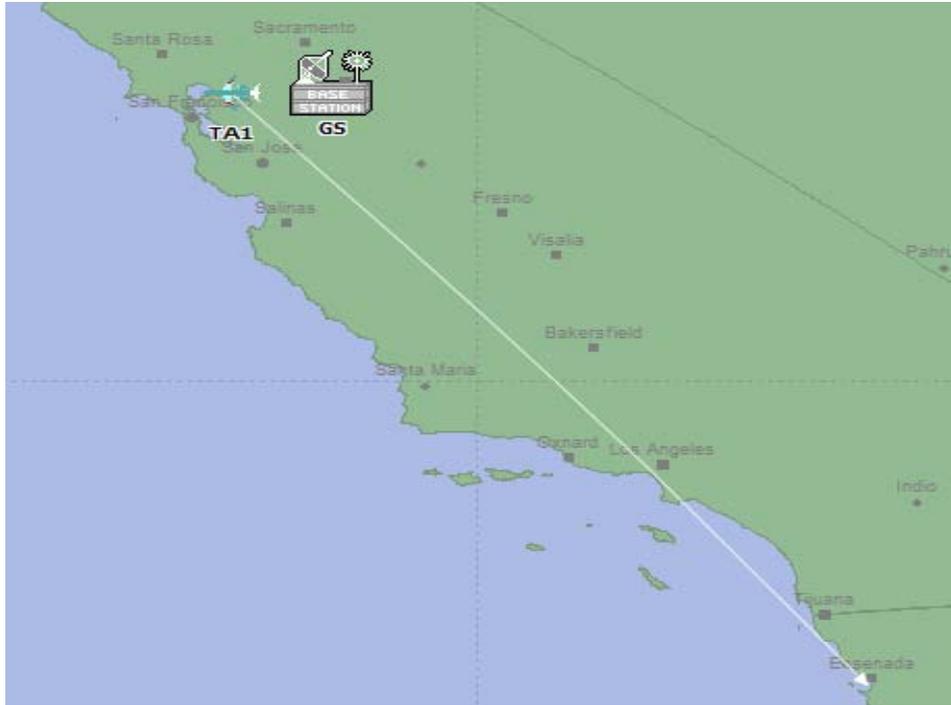


Figure 6: Simulation Scenario

Two configurations are performed and are compared in Figure 7. The left chart shows the bit error rate, signal-to-noise ratio, and throughput of over a simple wireless channel. The right chart shows the same data over the Markov Model driven aeronautical channel. It shows that the Markov Model successfully created an aeronautical effect which can be seen on the signal-to-noise ratio and bit error rate.

