Concepts of Networking Technology: Uncertainties in Future Networks

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***Chapter 1*: The puzzle: The Uncertainty Within:**

In this chapter we introduce the subject of uncertainty and in particular discuss the uncertainty equilibriums that directly affect design of networks. We show how despite the minimal knowledge we have today on quantifying and rectifying uncertainty equilibriums that affect world wide networks we still have created, somewhat unknowingly, a series of solutions that eventually reduces the impending uncertainty in networks. Such solutions and their motivations are discussed in this chapter

In this chapter we first define what uncertainty means, and how it relates to networks. We then define mathematical tools that would be used in this book to define uncertainty.

- Axioms: that specify properties associated with uncertainty.
- Interpretations: defining the link between observed phenomenon, (like bursty IP traffic) and with the axioms associated (Self Similar property of data sources). This tool involves, classical interpretation, frequency interpretation (how often does the uncertainty appear) and subjective interpretation.
- Measurement Procedures: facilitating methods to quantify uncertainty.

We then consider the basic notion of uncertainty in networks, from a fuzzy logic perspective and postulate operators (Boolean AND and OR) for associated uncertainty. The chapter defines three types of uncertainty related to networks:

- Volitional Uncertainty: this is associated with the decision a subject of interest would independently take, like a reconfigurable optical cross connect etc.
- Aleatory and Epistemic Uncertainty: The former is due to natural variations in a system (Jitter and Wander in SONET/SDH add-drop multiplexers). The latter is due to a unavailability of system information – the uncertainty involved in provisioning and the resource availability in geographically disjoint paths are two examples of these.
- Parameter and Model Uncertainty: Parameter uncertainty deals with the Boolean aspect of parameters involved in networking equipment. Parameters like buffer states, QoS and switching are all examples of parameter uncertainty. Model uncertainty on the other hand is the super set of all uncertainties and can be defined on a macro scale. It gives the absolute uncertainty associated with a system under our test. Leading mathematician Kolmogorov called this as the 'Uncertainty about the Truth of the Model'. This gives reliability and throughput of a network / network equipment.

Finally, we will build some mathematical expressions for understanding uncertainty. We will discuss Savage's axioms for rational decisions and extend this axioms for network elements through quantitative probabilistic methods. The chapter has a detailed appendix on Bayesian inference, Classical Statistical inference, and Hypothesis testing.

***Chapter 2*: The four legs of the chair: Aggregation, Switching, Scheduling and Transport**

Moving into real-time networks, we realize that efficient data flow, provisioning and eventually communication has four primary issues to be solved. These are aggregation, switching, scheduling and transport. We discuss the unified problem and then how over the generations of research, the problem was broken down into these 4 broad horizontal integrands.

This chapter talks about the technology aspect of uncertainty. We begin by venturing into Weibull's Analysis and Wiebull's distribution for axioms of uncertainty, reliability and basic analysis. The extension of the Weibull Analysis to Bayesian and Classical techniques leads to the Weibull estimation. We in this chapter further extend this estimation to networks. The three parameter Weibull distribution is extended to all four legs of the uncertainty equilibrium – aggregation, switching, scheduling and transport. For understanding the limits of the four network phenomenon's we consider, we will introduce another estimator – The Kaplan-Meier Estimator.

As an example, this chapter will consider the evolution of multi-service provisioning platforms (MSPPs) and MSSPs (service platforms) as an example of unified multi-layered complex solution and show how the Weibull Distribution can be fit to these emerging technology solutions.

Case Study: Monte Carlo Simulation of Networks

- Cooke's theorem for uncertainty and our interpretation for networks
- Non-linear model of uncertainty and its simulation
- Elements of DFT (discrete Fourier transform) model

***Chapter 3*. The relational/volitional/Parameter uncertainty: non-linear phenomenon**:
The relational uncertainty has solutions involving breaking the problem into multiple sub-problems. The unified problem of uncertainty faced in world-wide networks is almost impossible to solve using direct solutions due to economic as well as management issues. However, the problem can be broken into components, such that each component can be solved in a drastically simple way, creating near optimal local solutions. The vast standardization process by multiple world bodies means that the local solutions catered towards the fragments of the main problem are well accepted and in some cases even considered complete. We look at such cases first and then understand the reality behind the actual problem – whose solution is of course non-linear in time.