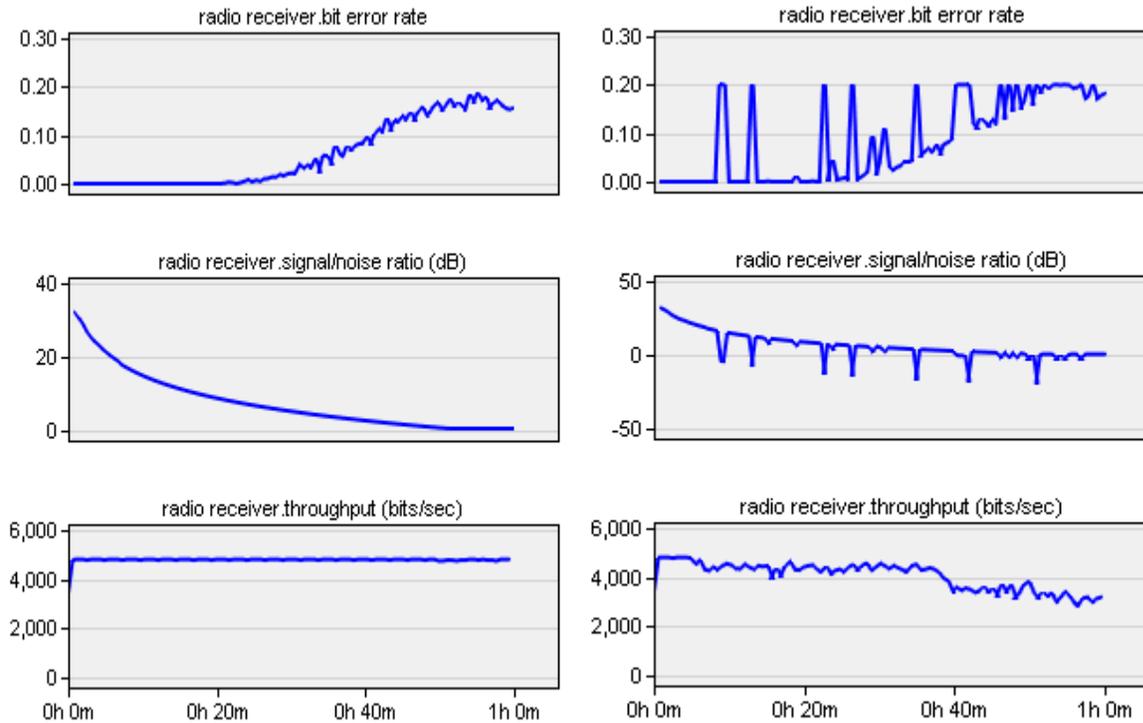


Figure 7: Comparison between default wireless channel and customized channel

## ESTIMATING THE PARAMETERS: HIDDEN MARKOV MODEL

For now we have customized channels in OPNET Modeler. The next step is to build an aeronautical channel based on real data. The question is how to find the parameters for the Markov Model to create exactly the same aeronautical channel based a current testing database. To solve this problem we use the Hidden Markov Model [4]. It can learn from the data to create a good Markov Model which is able to originate data with similar signature.

Studies about Hidden Markov Model have demonstrated that Baum-Welch algorithm can be used to find the Markov parameters. It can be used to read the data and produces a corresponded Transition Matrix.

The overall channel modeling flow chart is shown in Figure 8. The Hidden Markov Model produces parameters for the Markov Model based on aeronautical data. The Markov Model, implemented in the simulator, will then be in charge of producing simulated data.

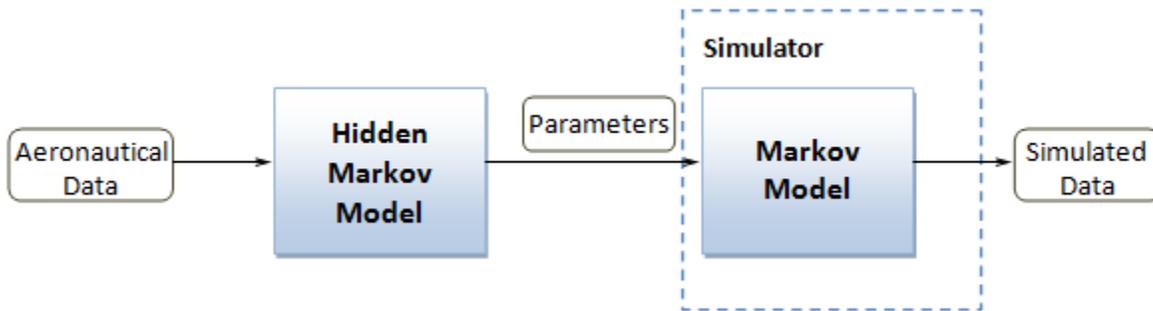


Figure 8: Hidden Markov Model and Markov Model Simulation Flow Chart

## CONCLUSION

Markov Model is a good tool and can be used to model the aeronautical channel which is of great importance in the iNET environment. We implemented a Markov Model driven channel into OPNET Modeler as well as a prototype of a test article and a ground station node model. Simulations have been performed to show that both the Markov Model and the new components such as test article and ground station can cooperate well.

## ACKNOWLEDGEMENTS

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