The relational uncertainty of this chapter, examines the effect of solving one part of the uncertainty for a specific purpose, while leaving the other aspects unaltered. We observe the bearing such systems have on a global network.

***Chapter 4*. Heuristic and Deterministic Solutions for Aggregation:**

The over provisioning approach. In this chapter, we consider a widely accepted and broadly deployed approach to creating a heuristic solution for dealing with apparent uncertainty in aggregation – by over provisioning networks. We calculate the benefit of over provisioning networks in terms of popular metrics such as cost and performance. The general observation of this chapter is that over provisioning creates a ripple in the end-to-end uncertainty equilibrium. We thereby conclude that if we over provision a section of the network or a sub-network, the benefits cannot be seen unless the whole network (end-to-end) uses the same heuristic provisioning method. The transverse of which also indicates that over provisioning leads to completely sub-optimal solutions.

At network edge (access) aggregation implies, coalescing multiple traffic flows to create super-flows that can be routed and transported as one entity between common links. However, the quality of service associated with each flow often dictates the aggregation policy at the edge, and switching policy at the core. The uncertainty is then quantified as the basic inability to guarantee a net flow for a particular service without due knowledge of the behaviour of the other flows that are to be aggregated.

Chapter 5 **The determinism behind non-blocking schemes: The switching story**

In this chapter we discuss switching philosophies. From a conceptual perspective, switching poses four fundamental questions: when to switch, what to switch, how much to switch and where to switch. This has been discussed independently several times in several works and offers nothing new. What we plan to do is to view this 4-pronged problem in switching from the uncertainty perspective. By applying Weibull's distribution it can be shown that a change in one of the 4 switching question states (when to switch, what to switch, how much to switch, and where to switch), shift the switching equilibrium from optimal to over-provisioned. A negative change shifts the equilibrium from optimal to lossy. We quantify these through our analysis and discussion.

The conceptual evolution of the non-blocking architecture can then be seen as an over-provisioned solution for the uncertainties involved. We build a model for switching and relate this model with the uncertainties involved. Further, we correlate the object to be switched (traffic flow etc.) and the switching patterns generated for random traffic schemes. We derive the interesting conclusion, that the uncertainty between switching and the flow to be switched can be reduced through added intelligence. As a by-product the cost of the switch also gets reduced in the process.

Switching has been a mature technology for the last 50 years. We explore switching from the perspective of decision theory. We build decision trees for switching, and show how the tree can be influenced by prior action. Discussion focussing on multi-attribute decision theory and weighted factors that has a positive effect on achieving dynamism and high throughput in switch matrices.

***Chapter 6*.** **Algorithms for management: Schedulers and Access protocols** – The third leg of the uncertainty chair is scheduling. Scheduling determines the effectiveness of the second uncertainty model – switching. If switches give the discreteness and robustness to networks, schedulers give the necessary qualitative edge. The aspect of providing class of service, and QoS is the primary function of schedulers. The uncertainty involved in scheduling leads to two heuristic solutions – Fairness and QoS, both interrelated. We build uncertainty bounds for fairness using scheduling theory and postulate a series of arguments balancing scheduling and switching as solutions for the interacting uncertainty. In this chapter we will also discuss the pros and cons of analyzing networks using the axioms of uncertainty as compared to stochastic analysis using Markovian models. Our primary argument is the uncertainty models are more real than classical stochastic models, and can be translated to products more pragmatically. We will show this through an access networking example using IP routers and switches.

Chapter 7. **Optimal capacity exercises: transport**
In this chapter we consider the famous routing and wavelength assignment problem in its theoretical basics. The RWA problem aims at providing an optimal transport mechanism for optical networks, by optimally assigning a set of wavelengths to a group of routes so as to yield in a universally connected logical graph, subject to of course a set of practical and physical constraints. The uncertainty involved here has already been quantified in literature. However its reduction is known to be NP complete and hence non-tractable. We examine alternate hybrids methods to reducing the uncertainty by using allied means such as switching and aggregation. These solutions are now appearing in industry roadmaps under the nomenclature of Multi-Service Transport Platforms (MSTP). Optical node architectures like Dynamic Optical Add-drop multiplexers that allow any wavelength to be dropped to any port and hold the reverse true for adding wavelengths are completely opposite to the classical RWA model. The DOADM concept as an example, performs the integration of switching and transport layers, and in a broad way is a heuristic solution to the uncertainty equilibrium. We study its effects from a probabilistic and stochastic perspective on next generation network systems like sub-lambda provisioning and burst transport.

Chapter 8: **Is the uncertainty continuous or discrete? Effects of continuous or discrete uncertainty of network elements**
In this philosophical chapter we attempt to quantify the uncertainties discussed from a statistical perspective. One theory explores the reduction of these uncertainties to a probabilistic model. We examine this theory, and also see how this fails for world wide networks. We then consider another possible explanation – that of continuous uncertainty. We build this theory and examine some postulates. We see how moving within uncertainty can have minimal effect on the solution if the movement is minimal. While on the other hand effective movement can lead to breaking down the uncertainty equilibrium and hence creating optimal solutions.
This chapter also focuses on the effects of uncertainty on network elements. Quantitatively we observe the amount of over-provisioning in today's elements and as a result the sheer wastage of resources. We propose models and methods to alleviate this problem under a broad framework that is time and technology independent.

Chapter 9: The **management puzzle: (sub topic: scalability and software interoperability issues).** A thin layer of uncertainty residing on the four legs of the chair is uncertainty in management. Management of systems, sub-systems and components poses a different level of risk and leads to heuristic anticipatory schemes. We study the cause and effect of such schemes. We examine a solution to the problem with the recently proposed paradigm of Opportunistic Optical Network or OON using Light-trail communication. Two sub-issues of scalability of management systems in heterogeneous environments and software based interoperability are also considered.
Management has a large human component associated with it. Human interaction with networks is a new area, not dealt before. We focus on how to efficiently manage networks without the uncertainty of human error. We use the axioms of human reliability

and show how to build influence diagrams in the design of management systems for networks. Two mains axioms we use are:

- Time reliability correlations
- Success likelihood indexing

Finally we discuss human error event trees for enterprise and provider networks through an example discussing present OSS or Operation Support and Services infrastructure as detailed by Telcordia Standards.

Chapter 10: **Solving the Uncertainty: New methods and adaptable solutions.**

In this final chapter we discuss future alternatives and approaches to solving uncertainty bounds in networks of the future. We look at both unified and distributed approaches to solving the bounds of uncertainty. Based on our principle uncertainty model we conclude that solutions have to take into account multiple factors that directly do not have an effect, but which cause an impact on the performance of the whole system. We evaluate and discuss such solutions. Eventually the chapter shows a way by which such solutions can be used to solve a very broad class of uncertainty related problems that affect human society.

This last chapter has two components, a series of analytical models and a conceptual proof showing the correctness of these theories.

We demonstrate some methods for analyzing uncertainty in networks:-

- Identification of Uncertainties
    - Normal Uncertainties
    - Special events
- Quantification of uncertainties
- Projection of risk in network provisioning
- The Critical Path Method for avoiding Uncertain times! This special case study deals with showing the reader how to construct a critical path in order to avoid uncertainty in networks. The critical path method is shown through two examples:
    - End-to-End provisioning in metropolitan networks
    - Ubiquitous provisioning over hybrid (wireless + wire-line) networks.
- Human – network interaction
- Probabilistic inversion techniques for uncertainty analysis on broadband networks:
    - Elicitation variables and Target Variables – this shows how to model unknown network parameters from known network parameters with a degree of confidence.
    - Mathematical formulation of probabilistic inversion:
        - Case study: SONET/SDH wander/jitter
        - Case study Grid Computing – memory-processor interaction over distributed networks.
    - Prejudice and uncertainty: conclusion of the book.

We plan to provide 8 solved examples and the end of each chapter, power point (in MS ppt XP) on our website (www.cotrion.com/uncertainty) and a list of unsolved questions for the student. The solutions of these would be emailed to bonafide professors and lecturers.